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ABB CRITICAL HEAT FLUX CORRELATIONS FOR PWR FUEL

ABB Combustion Engineering Nuclear Power

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Abstract

This report describes the development of PWR Critical Heat Flux correlations for ABB 14x14 and 16x16 non-mixing vane fuel and for ABB 14x14 Turbo mixing vane fuel. The ABB-NV correlation is for non-mixing vane fuel and ABB-TV correlation is for Turbo mixing vane fuel. Both correlations utilize the same form but with different constants for a portion of the correlation. The correlations were developed based on ABB Critical Heat Flux (CHF) test data obtained from the Heat Transfer Research facility of Columbia University. The tests simulated 5x5 and 6x6 arrays of the fuel assembly geometry, non-mixing and Turbo mixing vane grids, uniform and non-uniform axial power shapes, uniform and non-uniform radial power distributions, with and without guide tubes, heated lengths from 48 to 150 inches and grid spacings from 8 to 18.25 inches. The functional form of the CHF correlation is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The correlation includes the following variables: pressure, local mass velocity, local quality, distance from grid to CHF location, heated length and the heated hydraulic diameter of the CHF subchannel. Special geometry terms are used in the correlation to correct CHF for grid, heated length, cold wall and guide tube effects. The Tong F_C shape factor was also optimized and applied to the correlation to account for the effects of non-uniform axial power shapes. The 95/95 DNBR limit for both the ABB-NV and ABB-TV CHF correlations is 1.13. The correlations are valid for use with ABB thermal hydraulic codes TORC and CETOP. The range of applicability for the correlations:

Parameter	ABB-NV Range	ABB-TV Range
Pressure (psia)	1750 to 2415	1500 to 2415
Local mass velocity (Mlbm/hr-ft^2)	0.8 to 3.16	0.90 to 3.40
Local quality	-0.14 to 0.22	-0.10 to 0.225
Heated length, inlet to CHF location (in)	48 to 150	48 to 136.7
Grid spacing (in)	8 to 18.86	8 to 18.86
Heated hydraulic diameter ratio, Dhm/Dh	0.679 to 1.08	0.679 to 1.00

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Nomenclature:

C	Coefficient for F_C shape factor, ft^{-1}
CC	Coefficient for F_{GT}, [ ]
DG	Distance from upstream grid to CHF location, inches
Dh	Heated hydraulic diameter of subchannel, inches
Dhm	Heated hydraulic diameter of a matrix subchannel, inches
F_C	Tong's non-uniform shape factor
F_{CW}	Guide Tube heated hydraulic diameter term in correlation
F_{GR}	Distance from grid term in correlation
F_{HL}	Heated length term in correlation
F_{GT}	Guide Tube proximity term in correlation
GL	Local mass velocity, Mlbm/hr-ft^2
Gl	Local mass velocity, lbm/hr-ft^2
HL	Distance from BOHL to CHF location, inches
hfg	Latent Heat of Vaporization, Btu/lbm
l_{crit}	Distance from BOHL to CHF location, inches
N	Number of data points
Pe	Non-dimensional inverse Peclet Number
Pr	Pressure, psia
s	Sample standard deviation
q''_{CHF}	Critical heat flux, MBtu/hr-ft^2
q''_{local}	Local heat flux, MBtu/hr-ft^2
XL	Local quality, fraction
μ	Sample mean

Abbreviations:

ABB	ABB Combustion Engineering Nuclear Power
ANOVA	Analysis of Variance
BOHL	Beginning of Heated Length
B. P.	Bottom Peaked
CES	Standard ABB Non-mixing Grid
CES-R	Reinforced Standard ABB Non-mixing Grid
CHF	Critical Heat Flux
DNB	Departure from Nucleate Boiling
DNBR	Departure from Nucleate Boiling Ratio
$DNBR_{95}$	95/95 DNBR Limit
NRC	U. S. Nuclear Regulatory Commission
MDNBR	Minimum Departure from Nucleate Boiling Ratio
M/P	Measured over Correlation Predicted
NV	No Mixing Vane
O. D.	Outside Diameter
PWR	Pressurized Water Reactor
T. P.	Top Peaked
TV	Turbo Mixing Vane Grid

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1.0 Introduction

This report describes the development of PWR CHF correlations for ABB 14x14 and 16x16 non-mixing vane fuel and for ABB 14x14 Turbo mixing vane fuel. The ABB-NV correlation is for non-mixing vane fuel and the ABB-TV correlation is for Turbo mixing vane fuel. Both correlations utilize the same form but with different constants for a portion of the correlation. The correlations were developed based on ABB CHF test data obtained from the Heat Transfer Research facility of Columbia University. The tests simulated 5x5 and 6x6 arrays of the fuel assembly geometry, non-mixing and Turbo mixing vane grids, uniform and non-uniform axial power shapes, uniform and non-uniform radial power distributions, with and without guide tubes, heated lengths from 48 to 150 inches and grid spacings from 8 to 18.25 inches.

The following sections describe the existing ABB CHF correlations used in design analyses, why new correlations were developed and brief summary of the contents of this report.

1.1 Existing ABB CHF Correlations

ABB currently uses the CE-1 correlation for 14x14 and 16x16 non-mixing vane fuel as described in References 1 and 2. The form of the CE-1 correlation is one that was proposed by Barnett (Reference 3) for uniformly heated tubes based on the assumption that CHF depends on local coolant conditions and is linearly dependent with quality and inlet subcooling. The 95/95 DNBR limits for CE-1, approved by NRC in Reference 2, are 1.15 for the 14x14 geometry and 1.19 for 16x16 geometry. The CE-1 correlation was approved for use in ABB's TORC and CETOP thermal hydraulic codes defined in References 4 – 6.

ABB has also developed CHF correlations for 15x15 and 17x17 Westinghouse R-grid fuel in Reference 7 (CE-X1 correlation) and for the ABB 17x17 and 16x16 split-vane mixing grid fuel in Reference 8 (ABB-X2 correlation). These correlations have been submitted to licensing authorities in Europe to support the implementation of ABB split-vane mixing grid fuel in Westinghouse type plants for the European fuel market. These correlations have not been submitted to the NRC. Both CE-X1 and ABB-X2 correlations have a 95/95 DNBR limit of 1.17.

1.2 Need for a New Correlation

A new correlation form was developed for ABB non-mixing and mixing vane grid fuel for the following reasons:

1. A new correlation was needed to fit the ABB 6x6 CHF test data that supports the 14x14 Turbo spacer grid for Turbo fuel. Further details on a description of Turbo fuel is given in Reference 9.
2. Incorporate the following improvements in the correlation for non-mixing vane fuel:
   a. Special geometry effects for the grid, heated length and guide tube were needed in the correlation to improve the fit and poolability of CHF data.
   b. The Tong F_C shape factor, Reference 10, used with the CE-1 correlation in Reference 2 for non-uniform axial power shapes conservatively overestimates the measured to predicted CHF. To improve the fit, the constants of the F_C shape factor can be optimized to ABB's non-uniform CHF data.
   c. CE-1 was developed with multiple CHF indications for each test run. For the purpose of calculating the 95/95 DNBR limit, it is more appropriate to use primary CHF indications.

As a result of the above reasons it was decided to develop a new correlation form which would fit both the ABB 14x14 and 16x16 non-mixing vane and the 14x14 Turbo mixing vane CHF databases. Two correlations were developed, ABB-NV and ABB-TV, utilizing the same form but with different constants for a portion of the correlation. This new DNB correlation form also includes the optimized F_C shape factor constants. The new ABB-NV correlation will not supercede the CE-1 correlation. The CE-1 correlation will still be available to clients who choose not to use the new ABB-NV correlation.

1.3 The New ABB PWR CHF Correlations

The new form of the correlation is similar to the ABB-X2 correlation developed for ABB 17x17 and 16x16 split-vane mixing grid fuel in Reference 8. The form is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The form assumes that there is a linear relationship between CHF and local quality. This relationship has been observed in many rod bundle CHF tests, and it applies well to the

ABB CHF tests. The correlation includes the following variables: pressure, local mass velocity, local quality, distance from grid to CHF location, heated length from inlet to CHF location and heated hydraulic diameter of the CHF channel. Special geometry terms are applied to the correlation to correct CHF for grid, heated length, cold wall and guide tube effects. The F_c shape factor was also optimized and applied to the correlation to account for the effects of non-uniform axial power shapes.

The form of the ABB-X2 correlation was initially developed with the primary variables: pressure, local mass velocity, and local quality. [ ] terms of the correlation, described in Section 3, use these primary variables. This [ ] expression is based on a partial expansion of pressure and local mass velocity to the second order and local quality to the first order. A full expansion would include 17 terms. The selection of these terms were based on examining approximately 50 CHF tests which covered different spacer grid designs from ABB and Westinghouse data bases, a wide range of heated lengths, grid spacings, hydraulic diameters, radial and axial power distributions and guide or thimble tube geometries.

A description of the ABB CHF tests supporting the ABB-NV and ABB-TV correlations is summarized in Section 2 of this report. Several tests were added to the non-mixing vane database to support the special geometry terms for the correlation form and for validation. Sections 3 and 4 describe the test data evaluation, and the development and validation of the ABB-NV and ABB-TV correlations, respectively. The test data were evaluated by using the ABB thermal hydraulic code, TORC (Reference 4). TORC was used to predict local coolant conditions for the CHF test sections. A TORC model was prepared for each test section and appropriate empirical grid mixing factors for the ABB mixing grid design were input into the model. Section 5 summarizes the optimization of the F_c shape factor constants, preserving the Tong F_c shape factor form, to fit the ABB non-uniform axial power shape CHF data.

Section 6 summarizes the statistical evaluation for the ABB-NV and ABB-TV correlations. A statistical evaluation was performed with the correlation for each test section and test subsets (groups of tests). Tests for normality were performed to check the hypothesis that the data are normally distributed. Statistical tests were performed to determine if all or selected data groups belong to the same population, in order to be combined for the evaluation of the 95/95 DNBR tolerance limit. For normally distributed groups, homogeneity of variance was examined using Bartlett's test and homogeneity of the means was examined with the t-test or an analysis of variance test (an F-test). The t-test was applied to test for equality of means for two groups and the F-test was applied to multiple groups. For groups that did not pass the normality test, the Kruskal-Wallis One Way Analysis of Variance by Ranks test is used to test the null hypotheses that the medians, or averages, of the tests or groups are the same. For normally distributed groups, Owen's one-sided tolerance limit factor, Reference 11, is used to compute the 95/95 DNBR limit. For groups that are not normally distributed, a distribution-free or nonparametric limit, from Chapter 2 of Reference 12, is established. The highest 95/95 DNBR limit from the test subsets is determined for the ABB-NV and ABB-TV correlation. The 95/95 DNBR limit for both correlations was determined to be 1.13. Scatter plots of the ratio of measured to predicted (M/P) CHF versus correlation variables were also made to illustrate that the ratio does not show any trends relative to correlation variables.

Section 7 discusses how the new CHF correlations are applied in reload analyses.

A detailed summary of the correlation databases and the statistical output of the ABB-NV and ABB-TV correlations are given in the Appendices A-D. A detailed summary of the Test section radial and axial power distributions are given in Appendix E.

2.0 Description of Test Facility and Operation

The CHF experiments were conducted at Columbia University's Heat Transfer Research Facility. The ABB-NV correlation is based upon a re-evaluation of CHF data from tests that spanned the period from 1971 to 1977. The tests for the ABB-TV correlation spanned the period 1993 to 1997. A detailed description of the facility for the ABB-NV tests can be found in Reference 1. Since a number of modifications to the loop and data acquisition system have occurred since the release of Reference 1, a brief summary description of the loop and test procedure for the ABB-TV tests is provided below.

2.1 Facility Description

2.1.1 Heat Transfer Loop

The major components of the loop are the circulating pumps, the flow control and measuring spool piping section, the test section housing, the heat exchangers and mixing tee, the water purification system, and the feed water supply, make-up and bleed systems. The loop is filled with deionized de-aerated water from intermediate holding tanks. Vents located about the loop are activated to remove any trapped air.

2.1.2 Primary Flow Loop

The loop is constructed of 300 series stainless steel with the main piping of 3 and 4 inch nominal diameter. Water flow in the loop is provided by two 100 HP centrifugal pumps connected in parallel. The total flow supplied by the pumps is split with the main part going through the measuring spool piping and test section housing and the remainder through a series of heat exchangers. The flow through the measuring spool is varied by means of flow control valve electrically operated from the control room. The secondary flow through the heat exchangers, which is controlled by a series of valves operated from the control room, provides additional flow control capability. The test section flow is measured by a Venturi flow meter (primary) and a turbine flow meter (secondary) prior to the entrance to the test section housing. In the test section housing, the coolant removes the heat from the test section and exits the opposite end of the housing where it merges with the flow from the heat exchanger system in a mixing tee. The mixing tee provides a stable coolant temperature at the pump inlet and hence at the test section inlet.

The heat exchangers are of the shell and tube type and have 500 ft^2 total heat transfer area. These units can be operated singly or in any combination, providing a wide range of achievable subcoolings. The secondary side of the heat exchangers is a once through open loop with approximately 800 gpm of cooling water obtained from wells on site.

2.1.3 Test Section Flow Housing

The flow housing consists of five major components: a pressure housing, grid plate, top adapter, shroud box, and bottom adapter. Water from the measuring spool pipe enters at the top of the pressure housing, flows down in the annulus formed by the shroud and the pressure housing inner wall, passes through the bottom adapter holes and turns upward into the flow channel containing the rod bundle test section. The resulting steam-water mixture flows through the enlarged top adapter and through the grid plate into the mixing tee. The grid plate, machined from a nickel plate, positions the rod bundle, transfers the DC power to the individual rods, and holds the shroud box in place. The top adapter locates the shroud box with reference to the heated rod geometry and offers the transition between the heated rods and the unheated length. The shroud box is constructed of 17-4PH stainless steel bolted together to form a rigid square housing to fit the ceramic flow liners. This type of stainless steel material is chosen to closely match the expansion coefficient of the ceramic, thereby eliminating potential bypass flow. The ceramic flow liners are made 99.5% dense Aluminum Oxide (Al_2O_3) in 15 inch long sections. The ceramic channel extends beyond the rod bundle heated length, both upstream and downstream, ensuring a constant geometry to prevent adverse flow effects. Several pressure tap holes are drilled at selected locations along the axial length of the shroud box and flow liners to monitor the bundle performance during actual operation. The pressure tap lines are brought outside of the pressure housing through an instrument flange and connected to pressure transducers. The bottom adapter locates the inlet end of the flow channel with respect to the heated rods and has eight one-inch diameter holes equally spaced circumferentially to evenly distribute the inlet flow.

2.1.4 Electrical System

Heating of the test section is obtained from a D.C. power system. The complete power system consists of six D.C. generators and the motors that drive them, motor generator protective system, control panel in the control room for remote operation and the protective and interlocking system. The A.C. power system includes two 13.2 KV, 7 MW feeders with special interlocks to prevent feedback from one to the other feeder in the event of a fault or ground The entire system functions at an overall maximum voltage of 240 volts, which is generated by all six D.C. generators, two of which are boosted by two 3-phase full-wave bridge rectifiers. The output voltage from the six generators is controlled from two potentiometers, which provides a continuously variable output from two SCR power supplies. The system voltage can be varied continuously from zero to full power at 240 volts.

2.1.5 Instrumentation

The instrumentation required to successfully perform CHF experiments, as well as the instrumentation needed to operate the Heat Transfer Loop are:

- test section inlet mass flow rate,
- water temperature at the inlet and outlet of the test section,
- total pressure at the inlet and outlet of the test section,
- differential pressures between axial points in the test section,
- temperature in different sections of the loop,
- total D. C. power to the test section,
- heater rod wall temperature.

2.1.6 Data Acquisition System

The computer controlled data acquisition system is comprised of the following components.

- Model 382 HP BASIC/UX controller with 16 MB RAM
- 16" VGA graphics monitor
- 400 MB hard drive and 2 GB DAT tape drive
- HP 3852A Data acquisition/control unit

The software consists of a main program, which controls the use of a number of a data acquisition and reduction to engineering units subroutines. The main program is an on-line contact with the operator at the loop control area through one of its terminals. Depending on the option selected, the computer initiates a scanning procedure and performs a pre- or post-test reduction of certain variables. During the data reduction sequence, the computer picks up the appropriate scan from the magnetic tape, reduces the data to engineering units, and performs various checks on loop parameters.

2.2 Description of Typical Test Sections

2.2.1 ABB-NV Test Sections

The data used for the development and evaluation of the ABB-NV correlation were obtained from eighteen test bundles, thirteen with a uniform axial power shape and five with non-uniform axial power shapes. The test sections, described in Table 2-1, simulate a 5x5 array of the ABB fuel assembly geometry without mixing vanes. Nine of these test sections are representative of the ABB 14x14 fuel assembly geometry (0.440 inch O.D. heated rods and 0.580 inch rod pitch) and nine test sections are representative of the ABB 16x16 fuel assembly geometry (0.382 inch O.D. heated rods and 0.506 inch rod pitch).

Sixteen of the tests were conducted with a simulated guide tube. Typical radial geometries for the 14x14 test sections and 16x16 test sections, with and without a guide tube, are shown in Figures 2-1 through 2-4, respectively. The power split between the hot rods and cold rods ranged from [ ] The radial power distributions for the individual tests are given in Appendix E. The non-uniform tests were conducted with four axial power shapes, as shown in Figure 2-5. The typical axial geometry for the uniform axial power shape tests is shown in Figure 2-6 for the 14x14 geometry and Figure 2-7 for the 16x16 geometry. The typical axial geometry for the non-uniform axial power shape tests is shown in Figure 2-8 for the 14x14 geometry and Figure 2-9 for the 16x16 geometry. The range of rod thermocouple locations for the different axial power shapes is noted in the figures. The axial locations of rod thermocouples for the individual non-uniform tests are given in Appendix E. A summary of the test section geometry for the eighteen tests is shown in Table 2-1. The data from the source or "correlation" test sections were used to develop the coefficients for the ABB-NV correlation. The data from the "validation" test sections were used in the evaluation of the correlation.

The test grids for all the ABB-NV tests are similar to the reactor design. The standard grids, CES, were manufactured with Zircaloy-4 material for the early tests. The stronger Inconel 625 material was used in later tests to provide improved support for the heater rods. To provide additional support for the 150" heated length tests, the test grid springs were reinforced, CES-R. The use of the reinforced spacer grids was justified in Appendix D of Reference 1. By making these changes to the grid, the amount of rod deflection due to electromagnetic forces was minimized. Therefore, no intermediate support grids were necessary for minimizing rod bow and deflection.

2.2.2 ABB-TV Test Sections

The data used for the determination of the primary coefficients of the correlation and the evaluation of the ABB-TV correlation were obtained from three test bundles, two with a uniform axial power shape and one with a non-uniform axial power shape. The test sections, described in Table 2-2, simulate a 6x6 array of the ABB 14x14 Turbo mixing vane (TV) fuel assembly geometry (0.440 inch O.D. heated rods and 0.580 inch rod pitch). The 6x6 test array size was selected for this experimental program instead of a 5x5 array to reduce the thermal hydraulic impact of the cold wall on CHF measurements and to minimize the occurrence of CHF on peripheral rods. A spacer grid, which produces strong crossflow mixing and swirling flow patterns downstream of the grid, flattens the enthalpy profile in the test section and increases the probability of CHF occurring on peripheral rods. Peripheral rod CHF indications in the test section are not prototypical of in-core performance since the mixing vane orientation is not properly modeled in the peripheral region of the test section and there is a shroud wall. Therefore, by increasing the array size it was expected that the number of primary peripheral rod CHF indications would be reduced and the CHF test would better simulate in-core performance. In addition, the geometry around the simulated guide tube is a better representation of the reactor geometry.

Two of the tests were conducted with a simulated guide tube. Typical radial geometry's for the test sections with and without a guide tube are shown in Figures 2-10 and 2-11. The power split between the hot rods and cold rods for the ABB-TV tests was approximately [ ] The radial power distributions for the individual tests are given in Appendix E. The non-uniform test was conducted with a 1.47 peaked axial power shape, as shown in Figure 2-12. The typical axial geometry for the uniform axial power shape tests is shown in Figure 2-13. The axial geometry for the non-uniform axial power shape test is shown in Figure 2-14. The placements of the rod thermocouples for the uniform and non-uniform axial power shapes are noted in Figures 2-13 and 2-14. A summary of the test section geometry for the three tests is shown in Table 2-2. The correlation coefficients were based upon a subset of the test data This "correlation" database represents 80% of the CHF test points. The remaining 20% of the test data were used as a "validation" database for the evaluation of the correlation. The division of the data into correlation and validation databases was accomplished by sorting the data from each test as follows:

1.) The data from the Columbia University data file were sorted by pressure, then inlet temperature and then mass velocity in descending order.

2.) Every fifth point was then sorted out for use as a validation database.

The test grids are similar to the reactor design except they were fabricated from Inconel 600. Each spring on the Turbo grids has an integral backup arch to prevent damage to the grid cell spring. The use of the stronger Inconel material minimizes the amount of permanent deflection of the grid springs that occur due to electromagnetic forces being generated in the test section and the spring backup arch assures that there is no permanent spring deflection. By making these changes to the grid, the amount of rod deflection due to electromagnetic forces was minimized. The amount of rod bowing was also minimized by designing for the maximum wall thickness of the tubing and utilizing a tight clearance between rods ceramic cylinders and tube ID to increase rod stiffness. Therefore, no intermediate support grids were necessary for minimizing rod bow and deflection.

2.2.3 Demonstration Test Sections

In addition to the correlation and validation data sets, data from two special test sections are evaluated, one with a uniform axial power shape and one with a non-uniform axial power shape. The data from the special tests are used to demonstrate the correlation is valid or conservative when applied for those conditions. Test 72 is a special test that simulates the corner of four assemblies in contact with perimeter strips. [

] The radial geometry for this test is shown in Appendix E and the axial geometry is shown in Figure 2-7. Test 64 is a non-uniform test with a 23% power spike in the three high powered rods for a length of 4 inches at the elevation where CHF was anticipated. The results from this test are compared with the results from Test 59 to demonstrate there is no detrimental impact on the prediction of CHF performance due to the power spike. The radial and axial geometry for this test are shown in Appendix E. A summary of the test section geometry for the two demonstration tests is shown in Table 2-3.

2.3. Test Procedure and Operation

A description of the test procedures used for the ABB-NV tests is provided in section 3.0 of Reference 1. Although the general test procedure is the same, a brief description of the test procedures and operation for the more recent tests with the ABB Turbo mixing vane grid is provided below:

At the beginning of each test, cold flow pressure drop points were obtained over a range of flow conditions. At the start of each day of testing, a repeat pressure drop point is taken for comparison with earlier data. These data provide isothermal grid span pressure drop values to compare with prediction and establish a base for comparison in case of a malfunction of the rod bundle during the tests. Pressure drop measurements were obtained for each test at the following conditions:

Pressure:	1000 psia
Isothermal Temperature:	130 °F
Mass Velocity:	1.0 to 4.0 Mlbm/hr-ft^2

Several high temperature zero power points were also obtained a few times during testing by switching the power off and taking measurements as the test section temperature dropped. These points produced pressure drop measurements at higher Reynolds numbers and zero power (near isothermal) calibrations for subchannel thermocouples.

Heat balances were performed on the test section to check all loop and bundle instrumentation at high temperature and power and to check heat losses. These runs were accomplished at subcooled conditions before mixing or CHF data were obtained at the beginning of each day of operation. Mixing or CHF testing was not started until a test section heat loss was less than 2%. Heat loss is defined as the fraction of heat generated by the rods that is lost to the test section shroud walls.

Subchannel mixing data were obtained at non-boiling conditions for each test with a uniform axial power shape. Subchannel thermocouple data were recorded for each mixing test run after steady-state conditions were achieved for a constant pressure, inlet temperature, mass velocity and power. Power was determined for each test condition so the calculated outlet temperature in the hottest subchannel is close to the value specified in the mixing test matrix.

Critical Heat Flux experiments are performed by maintaining the following system conditions constant: test section outlet pressure, inlet temperature, and mass flow rate. The total power to the test section is then increased until a temperature excursion is observed by one or more thermocouples positioned inside the heater rods. The amount of the excursion is approximately 10 to 30°F and varies depending on system conditions. When the excursion is judged to be sufficient, the power to the test section is reduced. When the temperature excursion is minimal, confirmation of the validity of a CHF point is obtained by observing the temperature decay with power reduction. There is a characteristic temperature decay with time as the CHF zone is rewetted. This evidence is considered confirming in cases where the temperature decay pattern is typical. Otherwise, the experiment is repeated. When a CHF point is observed, the following measurements are recorded, while holding the test section power constant:

1. Recorded manually:

- test section outlet pressure
- pressure drop across the Venturi flow meter from a manometer
- test section pressure drop from a manometer
- rod(s) experiencing CHF.

2. Recorded by the data acquisition system:

- test section voltage
- bus to bus voltage
- generator amperages
- inlet temperature
- outlet temperature
- outlet pressure transducers
- turbine flow meter
- Venturi flow meter transducer
- test section pressure drop transducers
- subchannel temperatures
- heater rod temperatures.

The test matrices were designed to cover a wide range of operating conditions. Most of the points cover a local hot subchannel quality range from –10% to 22.5%.

TABLE 2-1

GEOMETRIC CHARACTERISTICS OF ABB-NV CORRELATION AND VALIDATION TESTS

Test No.	Bundle Array	Rod Diam. ~ in.	Rod Pitch ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	GT Diam. ~ in.	Axial Shape	Radial Split Hot/Cold	Shroud Clearance ~ in.	Grid Type	Grid Material
Correlation Data												
18	14x14	0.440	0.580	48	16.0	Yes	1.135	Uniform			CES	Zirc. 4
21	14x14	0.440	0.580	84	16.0	No		Uniform			CES	Zirc. 4
36	14x14	0.440	0.580	84	18.25	Yes	1.115	Uniform			CES	Inc. 625
38	14x14	0.440	0.580	150	17.4	Yes	1.115	Uniform			CES-R	Inc. 625
47	16x16	0.382	0.506	150	14.3	Yes	0.970	Uniform			CES	Inc. 625
48	16x16	0.382	0.506	84	14.3	No		Uniform			CES	Inc. 625
52	16x16	0.382	0.506	84	14.3	Yes	0.970	Uniform			CES-R	Inc. 625
73	16x16	0.382	0.506	150	15.7	Yes	0.980	Uniform			CES-R	Inc. 625
58	14x14	0.440	0.580	150	17.4	Yes	1.115	1.68 TP			CES-R	Inc. 625
59	16x16	0.382	0.506	150	14.2	Yes	0.970	1.46 Cosine			CES-R	Inc. 625
60	14x14	0.440	0.580	150	17.4	Yes	1.115	1.68 BP			CES-R	Inc. 625
66	16x16	0.382	0.506	150	14.2	Yes	0.970	1.47 TP			CES-R	Inc. 625
28	14x14	0.440	0.580	84	18.25	Yes	1.115	Uniform			CES	Zirc. 4
29	14x14	0.440	0.580	84	8.0	Yes	1.115	Uniform			CES	Zirc. 4
Validation Data												
41	16x16	0.382	0.506	84	17.4	Yes	0.970	Uniform			CES	Inc. 625
43	16x16	0.382	0.506	84	14.3	Yes	0.970	Uniform			CES-R	Inc. 625
51	16x16	0.382	0.506	84	14.3	Yes	0.970	Uniform			CES	Inc. 625
69	14x14	0.440	0.580	150	17.4	Yes	1.115	1.68 TP			CES-R	Inc. 625

* Test includes 3 Rods at zero power

TP – Top Peaked

BP – Bottom Peaked

TABLE 2-2

GEOMETRIC CHARACTERISTICS OF ABB-TV CORRELATION AND VALIDATION TESTS

Test No.	Bundle Array	Rod Diam. ~ in.	Rod Pitch ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	GT Diam. in.	Axial Shape	Radial Split Hot/Cold	Shroud Clearance ~ in.	Grid Type	Grid Material
Correlation Data												
91 C	14x14	0.440	0.580	136.7	18.86	No		Uniform	[	]	T. Mix *	Inc. 600
92 C	14x14	0.440	0.580	136.7	18.86	Yes	1.115	Uniform			T. Mix	Inc. 600
93 C	14x14	0.440	0.580	136.7	18.86	Yes	1.115	1.47 Cosine			T. Mix & T.Non-mix	Inc. 600
Validation Data												
91 V	14x14	0.440	0.580	136.7	18.86	No		Uniform	[	]	T. Mix	Inc. 600
92 V	14x14	0.440	0.580	136.7	18.86	Yes	1.115	Uniform			T. Mix	Inc. 600
93 V	14x14	0.440	0.580	136.7	18.86	Yes	1.115	1.47 Cosine			T. Mix & T. Non-Mix	Inc. 600

* Turbo Mixing Vane Grid

TABLE 2-3

GEOMETRIC CHARACTERISTICS OF ABB-NV SPECIAL TESTS

Test No.	Bundle Array	Rod Diam. ~ in.	Rod Pitch ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	GT Diam. ~ in.	Axial Shape	Radial Split Hot/Cold	Shroud Clearance ~ in.	Grid Type	Grid Material
64	16x16	0.382	0.506	150	14.2	Yes	0.980	1.46 Cosine *	[	]	CES-R	Inc. 625
72	16x16	0.382	.506 & 0.540	84	14.3	No		Uniform			HID-1**	Inc. 625

* 23% Power Spike - See Appendix E

** Grid Simulates the Corner of Four Adjacent 16x16 Assemblies with High Impact Design (HID-1) Non-mixing Grid Perimeter Strip

FIGURE 2-1

TYPICAL RADIAL GEOMETRY, ABB-NV TEST
FOR 21 ROD, 14x14 GEOMETRY

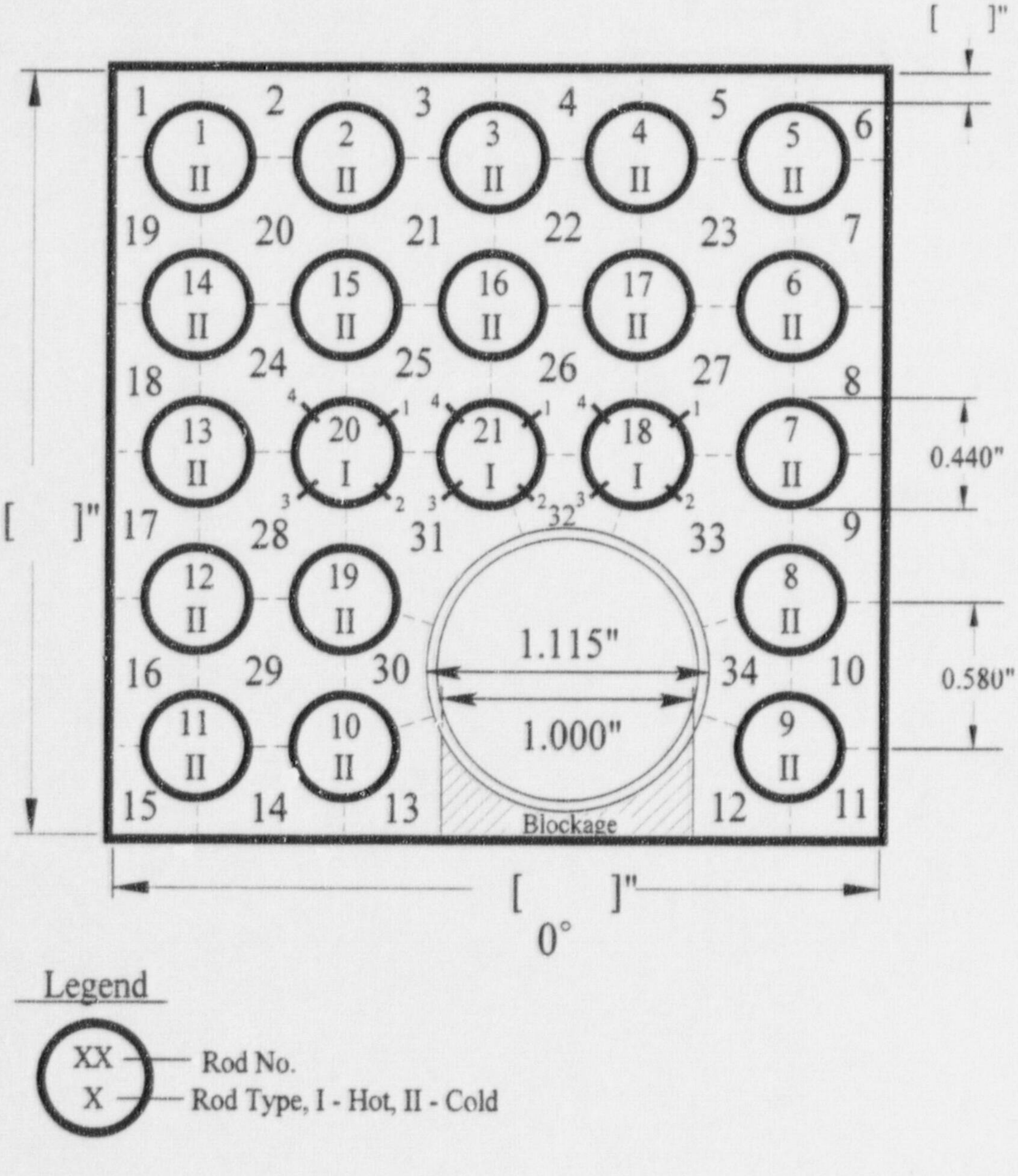


FIGURE 2-2

TYPICAL RADIAL GEOMETRY, ABB-NV TEST
FOR 25 ROD, 14x14 GEOMETRY

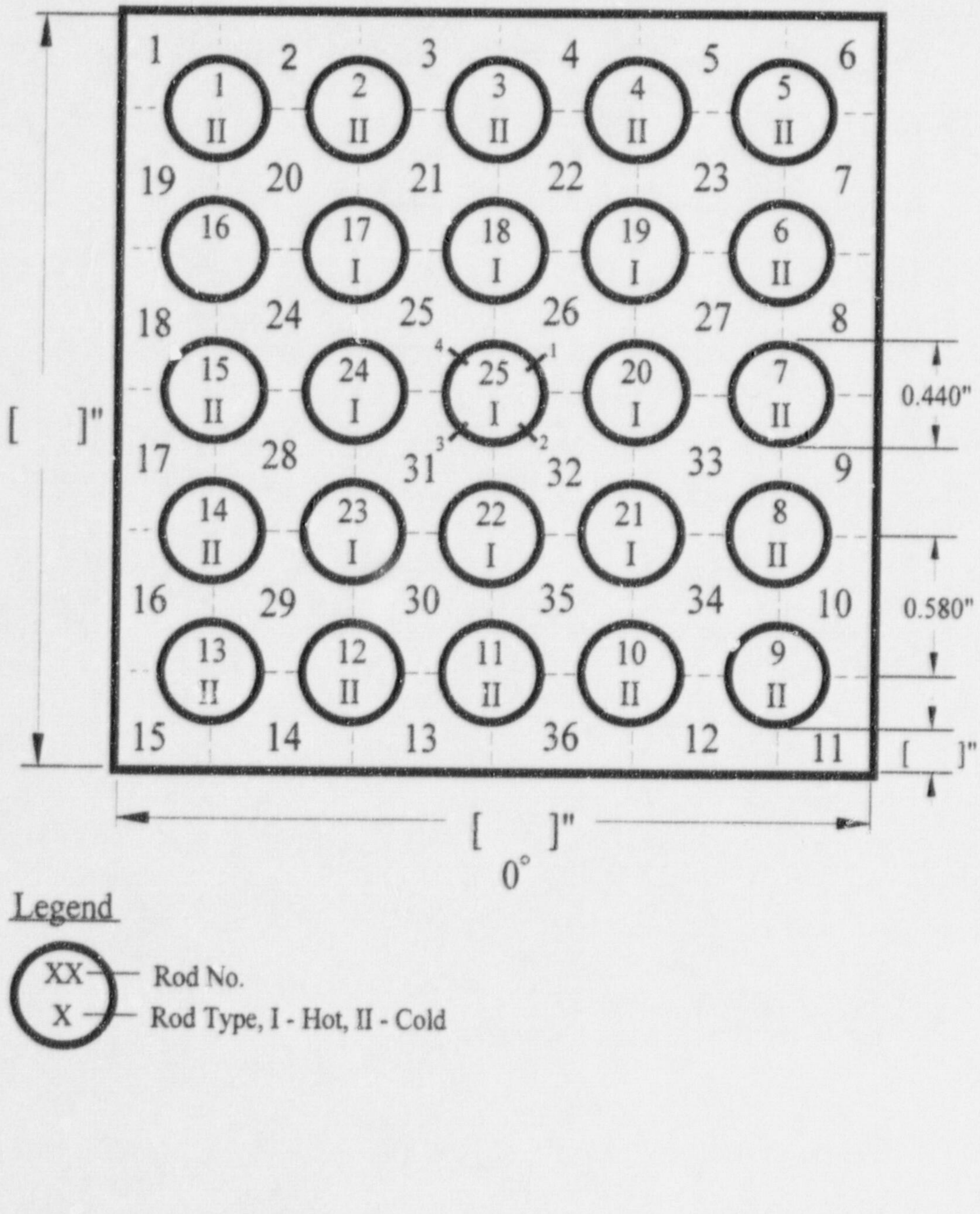
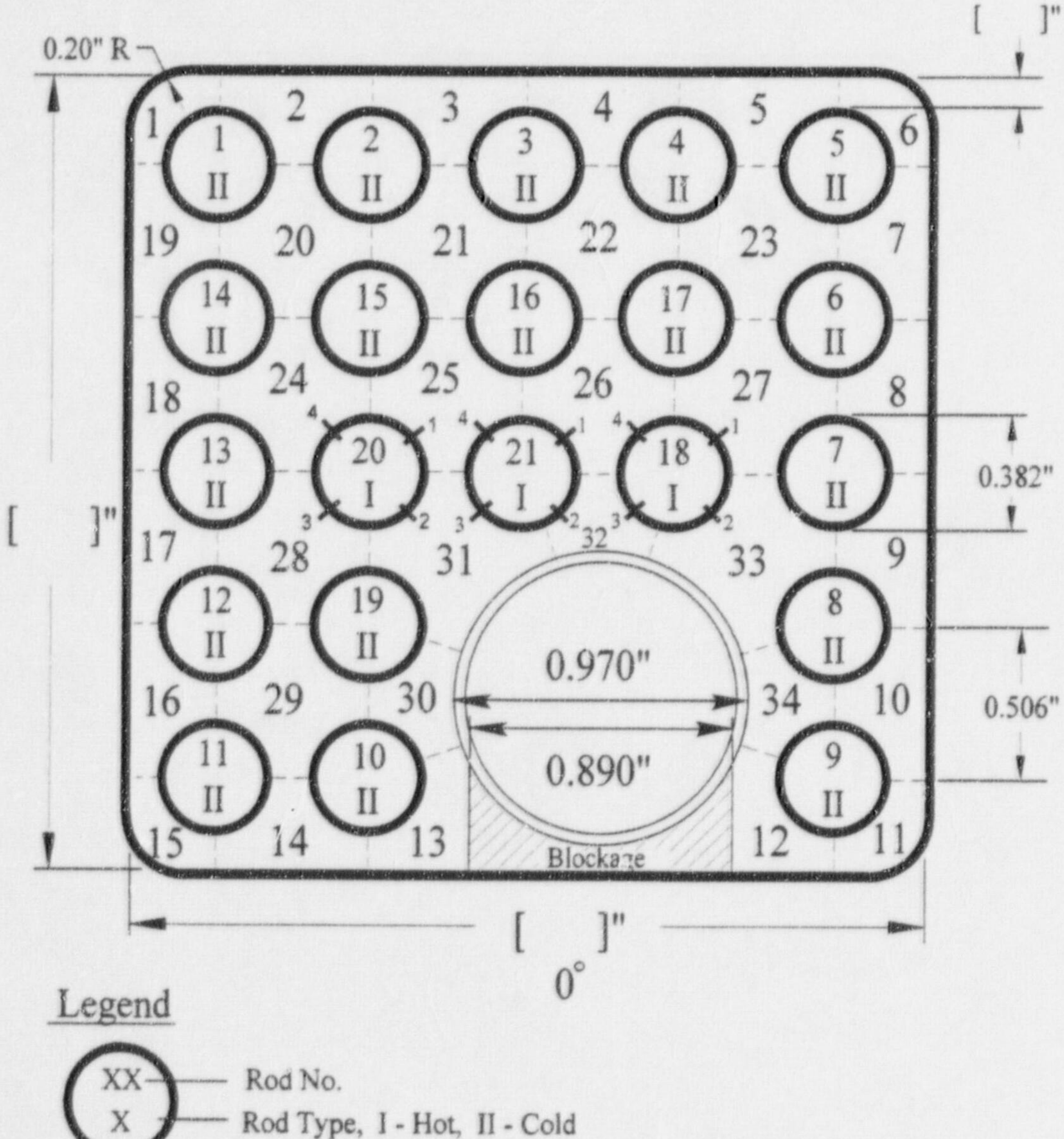


FIGURE 2-3

TYPICAL RADIAL GEOMETRY, ABB-NV TEST
FOR 21 ROD, 16x16 GEOMETRY



NON-PROPRIETARY INFORMATION
ABB COMBUSTION ENGINEERING, INC.

FIGURE 2-4

TYPICAL RADIAL GEOMETRY, ABB-NV TEST
FOR 25 ROD, 16x16 GEOMETRY

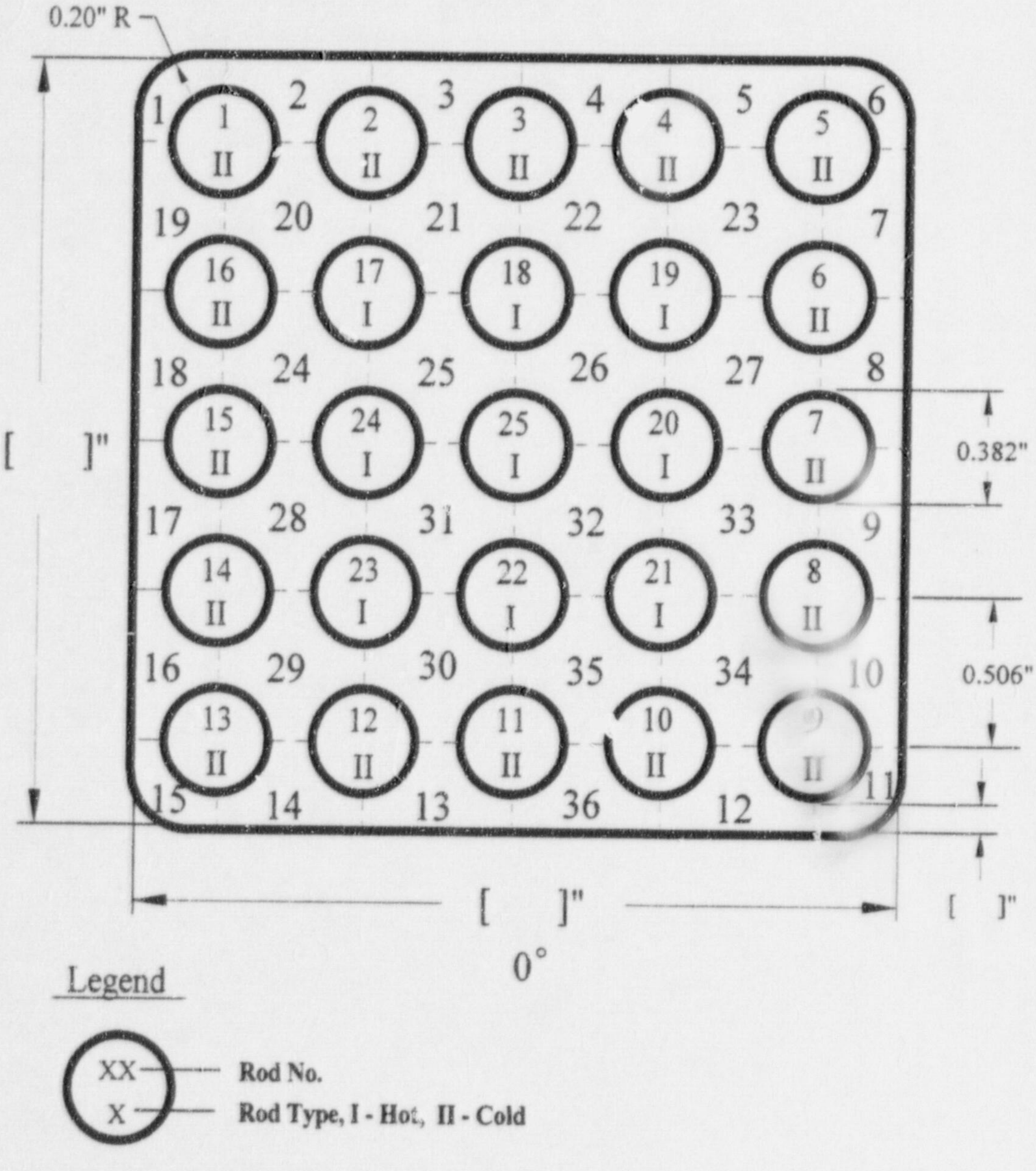


FIGURE 2-5
AXIAL HEAT FLUX DISTRIBUTION
ABB NON-MIXING VANE TESTS

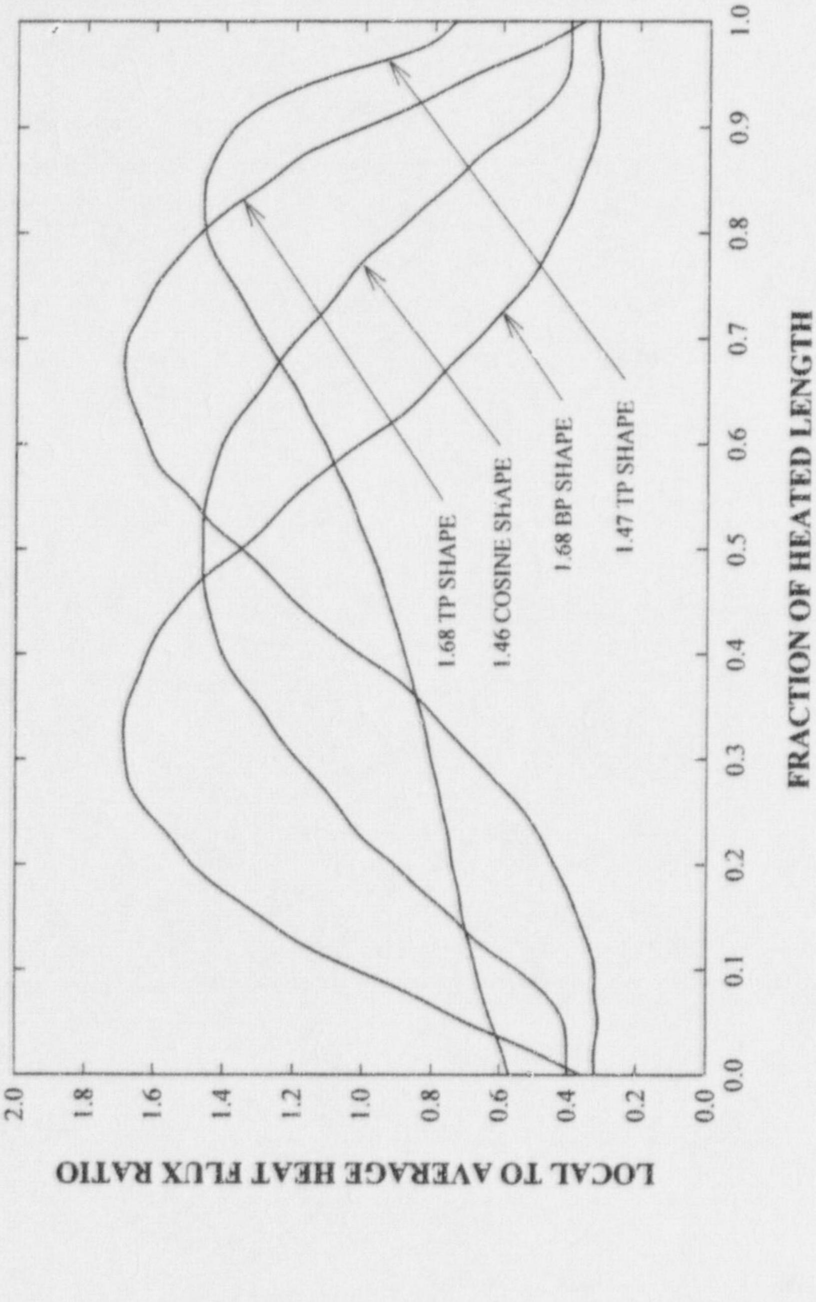


FIGURE 2-6

TYPICAL AXIAL GEOMETRY, ABB-NV TEST WITH UNIFORM AXIAL POWER SHAPE 14x14 GEOMETRY

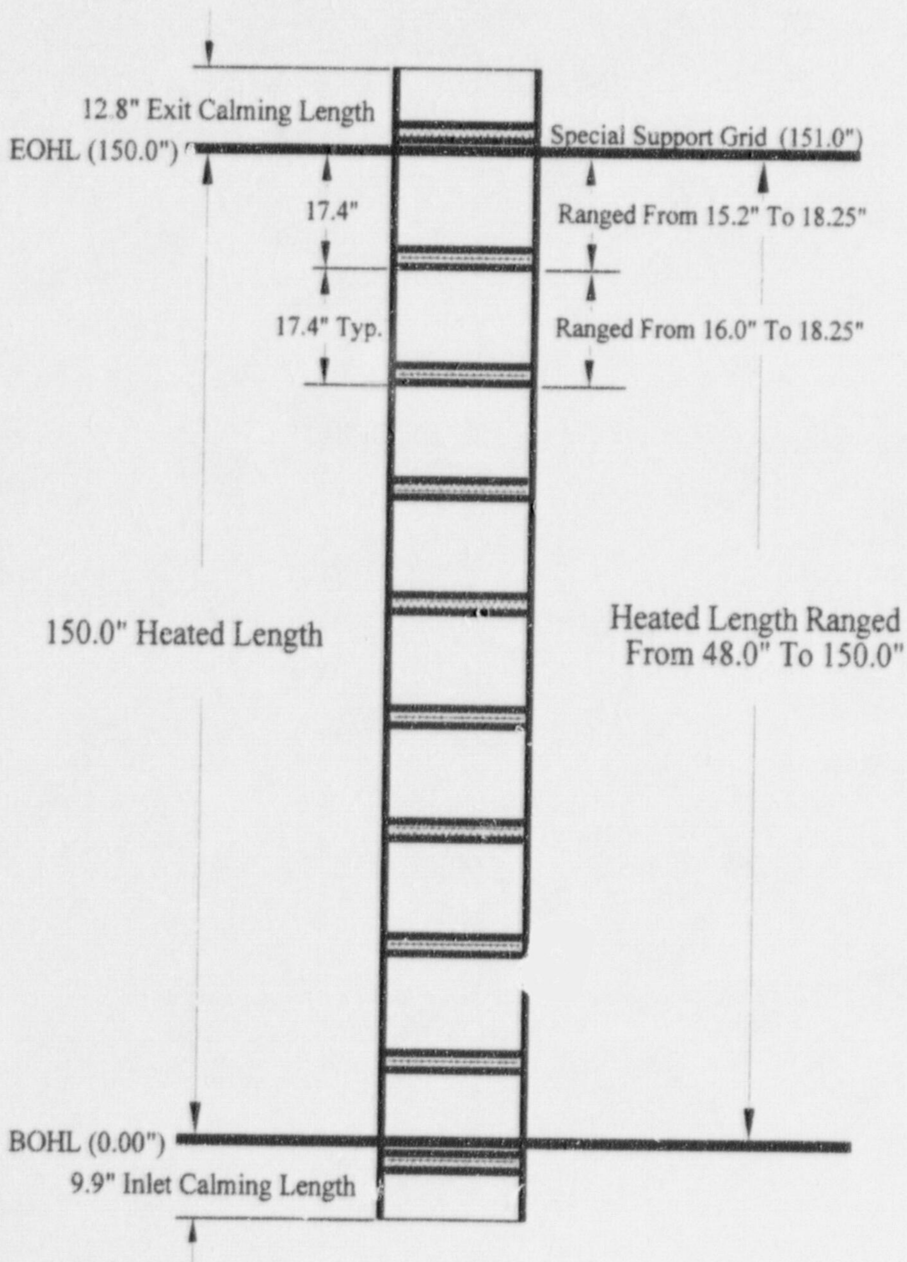


FIGURE 2-7

TYPICAL AXIAL GEOMETRY, ABB-NV TEST WITH UNIFORM AXIAL POWER SHAPE 16x16 GEOMETRY

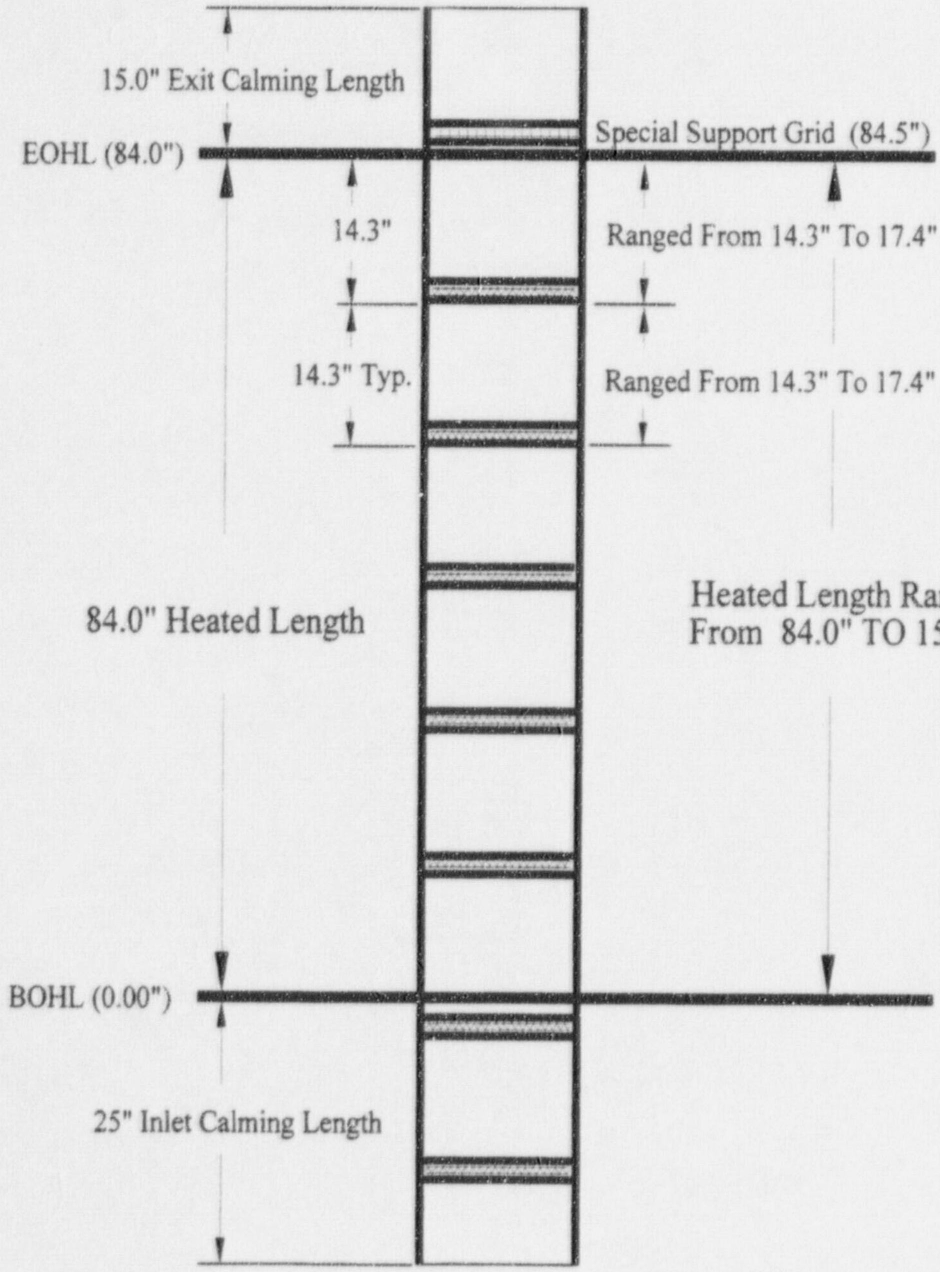


FIGURE 2-8

TYPICAL AXIAL GEOMETRY, ABB-NV TEST WITH NON-UNIFORM AXIAL POWER SHAPE 14x14 GEOMETRY

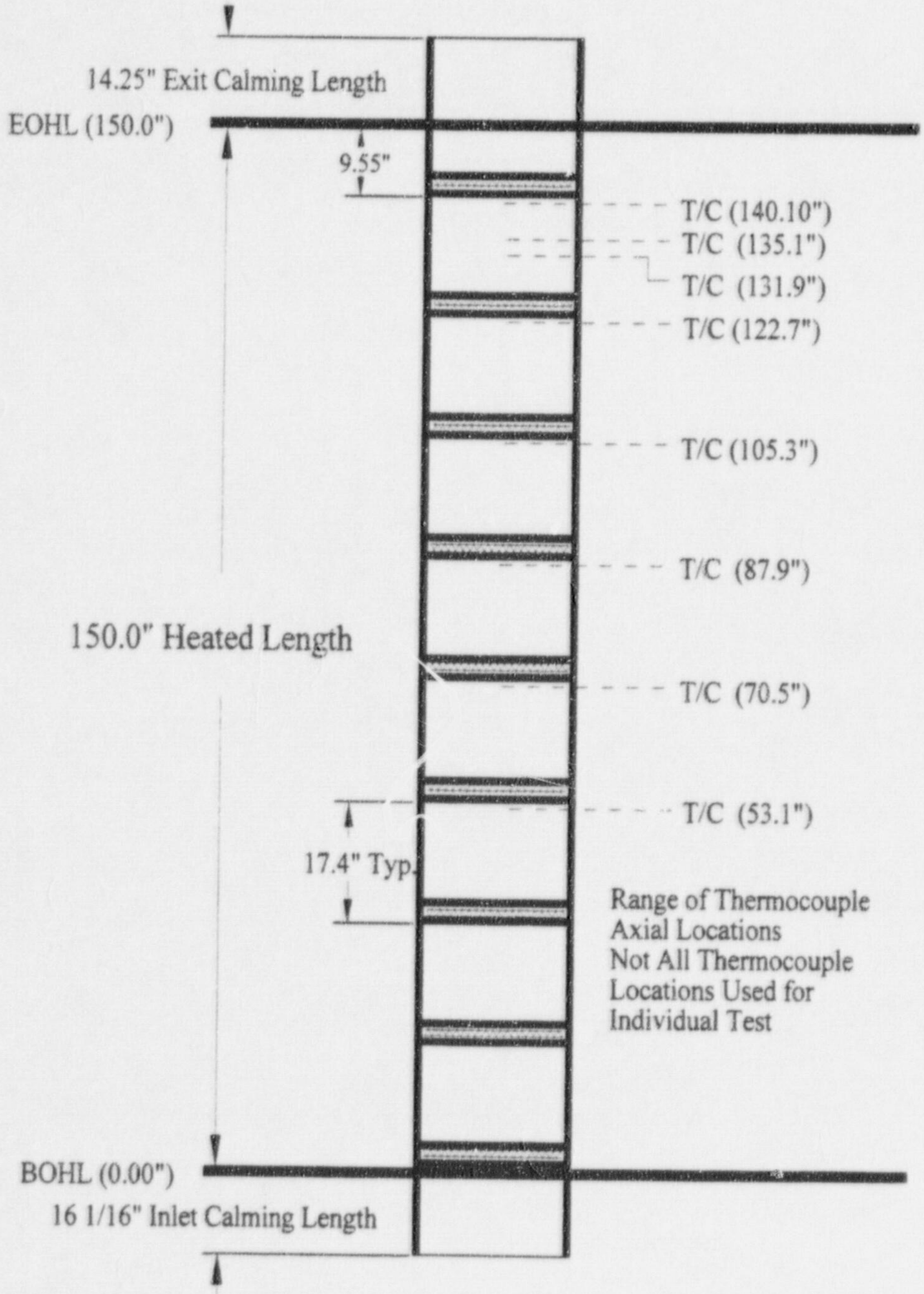


FIGURE 2-9

TYPICAL AXIAL GEOMETRY, ABB-NV TEST WITH NON-UNIFORM AXIAL POWER SHAPE 16x16 GEOMETRY

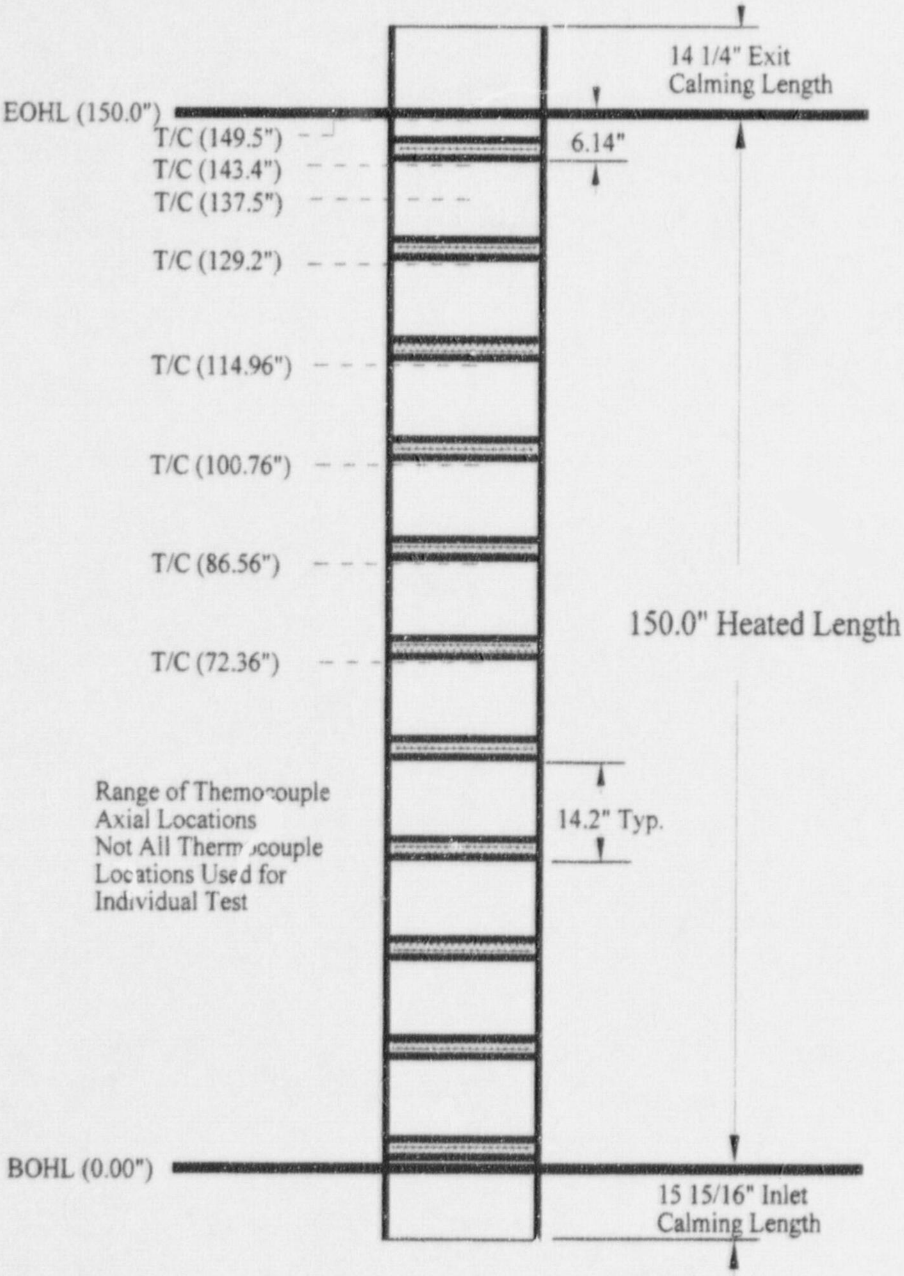


FIGURE 2-10

TYPICAL RADIAL GEOMETRY, ABB-TV TEST FOR 32 ROD, 14x14 GEOMETRY

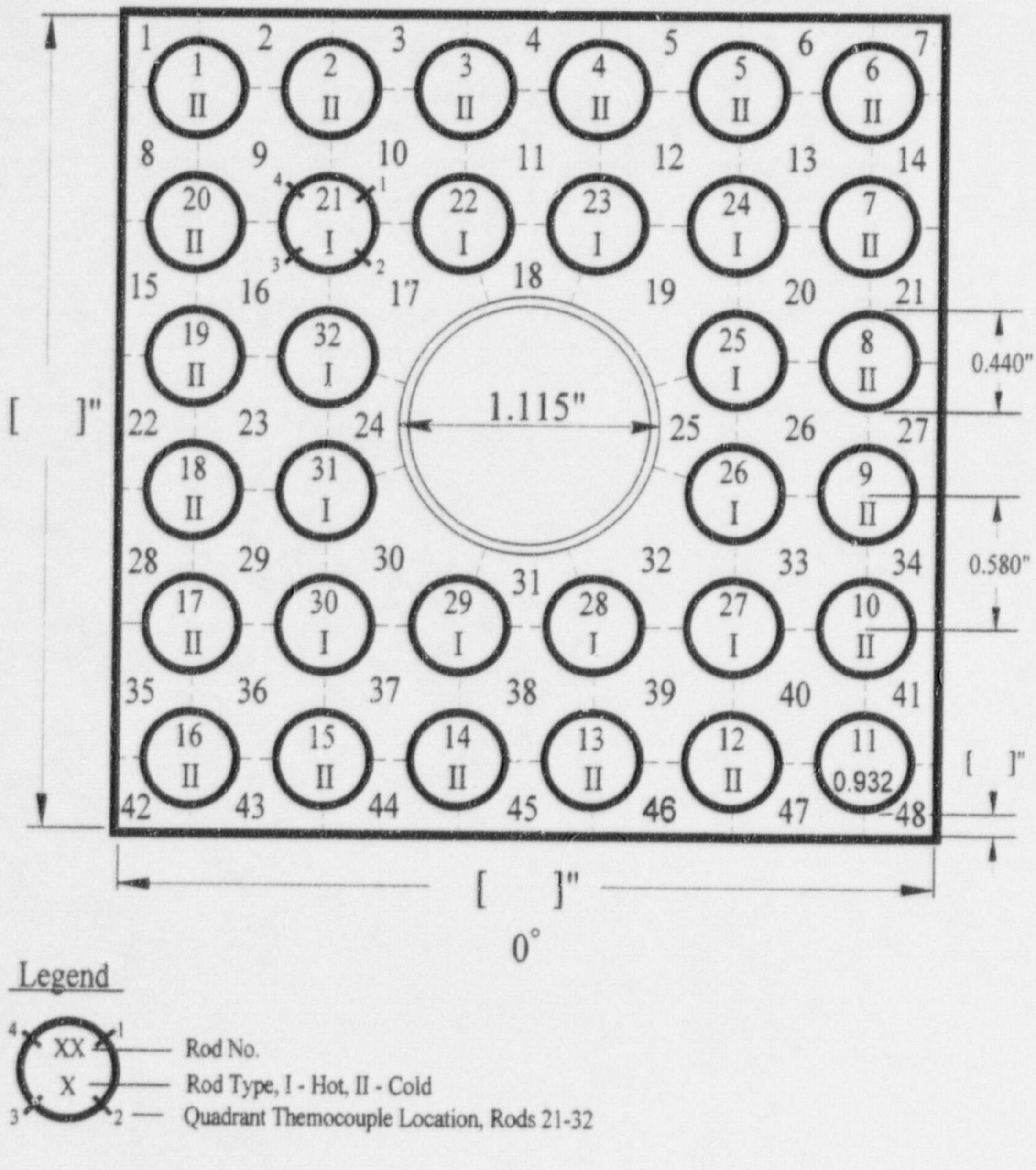


FIGURE 2-11

TYPICAL RADIAL GEOMETRY, ABB-TV TEST
FOR 36 ROD, 14x14 GEOMETRY

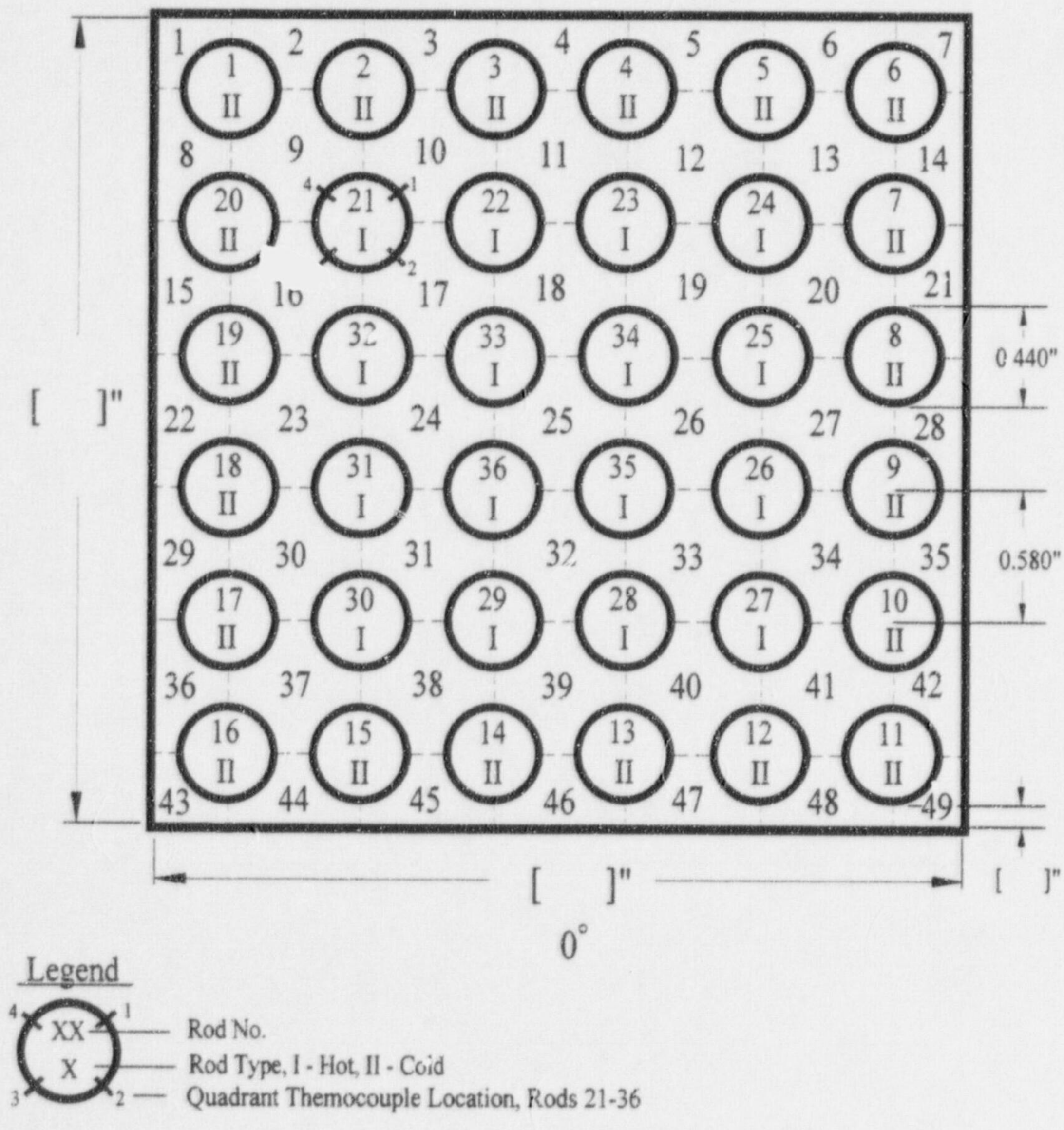


FIGURE 2-12
AXIAL HEAT FLUX DISTRIBUTION
ABB TURBO MIXING VANE TEST

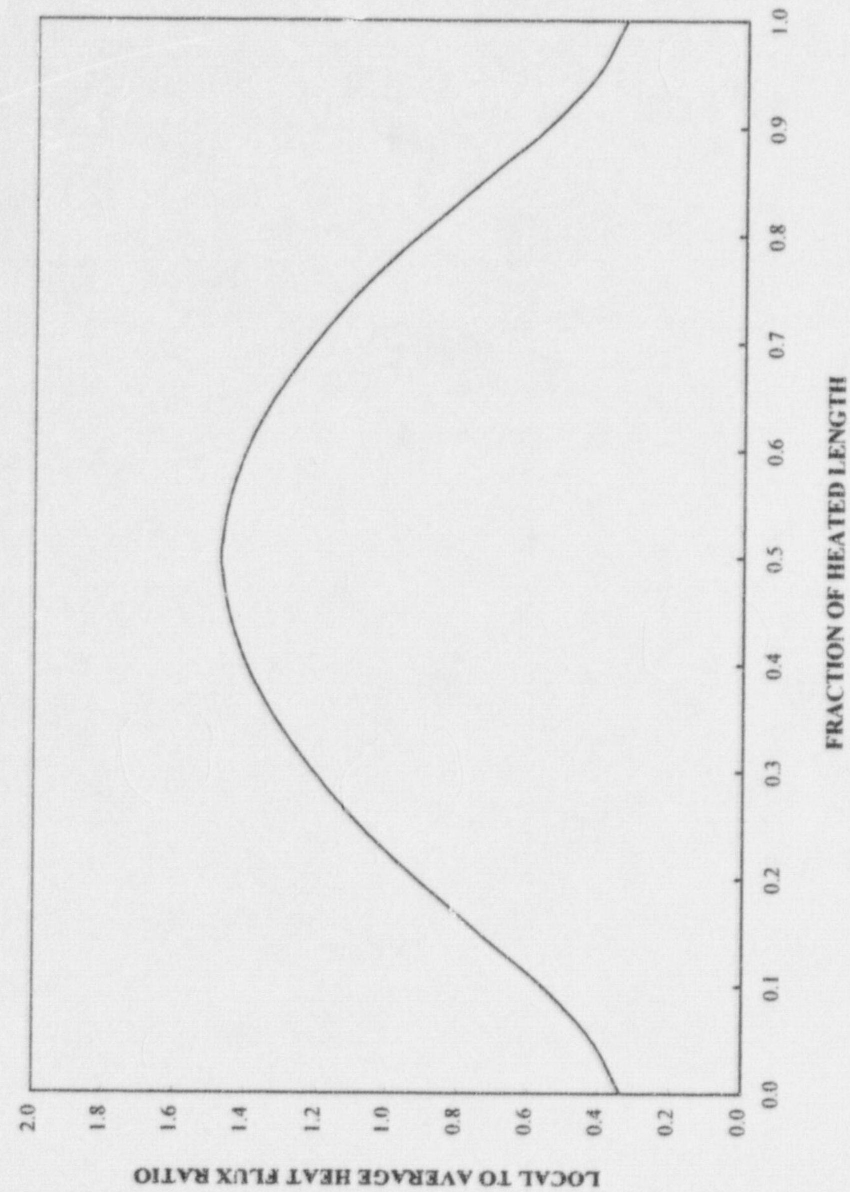


FIGURE 2-13

TYPICAL AXIAL GEOMETRY ABB-TV TEST
WITH UNIFORM AXIAL POWER SHAPE
14x14 GEOMETRY

EOHL (136.7")

BOHL (0.00")

FIGURE 2-14

TYPICAL AXIAL GEOMETRY ABB-TV TEST WITH NON-UNIFORM AXIAL POWER SHAPE 14x14 GEOMETRY

EOHL (136.7")

BOHL (0.00")

3.0 Development of ABB-NV Correlation for Non-mixing Grids

The ABB-NV correlation was developed based on ABB Critical Heat Flux (CHF) test data obtained from the Heat Transfer Research Facility of Columbia University. The tests were performed with simulated 5x5 arrays of the 14x14 and 16x16 fuel assembly geometry for non-mixing grids. The correlation database includes tests with uniform and non-uniform axial power shapes, uniform and non-uniform radial power distributions, with and without guide tubes, heated lengths from 48 to 150 inches and grid spacings from 8 to 18.25 inches.

The functional form of the CHF correlation is empirical and is based solely on experimental observations of the relationship between the measured CHF and the correlation variables. The new form of the correlation is similar to the ABB-X2 correlation developed for ABB 17x17 and 16x16 split-vane mixing grid fuel in Reference 8. The form assumes that there is a linear relationship between CHF and local quality. This relationship has been observed in many rod bundle CHF tests, and it applies well to the ABB CHF tests. The correlation includes the following variables: pressure, local mass velocity, local quality, distance from grid to CHF location, heated length from inlet to CHF location and the heated hydraulic diameter of the CHF subchannel. Special geometry terms are used in the correlation to correct CHF calculations for grid, heated length, heated diameter (cold wall) and guide tube effects. The Tong F_C shape factor for non-uniform axial power distribution, Reference 10, was optimized and applied to the correlation.

3.1 Description of Tests Supporting Correlation

A summary description of the ABB CHF tests supporting the ABB-NV correlation is provided in Section 2 of this report. The majority of tests in the ABB-NV correlation database are the same tests used to develop and support the CE-1 correlation in References 1 and 2. Included in this group are Tests 21, 36, 38, 47, 48, 52, 58, 59, 60 and 66. Several tests were added to the CE-1 non-mixing vane database to support the special geometry terms for the correlation form and for validation of the correlation.

Similar to the CE-1 correlation, the ABB-NV correlation is based upon a series of tests that provide a good representation of the thermal performance of ABB fuel assemblies. Selection of the test sections for the correlation database followed the selection process used for References 1 and 2. As stated in Appendix C of Reference 1, some early tests for the 14x14 fuel assembly geometry were performed with grids made of Zircaloy-4 and a large clearance, [ ] in., between the test section shroud and the peripheral heater rods. Later tests were performed with grids made with the stronger Inconel 625 material since some the data obtained with rod bundles using the Zircaloy-4 grids suffered from the effects of larger rod displacements due to electromagnetic attractive forces. The later tests were also run with a tighter shroud clearance, [ ] in., to reduce the enthalpy difference between the normally colder peripheral subchannels and the hotter interior subchannels and to reduce the excessively large bypass flow. Both of these changes provided a better representation of the thermal performance of ABB fuel assembly in the reactor. Therefore, when available, tests performed with Inconel 625 grids and tighter shroud clearance were chosen for both the ABB-NV database and CE-1 database in References 1 and 2. The inclusion of the tests with the larger shroud clearance provides conservative estimates of the CHF improvements due to the excessive bypass flow in the peripheral subchannels.

Tests 28 and 29 were selected to determine the coefficients for the [ ] distance from grid term in the ABB-NV correlation. The [ ] form was selected based upon the development of the ABB-X2 correlation, Reference 8, as discussed in Section 3.2. Tests 28 and 29 had essentially the same geometry except the grid spacing was 18.25 in. for Test 28 and 8.0 inches for Test 29, see Appendix E. Since the grid spacing is the only parameter change between Tests 28 and 29, the difference in performance between these tests is considered to be the most valid ABB data available for the determination of the grid spacing term for non-mixing grids.

Test 73 was performed with three zero power rods, as shown in Appendix E. This test was added to the ABB-NV database to provide a basis for use of the correlation with a single cold rod adjacent to the subchannel.

To develop a separate validation database for the ABB-NV correlation, data from four test bundles were selected. These test bundles were similar to tests in the correlation database with one geometric modification. Test 41 was a 16x16 test performed with 17.4 inch grid spacing.

Test 43 was an 84 inch heated length test performed with reinforced spacer grids to demonstrate the reinforced grid design had no impact on CHF performance. Tests 51 and 69 were tests performed to demonstrate moderately bowed rods, less than 50% gap closure, had no impact on CHF performance. The validation database accounted for approximately 26% of the data in the combined correlation and validation database.

In addition to the validation database, data from two special tests were reduced with the ABB-NV correlation. Test 72 is a special test that simulates the corner of four assemblies in contact with perimeter strips, Appendix E. [

Test 64 is a non-uniform test with a 23% power spike in the high powered rods for a length of 4 inches, Appendix E. The results from this test are compared with the results from Test 59 to demonstrate there is no detrimental impact on the prediction of CHF performance due to the power spike.

A summary of the geometric characteristics for the tests in the ABB-NV database are given in Tables 2-1 and 2-3. Figures showing the geometry for typical test sections are also shown in Section 2. Figures and Tables showing the specific test radial and axial power distributions are provided in Appendix E. The 5x5 array of rods was placed in a square metal shroud lined with unheated ceramic walls. The radial power split was created by using tubes with different wall thickness. The tubing was heated by passing D.C. current through the tube walls. Inconel 750 was used in the construction of the heaters in the early tests, prior to Test 38. Stainless steel 347 was used for Test 38 and Inconel 625 tubing was used for the later tests, after Test 38. The heaters were filled with alumina ceramic cylinders to maintain rod geometry, prevent deformation during testing, and to isolate the CHF detecting instrumentation from the tubing inner wall. For the uniform tests, every heater rod in each of the test bundles was instrumented approximately one-half inch from the end of the heated length for the detection of heater wall temperature excursions. The instrumentation used in each rod consisted of either a single thermocouple designed to respond to a temperature rise at any azimuthal location or four (quadrant) thermocouples positioned to permit identification of the particular subchannel(s) associated with the temperature excursion. For the non-uniform tests, every heater rod was instrumented with single thermocouples at multiple axial locations for the detection of CHF, as discussed in Section 2. The location of the rods with quadrant thermocouple instrumentation and the axial locations of thermocouples for the specific tests are shown in Appendix E.

3.2 Development of Correlation Form

As stated earlier, the form for the ABB-NV and ABB-TV correlations is similar to the ABB-X2 correlation developed for the ABB 17x17 and 16x16 split-vane mixing grid fuel in Reference 8. For comparison with the existing CE-1 correlation, the basis and form for the CE-1 correlation, Reference 1, is summarized below. The existing CE-1 correlation used the CHF correlation form proposed by Barnett (Reference 3) for uniformly heated tubes, as described in section 5.3 of Reference 1. The correlation form proposed by Barnett is based upon:

1.) Assumption that CHF depends on local coolant conditions.

2.) Observation that CHF is linearly dependent on inlet subcooling.

Written in terms of local coolant conditions, the CHF correlation form proposed by Barnett is given below:

$$q''_{CHF} = \frac{A' - 1/4\,(Dh)\,(Gl)\,(XL)\,(hfg)}{C'}$$

where:

q''_{CHF}	=	critical heat flux, Btu/hr-ft^2
Dh	=	heated diameter of subchannel, inches
Gl	=	local mass velocity at CHF location, lbm/ hr-ft^2
XL	=	local coolant quality at CHF location, decimal fraction
hfg	=	latent heat of vaporization, Btu/lbm
A'	=	unknown function of Pr, GL, Dh
C'	=	unknown function of Pr, GL, Dh
Pr	=	pressure, psia

Based upon an evaluation of the ABB CHF data used in Reference 1, the CE-1 Correlation had the following form:

CE-1 Expression:

$$q''_{CHF,U} = \frac{b1\,(Dh/Dhm)^{b2}\,[\,(b3 + b4Pr)\,(GL)^{(b5 + b6Pr)} - (GL)\,(XL)\,(hfg)\,]}{(GL)^{(b7Pr + b8(GL))}}$$

where
- $q''_{CHF,U}$ = critical heat flux for uniform axial power, MBtu/hr-ft^2
- Pr = Pressure, psia
- Dh = heated diameter of subchannel, inches
- Dhm = heated diameter of matrix subchannel, inches
- GL = local mass velocity at CHF location, Mlbm/ hr-ft^2
- XL = local coolant quality at CHF location, decimal fraction
- hfg = latent heat of vaporization, Btu/lbm

The form of the ABB-NV correlation was initially developed with the primary variables: pressure, local mass velocity, and local quality. [ ] terms of the correlation use the primary variables. This [ ] expression is based on a partial expansion of pressure and local mass velocity to the second order and local quality to the first order. A full expansion would include 17 terms. The selection of these terms were based on examining approximately 50 CHF tests which covered different spacer grid designs from ABB and Westinghouse data bases, a wide range of heated lengths, grid spacing, hydraulic diameters, radial and axial power distributions and guide or thimble tube geometries. The [ ] expression is given below:

$q''_{CHF,U}$ = [

]

This expression can be used to correlate the data from any test section. The correlation form is then multiplied by additional terms to account for geometry effects among tests for the ABB 14x14 and 16x16 non-mixing grid fuel assembly designs. These geometric parameters include the heated hydraulic diameters of the CHF subchannel, the distance from grid to CHF location, DG, the heated length from beginning of heated length (BOHL) to CHF location, and the proximity of matrix subchannels to large guide tubes in the ABB fuel designs. A description of the geometric terms for the ABB-NV correlation is provided below.

3.2.1 Heated Hydraulic Diameter of CHF Subchannel

For the ABB fuel assembly design, there is a difference in performance for the matrix subchannels near the guide tube and the guide side and corner subchannels. Channel 26 in Figure 2-1 is representative of a matrix subchannel near the guide tube, channel 32 is representative of the guide tube side subchannel and channel 31 is representative of the guide tube corner subchannel. For the ABB-NV correlation, the heated hydraulic diameter term, or also referred to as the "cold wall" term, is:

[ ]

where: Dhm = Heated hydraulic diameter of a matrix subchannel with the same rod diameter and pitch, inches.

Dh = Heated hydraulic diameter of the subchannel, inches

The term is [ ] The range of the test data for the ratio of heated hydraulic diameters is 0.679 – 1.08, so the lower limit for the ratio is set to 0.679.

3.2.2 Distance from Grid, DG

Following the development for the ABB-X2 correlation, Reference 8, an [ ] grid term was used in the correlation to correct CHF for different grid spacing. The tests used in the development of the CE-1 correlation were conducted with grid spacing that varied from 14.3 inches to 18.25 inches and it was concluded in Reference 1, page F-2, that there is no significant effect on CHF of axial grid spacing in the range considered. To evaluate the grid term, the data from Tests 28 and 29, were used. The purpose of this term is to account for the presence of the grid on CHF. This term results in lower CHF just upstream of a spacer grid, which produces better agreement with test results. It is noted that several tests in both the ABB-NV and ABB-TV databases had thermocouples placed below the spacer grid in multiple spans and one or more mid-span elevations, see figures in Section 2. The measured primary CHF point was always at the end of the span. The primary point would switch spans, depending on flow conditions, but would never go to the mid-span region, due to the increased CHF performance just downstream of the grid. The form of the distance from grid term is :

[ ]

where: DG = Distance from upstream edge of adjacent upstream grid to CHF axial location, inches

The grid multiplier is constrained to be constant, DG equals 8.00, below distances of 8.00 inches since there is no CHF data available in this region.

3.2.3 Heated Length, HL

A review of the 84-inch and 150 inch data in Appendix F of Reference 1 indicated a weak dependence on heated length. Test 18 was added to determine the form of a heated length term. Based upon an examination of the data for 48 inch, 84 inch and 150 inch heated lengths, the heated length term was determined to have an [

] The form of the distance from grid term is :

[ ]

where: HL = Distance from beginning of heated length (BOHL) to axial location of CHF.

The heated length multiplier is constrained to be constant, HL equals 48 inches, when the heated length is less than 48 inches since there are no CHF data available in this region. [

]

3.2.4 Proximity of Matrix Subchannel to Guide Tube

An examination of the CHF data for the matrix subchannels from both the ABB-NV and ABB-TV databases indicated an improvement in performance in the matrix subchannels for tests without the guide tube compared to data with the guide tube. This performance difference was a function of the three primary variables: pressure, local mass velocity and local quality. To account for this improvement in performance for matrix subchannels [ ], a group of terms were added with the form:

[ ]

Therefore, there are [ ] that use the primary variables in the correlation when the coefficient CC [ ]. For the CHF tests, the constant CC is [ ] For the fuel assembly, CC is [ ] Since there are few negative quality test points for the matrix tests, the multiplier is [ ]

The terms are then combined to produce the final ABB-NV correlation form:

$q''_{CHF,U}$ = [ ] * F_{CW} * F_{GR} * F_{HL} * F_{GT}

and F_{CW} = [ ] Guide tube heated hydraulic diameter factor

F_{GR} = [ ] Distance from grid factor

F_{HL} = [ ] Heated length factor

F_{GT} = [ ] GT proximity factor

The Departure from Nucleate Boiling Ratio (DNBR) is defined as:

$$DNBR = q''_{CHF,U} / q''_{local} * F_C$$

where $q''_{CHF,U}$ = Critical Heat Flux based on uniform axial power shapes, MBtu/hr-ft^2

Pr = Pressure, psia

GL = Local mass velocity at CHF, Mlbm/ hr-ft^2

XL = Local coolant quality at CHF, decimal fraction

Dh = Heated diameter of subchannel, inches

Dhm = Heated diameter of matrix subchannel, inches

DG = Distance from bottom of grid to CHF location, inches

HL = Heated length from beginning of heated length to CHF location, inches

CC = Constant is 0 for subchannels near guide tube & 1 for subchannels[ ]

q''_{local} = Local heat flux, MBtu/hr-ft^2

F_C = Optimized F-factor to correct $q''_{CHF,U}$ for NU shapes

3.3 Data Evaluation and Statistics

The test data from Columbia were evaluated by using the ABB thermal hydraulic code, TORC (Reference 4). The TORC code was used to predict local coolant conditions in each subchannel for the CHF test sections at multiple axial nodes. A TORC model was prepared for each test section in the database based on the test section axial and radial geometry and test section axial and radial power distributions. The TORC calculation used the observed values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux at CHF, as given in Appendix A. The input specifications for the TORC model for the non-mixing grid tests are summarized in Table 3-1. Following Reference 1, the interchannel energy transfer due to turbulent interchange is described by an inverse Peclet number of [ ] for the non-mixing vane grids. The following steps were performed for the optimization of the CHF correlation coefficients with the CHF "correlation" database:

[

]

A nonlinear regression analysis code was also used to sort and fit the test data. The optimization of the constants was performed on data within the following parameter ranges:

System Pressure - Pr = 1725 to 2450 psia
Local Quality - XL ≤ 0.225
Local Mass Velocity - GL = 0.8 to 3.3 Mlbm/ hr-ft^2

The code was also used to weed out repeat runs and the small number of primary peripheral rod indications (only one identified). The repeat runs were identified using the Columbia database. To eliminate potential bias due to changes in performance during the test, the duplicate points were selected from test runs at different points in the test on an alternating basis. [

] The primary peripheral rod indications were weeded out based on the same rationale applied in Reference 1. After the initial runs, the code was also used to weed out outliers, following the procedure described in Section 6. [

]

It is noted that all rejected points had values of measured to predicted (M/P) CHF ratio above the mean by [ ]

The data from Tests 28 and 29 were fit to the basic [ ] expression, based upon test section average conditions, multiplied by an [ ] distance from grid term. The resultant expression for the [ ] DG term is given below:

$$F_{GR} = [\quad]$$

A plot of F_{GR} versus distance from grid is shown in Figure 3-1, along with a plot of the same term developed for the ABB-X2 correlation for grids with the split vane mixing vane design, Reference 8. [ ].

It was determined that the uniform axial shape with heated lengths ranging from 48 inches to 150 inches provided the best data for the o[illegible]tion of the coefficients for the heated length term. The form of the term was determined [illegible] fitting the uniform data to the correlation form without the heated length term and plotting the results as a function of heated length. The uniform data in the correlation database were then fit to the correlation form with the distance from grid term coefficient fixed. The resultant expression for the [ ] heated length term is given below:

$$F_{HL} = [\quad]$$

A plot of F_{HL} versus heated length is shown in Figure 3-2. Since there is no data available for heated length of less than 48.0 inches, the correlation is constrained to be constant, HL equals 48.0 inches, for HL less than 48.0 inches.

[ ]

The "final" coefficients were then determined following steps four and five using the optimized constants for the axial shape factor from Section 5. The ABB-NV correlation with the final coefficients is shown on the following page.

Final Form for ABB-NV Correlation:

The means and standard deviations for the M/P CHF ratio for the correlation database and individual test sections are presented in Table 3-2, along with the range of the primary variables. The data from Tests [ ] are not included in the calculation of mean and standard deviation for the database or grid type since they were not included in the optimization of the correlation constants. As stated earlier, the statistics for the correlation database are based upon the primary CHF indication data only. The statistical output for the individual test points in the ABB-NV correlation database are provided in Appendix B. Further discussion of the statistical evaluation of the ABB-NV correlation is given in Section 6.

3.4 Validation of Correlation

An independent validation database was generated from tests excluded from the correlation database to verify performance of the ABB-NV correlation, as described in Section 3.1. The geometric characteristics for these tests are summarized in Table 2-1. In addition, data from two special tests were reduced to demonstrate conservative performance in peripheral cells and similar performance with a 23% power spike. The validation database was generated in a manner similar to the process used to generate the correlation database for the non-uniform tests.

A TORC model was prepared for each validation test section based on the test section axial and radial geometry and test section axial and radial power distributions. The TORC calculation used the observed values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux at CHF, as given in Appendix A. [

] For non-uniform tests, the calculated DNB ratio is modified with the optimized constants for the axial shape factor, F_C.

The means and standard deviations for the M/P CHF ratio for the validation database and individual test sections are presented in Table 3-3, along with the range of the primary variables. The statistical output for the individual test points in the ABB-NV validation database are provided in Appendix B. Further discussion of the statistical evaluation of the ABB-NV correlation is given in Section 6.

Test 72 is a special test that simulates the corner of four assemblies in contact with perimeter strips, Appendix F. [

] The data for Test 72 were generated for two subchannels. One data set was generated in the same manner as the validation database. For Test 72, the MDNBR location occurred in a matrix subchannel for all test runs. Due to the heated diameter term, [ ], the smallest ratio of M/P CHF is expected for the subchannel at the corner of the four assemblies. The local conditions in the corner subchannel adjacent to the primary rod were also used to confirm that the mean of the M/P CHF ratio for this subchannel is greater than 1. The Test 72 data were reduced with CC [ ] in the ABB-NV correlation. The results from the two cases are presented below:

Data Set	Subchannel	No. Points	Mean	Std. Dev.
Test 72	Assembly Corner	63	[	
Test 72	Matrix	58		]

The averages are [ ], indicating that the improvement on CHF performance due to increased turbulence with the peripheral tabs and increased flow area is greater than the improvement in the matrix subchannels away from the guide tube.

Test 64 is a non-uniform test with a 23% power spike in the high powered rods over a four inch length in the region where CHF was anticipated, Appendix E. The results from this test are compared with the results from Test 59 to demonstrate there is no detrimental impact on the prediction of CHF performance due to the power spike. The data for Test 64 were generated in the same procedure used for Test 69 of the validation data set. The presence of the power spike was not modeled. The M/P CHF ratio results are compared with the results from Test 59 below:

Data Set	No. Points	Mean	Std. Dev.
Test 64	70	[	
Test 59	73		]

Overall, it is apparent there is no detrimental (non-conservative) effect of the power spike on the predicted CHF with the ABB-NV correlation. The results are checked graphically in Figures 3-3 through 3-5, where the M/P CHF ratio values for Tests 59 and 64 are plotted as a function of pressure, local mass velocity and local quality, respectively. Based upon an examination of those graphs, there are no regions that have an identifiable difference, or any significant trends. Therefore, it is concluded that there is no detrimental change in the correlation CHF performance due to local power spikes.

TABLE 3-1

INPUT SPECIFICATIONS FOR ABB-NV TEST TORC MODEL

1. Supplementary output file selected: N7=1 in Card Group 1.
2. Single phase friction factor: $f = 0.184 * Re^{-0.2}$ (approximation of Moody)
3. Two-phase pressure drop predicted by the modified Martinelli-Nelson model.
4. There is no forced flow diversion.
5. Uniform Test, uniform axial power distribution
   Non-uniform Test, non-uniform axial power distribution specific to test
6. Average grid loss coefficient used:

   [ ]

7. The COBRA III-C crossflow resistance relationship is used.
8. The diversion crossflow resistance factor (Kij)=0.1
9. The turbulent momentum factor: 1.0
10. The traverse momentum parameter (S/L)=0.5
11. The number of axial nodes: 40 for L=150 inch tests, 23 for L<150 inch tests
12. The allowable fractional error in flow convergence: 0.005
13. Interchannel energy transfer due to turbulent interchange and flow scattering is described by an inverse Peclet number. This applies to both single and two-phase conditions.
    Pe = [ ] - All non-mixing grid tests
14. Thermal conduction in the coolant is neglected.
15. Homogenous model was used for two-phase flow.
16. Uniform mass velocity was used as the inlet flow option.
17. Variable axial nodes used to set node just below each grid for non-uniform tests.

TABLE 3-2

CHF TEST STATISTICS FOR ABB-NV CORRELATION DATABASE

Test No.	Bundle Array	Rod Diam. ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	Axial Shape	N	ABB-NV M/P Mean, μ	M/P s
								[	
18	14x14	0.440	48	16.0	Yes	Uniform	52		
21	14x14	0.440	84	16.0	No	Uniform	34		
36	14x14	0.440	84	18.25	Yes	Uniform	45		
38	14x14	0.440	150	17.4	Yes	Uniform	38		
47	16x16	0.382	150	14.3	Yes	Uniform	57		
48	16x16	0.382	84	14.3	No	Uniform	55		
52	16x16	0.382	84	14.3	Yes	Uniform	49		
73	16x16	0.382	150	15.7	Yes	Uniform	68		
58	14x14	0.440	150	17.4	Yes	1.68 TP*	57		
59	16x16	0.382	150	14.2	Yes	1.46 Cosine	73		
60	14x14	0.440	150	17.4	Yes	1.68 BP*	67		
66	16x16	0.382	150	14.2	Yes	1.47 TP	67		
									]
	14x14	0.440					226	1.0044	0.0604
	16x16	0.382					302	1.0046	0.0624
	ALL						528	1.0045	0.0615

* TP – Top Peaked, BP – Bottom Peaked

Primary Variable Range for Correlation Database, Minimum of Five Points

Pressure Max.	Pressure Min.	GL, Local mass Velocity Max.	GL, Local mass Velocity Min.	XL, Local Quality Max.	XL, Local Quality Min.
[	]	[	]	[	]

Notes:

N - Number of Data Points

s - Standard Deviation of M/P

Tests [ ] are biased conservatively high and were not included in optimization of correlation coefficients and are not included in statistics for grid type or correlation database

TABLE 3-3

CHF TEST STATISTICS FOR ABB-NV VALIDATION DATABASE

Test No.	Bundle Array	Rod Diam. ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	Axial Shape	N	ABB-NV M/P Mean, μ	M/P s
41	16x16	0.382	84	17.4	Yes	Uniform	40	[	]
43	16x16	0.382	84	14.3	Yes	Uniform	50		
51	16x16	0.382	84	14.3	Yes	Uniform	49		
69	14x14	0.440	150	17.4	Yes	1.68 TP	48		
	ALL						187	1.0040	0.0570

Primary Variable Range for Correlation Database, Minimum of Three Points

Pressure		GL, Local mass Velocity		XL, Local Quality	
Max.	Min.	Max.	Min.	Max.	Min.
[	]	[	]	[	]

Notes:
N - Number of Data Points
s - Standard Deviation of M/P

Test 41 performed with 17.4 inch grid spacing for 16x16 fuel assembly design
Test 43 performed with CES-R grid
Tests 51 and 69 performed with moderately bowed rods, < 50% Gap Closure

FIGURE 3-1

RATIO OF CHF AS A FUNCTION OF DISTANCE FROM GRID

[ ]

FIGURE 3-2

RATIO OF CHF AS A FUNCTION OF HEATED LENGTH

[ ]

FIGURE 3-3

VARIATION OF THE M/P CHF RATIO WITH PRESSURE
FOR TESTS 59 AND 64

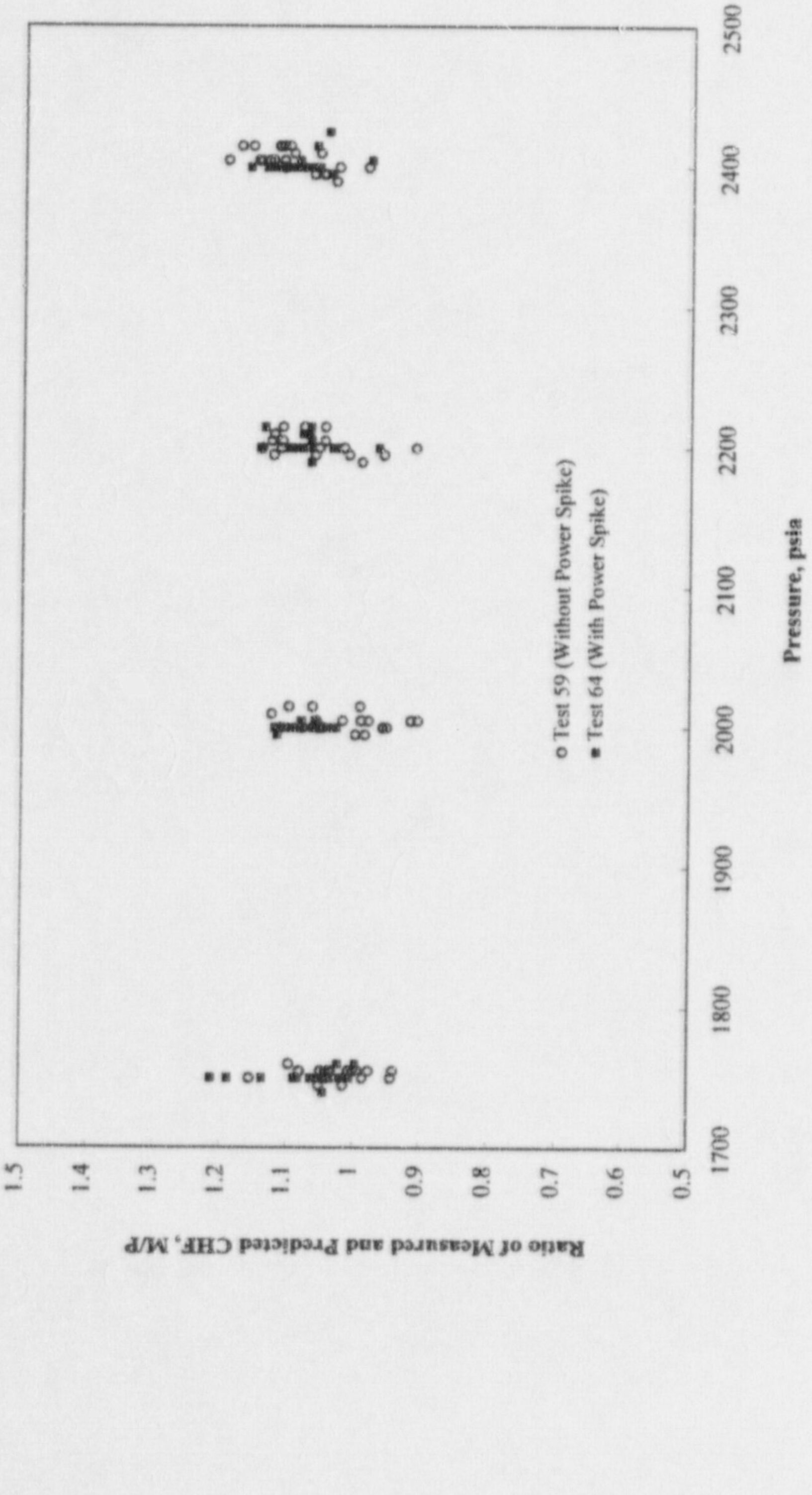


FIGURE 3-4

VARIATION OF THE M/P CHF RATIO WITH MASS VELOCITY
FOR TESTS 59 AND 64

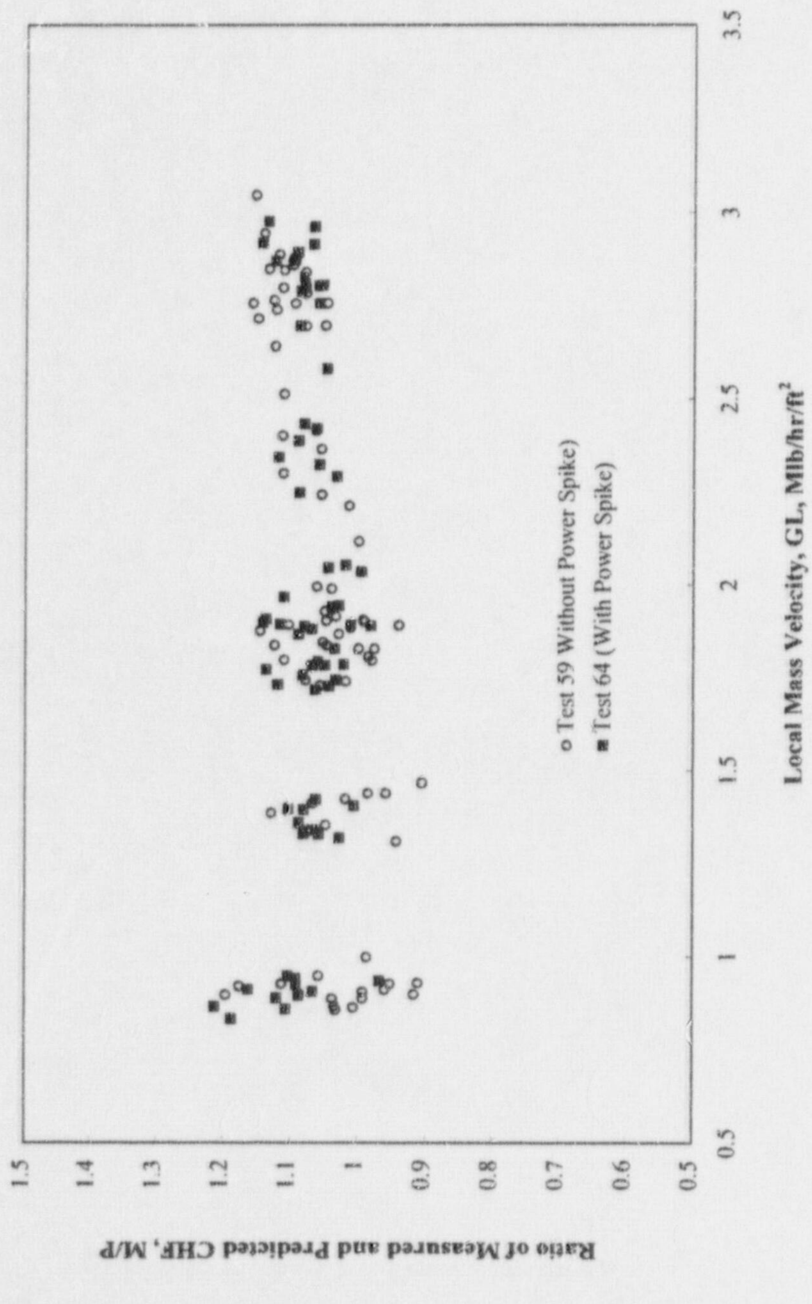
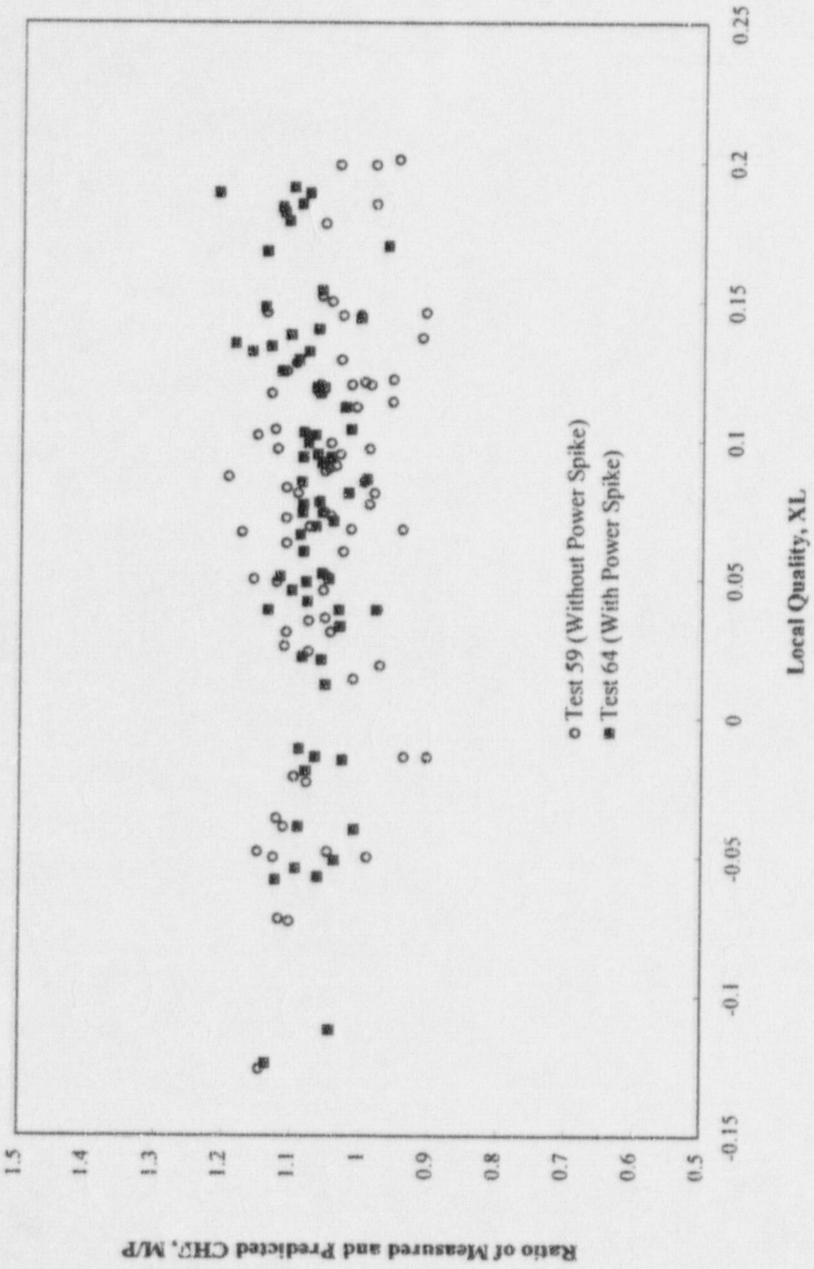


FIGURE 3-5

VARIATION OF THE M/P CHF RATIO WITH LOCAL QUALITY FOR TESTS 59 AND 64



4.0 Development of ABB-TV Correlation for 14x14 Turbo Mixing Grids

The ABB-TV correlation was developed based on ABB Critical Heat Flux (CHF) test data obtained from the Heat Transfer Research Facility of Columbia University. The tests simulated a 6x6 array of the 14x14 fuel assembly geometry for Turbo mixing grids. The correlation database includes tests with uniform and non-uniform axial power shapes, a non-uniform radial power distribution, with and without guide tubes.

The functional form of the ABB-TV correlation is the same as the ABB-NV correlation with coefficients [

] The Tong F_C shape factor for non-uniform axial power distributions was optimized with data from the non-uniform Turbo mixing grid test combined with non-uniform data with non-mixing grids, as described in Section 5.

4.1 Description of Tests Supporting Correlation

A summary of the ABB CHF tests supporting the ABB-TV correlation is provided in Section 2 of this report. The ABB Turbo mixing grid tests used a 6x6 array of electrically heated rods with uniform and non-uniform axial power shapes, which simulated the geometry of the reactor assembly. A 6x6 array was selected for the mixing grid tests to minimize the number of peripheral rod primary indications, as described in Section 2. Figures showing the geometry for typical test sections are also shown in Section 2. The 6x6 array of rods was placed in a square metal shroud lined with unheated ceramic walls. The rod to wall gap for these tests was sized to assure that CHF did not occur on peripheral rods while maintaining similar hydraulic resistance in the grid region for peripheral and interior subchannels. A relative radial power split of approximately [ ] between hot and cold rods was used in the CHF tests to assure that primary CHF indications occurred on interior rods. The radial power split was created by using tubes with different wall thickness. The tubing was heated by passing D.C. current through the tube walls. Inconel 600 and 625 tubing was used in the construction of the heaters. The heaters were filled with alumina ceramic cylinders to maintain rod geometry, prevent deformation during testing, and to isolate the CHF detecting instrumentation from the tubing inner wall.

For uniform axial power shape tests, cold rods (relative power factor 1.00) had a single thermocouple positioned 0.5 inches upstream of the end of heated length. Hot rods (relative power factor [ ]) had quadrant thermocouple instrumentation located 0.5 inches upstream of the end of heated length and a single thermocouple located near mid-span of the last grid span. For the non-uniform axial power shape test, non-directional type thermocouples were used in cold and hot rods at various axial levels, as shown in Section 2. The location of the rods with quadrant thermocouple instrumentation and the axial locations of thermocouples for the specific tests are shown in Appendix E.

Mixing tests were also performed for test sections with a uniform axial power shape to determine the empirical mixing factors (inverse Peclet numbers) for the Turbo mixing grid. To evaluate the subcooled subchannel mixing, a thermocouple was installed in each subchannel at the end of the heated length to measure subchannel outlet temperature. A thermocouple support grid was used to locate these thermocouples in the center of the subchannels.

A summary of the geometric characteristics for the tests in the ABB-TV database is given in Table 2-2. The Columbia data from the three Turbo vane tests were sorted prior to development of the correlation to form separate correlation and validation databases. The sorting technique is described in Section 2.2.2. Approximately 20% of the raw data were set aside for the validation of the correlation. The database for both the correlation and validation data sets are given in Appendix C.

4.2 Development of Correlation Form

The functional form of the ABB-TV correlation is the same as the ABB-NV correlation, described in Section 3. The coefficients for the [ ] distance from grid, DG, term from the ABB-NV correlation is applied to the ABB-TV correlation. Based on Figure 3-1, one would expect the decay of CHF performance for the Turbo mixing grid to be similar to the expression for the mixing grids from the ABB-X2 correlation, Reference 8. However, the mixing vane design is different, resulting in different mixing factors and, likely, a different curve for [

]

[

]

[

]

A brief description of the remaining geometric terms for the ABB-TV correlation is provided below.

4.2.1 Heated Hydraulic Diameter of CHF Subchannel

The ABB-TV correlation has the same form for the heated hydraulic diameter (cold wall) term as the ABB-NV correlation. The coefficient is expected to differ due to the location of the mixing vanes and increased mixing. For the ABB 14x14 Turbo fuel assembly tests, channel 26 in Figure 2-10 is representative of a matrix subchannel near the guide tube, channel 31 is representative of the guide tube side subchannel and channel 32 is representative of the guide tube corner subchannel. For the ABB-TV correlation, the heated hydraulic diameter term is the same as the ABB-NV correlation in Section 3:

[ ]

where: Dhm = Heated hydraulic diameter of a matrix subchannel with the same rod diameter and pitch, inches

Dh = Heated hydraulic diameter of the subchannel, inches

The range of the test data for the ratio of heated hydraulic diameters is 0.680 – 1.00. Since this is essentially the same range as the ABB-NV correlation, the lower limit for the ratio is kept as 0.679.

4.2.2 Proximity of Matrix Channel to Guide Tube

As stated in Section 3, an examination of the CHF data for the matrix subchannels from both the ABB-NV and ABB-TV databases indicated an improvement in performance in the matrix subchannels for tests without the guide tube compared to data with the guide tube. To account for this improvement in performance for matrix subchannels [ ], a group of terms were added with the form:

[ ]

For the CHF tests, the constant CC is [ ] As for the ABB-NV correlation, the multiplier is [ ]

The terms are then combined to produce the final ABB-TV correlation form:

$q''_{CHF,U}$ = [ ] * F_{CW} * F_{GR} * F_{HL} * F_{GT}

and	F_{CW}	= [ ]	Guide tube heated hydraulic diameter factor
	F_{GR}	= [ ]	Distance from grid factor
	F_{HL}	= [ ]	Heated length factor
	F_{GT}	= [ ]	GT proximity factor

where	$q''_{CHF,U}$	= Critical Heat Flux based on uniform axial power shapes, MBtu/hr-ft^2
	Pr	= Pressure, psia
	GL	= Local mass velocity at CHF, Mlbm/ hr-ft^2
	XL	= Local coolant quality at CHF, decimal fraction
	Dh	= Heated diameter of subchannel, inches

Dhm	=	Heated diameter of matrix subchannel, inches
DG	=	Distance from bottom of grid to CHF location, inches
HL	=	Heated length from beginning of heated length to CHF location, inches
CC	=	Constant is 0 for channels near guide tube & 1 for suchannels [ ]

4.3 Data Evaluation and Statistics

The test data from Columbia were evaluated by using the ABB thermal hydraulic code, TORC, (Reference 4), to predict local coolant conditions in each subchannel for the CHF test sections at multiple axial nodes. A TORC model was prepared for each test section in the database based on the test section axial and radial geometry and test section axial and radial power distributions. The TORC calculation used the observed values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux at CHF, as given in Appendix C.

The subchannel mixing data (exit subchannel temperature measurements) from Tests 91 and 92 were evaluated to determine the empirical mixing factors (inverse Peclet numbers) for the mixing grid. The mixing factor is used in the TORC code to quantify the energy exchange between adjacent channels due to the turbulent mixing. To evaluate this mixing factor, exit subchannel temperature measurements were compared to prediction with the TORC code. The mixing factor was varied in TORC until a best fit was obtained between measurements and predictions. The empirical mixing factor for the matrix channel test, Test 91, was determined to be [ ] and the empirical mixing factor for the test with the simulated guide tube, Test 92, was determined to be [ ]. For both tests, the inverse Peclet number is relatively constant versus pressure, exit quality, inlet Reynolds number and mass velocity, as expected. [

]. The input specifications for the TORC model for the Turbo mixing grid tests are summarized in Table 4-1. The following steps were performed for the optimization of the coefficients with the correlation database:

A nonlinear regression analysis code was also used to sort and fit the test data. The optimization of the constants was performed on data within the following parameter ranges:

System Pressure - Pr = 1440 psia to 2500 psia
Local Quality - XL $\leq$ 0.25
Local Mass Velocity - GL = 0.8 to 3.7 Mlbm/ hr-ft^2

As stated above, all available data points were used to optimize the coefficients. The coefficients were optimized using the actual test section geometry for the heated hydraulic diameter in the matrix and guide tube channels. The initial correlation, the coefficients optimized with the uniform data, was then used to evaluate the non-uniform axial power shape data and the constants for the coefficient C in the Tong expression for the axial shape factor, F_C, as described in Section 5.

The "final" coefficients were then determined following steps three and four using the optimized constants for the axial shape factor from Section 5. The ABB-TV correlation with the final coefficients is shown on the following page:

The means and standard deviations for the M/P CHF ratio for the correlation database and individual test sections are presented in Table 4-2, along with the range of the primary variables As stated earlier, the statistics for the correlation database are based upon the primary CHF subchannel data only. The statistical output for the individual test points in the ABB-TV correlation database are provided in Appendix D. Further discussion of the statistical evaluation of the ABB-TV correlation is given in Section 6.

Final Form for ABB-TV Correlation:

4.4 Validation of Correlation

An independent validation database was generated from data excluded from the correlation database to verify performance of the ABB-TV correlation, as described in Sections 2.2.2 and 4.1. Since the data were extracted from the Columbia data for Tests 91, 92 and 93 prior to the development of the correlation constants, the geometric characteristics for these data are identical to the correlation database, as summarized in Table 2-2. The validation database was generated in a manner similar to the process used to generate the correlation database for the non-uniform tests.

A TORC model was prepared for each validation test section based on the test section axial and radial geometry and test section axial and radial power distributions. The TORC calculation used the observed values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux at CHF, as given in Appendix C. The appropriate mixing factor was selected for the test geometry, from Table 4-1. [

]. For non-uniform tests, the calculated DNB ratio is modified with the optimized constants for the axial shape factor, F_C.

The means and standard deviations for the M/P CHF ratio for the validation database and individual test sections are presented in Table 4-3, along with the range of the primary variables The statistical output for the individual test points in the ABB-TV validation database are provided in Appendix D. Further discussion of the statistical evaluation of the ABB-TV correlation is given in Section 6.

TABLE 4-1

INPUT SPECIFICATIONS FOR ABB-TV TEST TORC MODEL

1. Supplementary output file selected: N7=1 in Card Group 1.
2. Single phase friction factor: $f = 0.184 * Re^{-0.2}$ (approximation of Moody)
3. Two-phase pressure drop predicted by the modified Martinelli-Nelson model.
4. There is no forced flow diversion.
5. Uniform Test, uniform axial power distribution
   Non-uniform Test, non-uniform axial power distribution specific to test
6. Average grid loss coefficient used:

[ ]

7. The COBRA III-C crossflow resistance relationship is used.
8. The diversion crossflow resistance factor (Kij)=0.1
9. The turbulent momentum factor: 0.0
10. The traverse momentum parameter (S/L)=0.5
11. The number of axial nodes: 40
12. The allowable fractional error in flow convergence: 0.002
13. Interchannel energy transfer due to turbulent interchange and flow scattering is described by an inverse Peclet number. This applies to both single and two-phase conditions.
    Pe = [ ]
    Pe = [ ]
14. Thermal conduction in the coolant is neglected.
15. Homogenous model was used for two-phase flow.
16. Uniform mass velocity was used as the inlet flow option.
17. Variable axial nodes used to set node just below each grid for non-uniform tests.

TABLE 4-2

CHF TEST STATISTICS FOR ABB-TV CORRELATION DATABASE

Test No.	Bundle Array	Rod Diam. ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	Axial Shape	N	ABB-NV M/P Mean, μ	M/P s
91 C	14x14	0.440	136.7	18.86	No	Uniform	73	[	]
92 C	14x14	0.440	136.7	18.86	Yes	Uniform	79		
93 C	14x14	0.440	136.7	18.86	Yes	1.47 Cosine	82		
	ALL						234	1.0002	0.0486

Primary Variable Range for Correlation Database, Minimum of Five Points

Pressure Max.	Pressure Min.	GL, Local mass Velocity Max.	GL, Local mass Velocity Min.	XL, Local Quality Max.	XL, Local Quality Min.
[	]	[	]	[	]

Notes:
N - Number of Data Points
s - Standard Deviation of M/P

TABLE 4-3

CHF TEST STATISTICS FOR ABB-TV VALIDATION DATABASE

Test No.	Bundle Array	Rod Diam. ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	Axial Shape	N	ABB-NV M/P Mean, μ	M/P s
91 V	14x14	0.440	136.7	18.86	No	Uniform	20	[	
92 V	14x14	0.440	136.7	18.86	Yes	Uniform	22		
93 V	14x14	0.440	136.7	18.86	Yes	1.47 Cosine	20		]
	ALL						62	0.9974	0.0477

Primary Variable Range for Correlation Database, Minimum of Three Points

Pressure		GL, Local mass Velocity		XL, Local Quality	
Max.	Min.	Max.	Min.	Max.	Min.
[	]	[	]	[	]

Notes:

N - Number of Data Points

s - Standard Deviation of M/P

5.0 Optimization of Tong F_C Shape Factor for Non-uniform Axial Power Shapes

The optimization of the Tong shape factor, F_C, for non-uniform axial power shapes was performed with the combined ABB non-uniform test data from the ABB-NV correlation database, Appendix A, and the ABB-TV correlation database, Appendix C. The basic approach was to preserve the Tong form for F_C, Reference 10, and to re-fit the constants (a), (b), and (c), in the expression for the coefficient C, shown below.

$$C = (a) * (1 - XL_{crit})^{(b)} / (GL)^{(c)} \quad ft^{-1}$$

The non-uniform test data from the correlation and validation databases were then evaluated to ensure the ABB-NV and ABB-TV correlations, combined with the modified values of F_C, conservatively covered all regions of the correlation parameter range.

5.1 Description of Non-uniform Axial Power Shape Tests

Correlation data were obtained with five test bundles with a non-uniform axial power shape, four for the ABB-NV correlation and one for the ABB-TV correlation. For the ABB-NV correlation, two test sections are representative of the ABB 14x14 fuel assembly geometry (0.440 inch O.D. heated rods and 0.580 inch rod pitch) and two test sections are representative of the ABB 16x16 fuel assembly geometry (0.382 inch O.D. heated rods and 0.506 inch rod pitch). The non-uniform correlation data for the ABB-TV correlation were obtained with a test section that is representative of the ABB 14x14 Turbo fuel assembly geometry. In addition, data from a non-uniform test were included in the validation database for the evaluation of the ABB-NV correlation and data from a special non-uniform test with a 23% power spike were included to determine the effect, if any, of the power spike on the CHF performance. In all, data from seven non-uniform axial power shape tests were examined in eight data sets during the development and evaluation of the ABB-NV and ABB-TV correlations. The seven non-uniform tests were performed with five axial power distributions, as shown in Figures 2-5 and 2-12. Summaries of the characteristics of the seven test bundles are provided in Tables 2-1 through 2-3.

5.2 Optimization of F_C Shape Factor Coefficients

The process used to determine the coefficients for the non-uniform axial shape correction factor for the ABB standard non-mixing grids (ABB-NV) and Turbo mixing grids (ABB-TV) is described below.

5.2.1 Summary of Evaluation of Non-uniform Data with CE-1 Correlation

The data from the four ABB-NV non-uniform tests in the correlation database were analyzed with CE-1 correlation and the TORC thermal hydraulic code in Reference 2 using the Tong constants for the F_C shape factor, Reference 10. The F_C shape factor is incorporated into the TORC code and the CHF was calculated with the expression:

$$q''_{CHF,NU} = q''_{CHF,U} / F_C$$

and $$DNBR = q''_{CHF,NU} / q''_{local}$$

where:

$q''_{CHF,U}$ - local critical heat flux in subchannel predicted by the CE-1 correlation.

q''_{local} - maximum local heat flux in corresponding subchannel.

F_C - Tong non-uniform heat flux factor.

F_C - Shape Factor, defined as:

$$F_C = \frac{C}{q''_{CHF,NU} * (1 - e^{-C\, l_{crit}})} \int_0^{l_{crit}} q''_{(z)}\, e^{-C(l_{crit}-z)}\, dz$$

The Tong empirically determined coefficient, C, is evaluated with the expression:

$$C = 1.8 * (1 - XL_{crit})^{4.31} / (GL)^{0.478} \ ft^{-1}.$$

where:	$q''_{CHF,NU}$	-	non-uniform heat flux at CHF location lcrit, MBtu/hr-ft^2
	$q''(z)$	-	local heat flux versus axial length, MBtu/hr-ft^2
	lcrit	-	distance from inlet to CHF location, ft
	z	-	axial length, ft
	XL_{crit}	-	equilibrium quality at CHF locations
	GL	-	mass velocity, Mlbm/hr-ft^2

The mean of the M/P CHF ratio following this approach ranged from 1.119 to 1.287, as shown on page 5-4 of Reference 2. The predicted CHF values used in Reference 2 were based on the local conditions at the location of the MDNBR for a channel adjacent to the rod with the primary CHF indication. A summary of the staff evaluation of the non-uniform data with the CE-1 data, provided in Reference 2, states the following:

> Although CE-1 correlation predicts the measured CHF for uniform axial heat flux, it underpredicts the CHF for non-uniform axial heat flux distribution when it is combined with the F factor.
>
> Study at Georgia Institute of Technology concluded that although the F factor could possibly be optimized, it is not the only source of error, there was bias from another source.
>
> Since the CE-1 correlation combined with the F factor underpredicts CHF for non-uniform shapes, the MDNBR limits applicable to uniform shapes is applicable to non-uniform shapes.

5.2.2 Evaluation of Non-uniform Data with F_C Shape Factor Varied

The need for a non-uniform axial shape factor for the ABB-NV and ABB-TV correlations was re-examined using the non-uniform database for the non-mixing grids and the non-uniform test with the Turbo mixing grids. Initially, the data from the five test sections in the correlation databases were reduced with the ABB-NV and ABB-TV correlations with [

] The data were reduced in a manner similar to the procedure described in

Reference 2 with the coefficient C in the expression for F_C calculated with the empirical constants from Reference 10. The results, given in Table 5-1 and Figure 5-1, are very similar to the results obtained with the CE-1 correlation, reported in Reference 2.

The TORC code was run with the F_C shape factor [ ] This process was [ ] Since the results had little variation, only the final results are presented here. The TORC calculation for each data set used the observed values of pressure, inlet temperature, bundle average mass velocity and bundle average heat flux at CHF, as given in Appendices A and C. A TORC input deck was created for each data set in the database based on the axial and radial geometry and axial power shapes. A summary of additional input specifications used for the TORC calculation is given in Tables 3-1 and 4-1. [ ]. All points outside the parameter limits of the ABB-NV and ABB-TV correlations were excluded. The results for the eight data sets are given in Table 5-2 and Figure 5-2.

The mean of the ratio of measured to predicted CHF for all of the non-uniform data, for F_C [ ]and the standard deviation is [ ]. Based upon individual tests, the mean ranged from [ ] and the standard deviation ranged from [ ]. The results from all ABB non-uniform tests were improved [ ]. To examine trends in the data with F_C set to [ ], plots of the M/P CHF ratio were generated as a function of mass velocity and quality, the two terms in the expression for the coefficient C. While no trend was apparent in the plot as a function of quality, there was an observed trend in the plot of the M/P CHF ratio as a function of local mass velocity, Figure 5-3. The plot indicated the average M/P CHF ratio would [ ] A plot of [ ], as a function of quality, Figure 5-4, shows a trend in that data, indicating a [ ] An examination of all data sets indicate the trend, or slope, in the data is similar for all tests and all axial power shapes although the average M/P CHF ratio is [ ] This is not surprising since these tests had [ ], Table 5-2.

If these tests are removed, the mean value of the M/P CHF ratio [ ] to adequately cover this region.

5.2.3 Optimization of Constants in Coefficient C

Based upon the evaluation of the non-uniform data [ ], it was concluded that the expression for F_C should be optimized using the ABB non-uniform data. The basic approach was to preserve the Tong form for F_C and to re-fit the constants (a), (b), and (c), in the expression for the coefficient C, shown below. The constants were re-fit with the non-uniform data from the five correlation data sets, so the validation data would be independent of the process.

$$C = (a) * (1 - XL_{crit})^{(b)} / (GL)^{(c)} \quad ft^{-1}$$

The optimum set of constants was determined using an iterative process similar to the process used to evaluate the non-uniform data for F_C [ ].

The data for the five test sections in the correlation databases were evaluated using the ABB-NV and ABB-TV correlations with coefficients from the uniform tests only. Following the determination of the constants (a), (b) and (c), the final correlation coefficients were determined, as described in Sections 3 and 4. The evaluation process with the TORC code was then repeated to confirm these constants for the ABB-NV and ABB-TV correlations with the final coefficients.

Based upon this procedure, the optimum set of constants for the coefficient C for the ABB non-uniform data are:

$$C = [\quad] * (1 - XL_{crit})^{[\quad]} / (GL)^{[\quad]} \quad ft^{-1}.$$

5.3 Data Evaluation and Statistics

The data from all eight non-uniform data sets were evaluated with the TORC thermal hydraulic code using the Tong F_C shape factor with the optimized constants for the coefficient C. The F_C shape factor is incorporated into the TORC code and the CHF was calculated with the expression:

$$q''_{CHF,\,NU} = q''_{CHF,\,U} \,/\, F_C$$

and

$$DNBR = q''_{CHF,\,NU} \,/\, q''_{local}$$

where:

	$q''_{CHF,\,U}$	-	local critical heat flux in channel predicted by the ABB-NV or ABB-TV correlation.
	q''_{local}	-	local heat flux in corresponding channel.
	F_C	-	Re-fit Tong non-uniform heat flux factor (F factor)

F_C - Shape Factor, is still defined as:

$$F_C = \frac{C}{q''_{CHF,\,NU} * (1 - e^{-C\,l crit})} \int_0^{l_{crit}} q''_{(z)}\, e^{-C(l crit-z)}\, dz$$

The coefficient C is evaluated with the ABB empirical constants in the expression:

$$C = [\quad] * (1 - XL_{crit})^{[\quad]} / (GL)^{[\quad]} \ ft^{-1}.$$

The results for all eight data sets of ABB non-uniform data are shown in Table 5-3 and Figure 5-5.

A plot of the M/P CHF ratio as a function of local mass velocity with F_c calculated with the ABB empirical constants for the coefficient C is shown in Figure 5-6. [

]

Based upon the evaluation performed with all ABB non-uniform data, it is concluded the ABB-NV and ABB-TV correlations, combined with the modified constants for the coefficient C, adequately cover all regions of the correlation parameter range.

TABLE 5-1

SUMMARY OF ABB-NV AND ABB-TV CORRELATION PREDICTIONS FOR NON-UNIFORM AXIAL POWER CHF CORRELATION DATA

F_C Shape Factor Determined From Tong Empirical Expression for Coefficient C in Reference 10

Test Section	Grid Design	Axial Power Shape	No. of Data	M/P Mean, μ	M/P s	GL Min.	GL Max.	XL Min.	XL Max.
Test 58	14x14 NV	1.68 Top Peak	54						
Test 59	16x16 NV	1.46 Cosine	70						
Test 60	14x14 NV	1.68 Bottom Peak	64						
Test 66	16x16 NV	1.47 Top Peak	66						
Test 93C	14x14 TV	1.47 Cosine	81						
ALL			335						

s - Standard Deviation of M/P CHF Ratio

TABLE 5-2

SUMMARY OF ABB-NV AND ABB-TV CORRELATION PREDICTIONS FOR NON-UNIFORM AXIAL POWER CHF DATA

F_C Shape Factor [ ]

Test Section	Grid Design	Axial Power Shape	No. of Data	M/P Mean, μ	M/P s	GL Min.	GL Max.	XL Min.	XL Max.
Test 58	14x14 NV	1.68 Top Peak	57						
Test 59	16x16 NV	1.46 Cosine	73						
Test 60	14x14 NV	1.68 Bottom Peak	68						
Test 66	16x16 NV	1.47 Top Peak	68						
Test 93C	14x14 TV	1.47 Cosine	82						
Test 69 V	14x14 NV	1.68 Top Peak	48						
Test 93 V	14x14 TV	1.47 Cosine	17						
Test 64	16x16 NV	1.46 Cosine with 23% Power Spike	70						
ALL			483						

s - Standard Deviation of M/P CHF Ratio

TABLE 5-3

SUMMARY OF ABB-NV AND ABB-TV CORRELATION PREDICTIONS FOR NON-UNIFORM AXIAL POWER CHF DATA

F_C Shape Factor Determined From ABB Empirical Expression for Coefficient C

Test Section	Grid Design	Axial Power Shape	No. of Data	M/P Mean, μ	M/P s	GL Min.	GL Max.	XL Min.	XL Max.
Test 58	14x14 NV	1.68 Top Peak	57						
Test 59	16x16 NV	1.46 Cosine	73						
Test 60	14x14 NV	1.68 Bottom Peak	67						
Test 66	16x16 NV	1.47 Top Peak	67						
Test 93C	14x14 TV	1.47 Cosine	82						
Test 69 V	14x14 NV	1.68 Top Peak	48						
Test 93 V	14x14 TV	1.47 Cosine	17						
Test 64	16x16 NV	1.46 Cosine with 23% Power Spike	70						
ALL			481						

s - Standard Deviation of M/P CHF Ratio

FIGURE 5-1

MEASURED AND PREDICTED CRITICAL HEAT FLUXES
FOR THE ABB NON-UNIFORM DATA
AND ABB-NV OR ABB-TV CORRELATION

F_c Determined with Tong Empirical Constants for Coefficient C

FIGURE 5-2

MEASURED AND PREDICTED CRITICAL HEAT FLUXES
FOR THE ABB CORRELATION NON-UNIFORM DATA
AND ABB-NV OR ABB-TV CORRELATION

F_c [ ]

FIGURE 5-3

VARIATION OF M/P CHF RATIO WITH MASS VELOCITY

FIGURE 5 4

VARIATION OF M/P CHF RATIO WITH LOCAL QUALITY, [ ]

FIGURE 5-5

MEASURED AND PREDICTED CRITICAL HEAT FLUXES
FOR THE ABB NON-UNIFORM DATA
AND ABB-NV OR ABB-TV CORRELATION

F_c Determined with ABB Empirical Constants for Coefficient C

[ ]

FIGURE 5-6

VARIATION OF M/P CHF RATIO WITH MASS VELOCITY

F_c Determined with ABB Empirical Constants for Coefficient C

FIGURE 5-7

VARIATION OF M/P CHF RATIO WITH LOCAL QUALITY

F_C Determined with ABB Empirical Constants for Coefficient C

6.0 Statistical Evaluation

The mean and standard deviation for the ratio of measured to ABB-NV predicted CHF are shown in Table 3-2 for the correlation database and the individual test sections and Table 3-3 for the validation database and individual test sections. Similarly, the mean and standard deviation for the ratio of measured to ABB-TV predicted CHF are given in Table 4-2 for the correlation database and individual test sections and Table 4-3 for the validation database and individual test sections. A statistical evaluation is performed with the ABB-NV and ABB-TV correlations for each test section, bundle array, the correlation database, the validation database and the combined correlation and validation database to determine the one-sided 95/95 DNBR limit applicable to each correlation. As stated in Section 3, [

] per the procedure given in Chapter 17 of Reference 12, a more rigorous test than the often-used Chauvenet's Criterion, Reference 13. Tests for normality at the 95% confidence level were performed on the above data sets to determine the proper statistical methods to be used for the data. The W and D' tests, Reference 14, were used to evaluate normality. The W test is applied to tests with less than 50 test points and the D' test is applied to all other test groups.

Statistical tests were performed to determine if all or selected data groups belong to the same population, in order to be combined for the evaluation of the 95/95 DNBR tolerance limit. For normally distributed groups, homogeneity of variance was examined using Bartlett's test and homogeneity of the means was examined with the t-test or One Way Analysis of Variance (ANOVA) F-test. The t-test was applied to test for equality of means for two groups and the F-test was applied to multiple groups. For groups that did not pass the normality test, the Kruskal-Wallis One Way Analysis of Variance by Ranks test is used to test the null hypotheses that the medians, or averages, of the tests or groups are the same. Since the groups that failed the D' normality test, passed other normality tests, such as the Kolmogorov-Smirnov test, the Bartlett and F-tests were initially applied to check for poolability of these groups. Data that did not pass any of these tests were not combined. Since it is proper to utilize all data in the evaluation of the correlation, the one-sided 95/95 are calculated for the combined correlation and validation database, if the data are poolable or for each subset of data if not all of the data are poolable. For normally distributed groups, Owen's one-sided tolerance limit factor, Reference 11, is used to compute the 95/95 DNBR limit. For groups that are not normally distributed, a distribution-free or nonparametric limit, from Chapter 2 of Reference 12, is established. To cover all regions with the 95/95 limit, the most conservative limit for any subset is applied to the entire set of data.

Scatter plots were then generated for each of the variables in the correlation to examine the correlation for trends or regions of non-conservatism. The measured to correlation predicted CHF ratio is plotted as a function of pressure, local mass velocity, local quality, heated hydraulic diameter, distance from bottom of adjacent upstream grid, and heated length from BOHL to location of CHF. The 95/95 DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points. The total number of test points that fall below the limit are also identified.

6.1 Statistical Tests

6.1.1 Treatment of Outliers

Each database is examined for outliers by the following method:

The probability of rejecting an observation when all data belong to the same group, α, was selected to be 0.05. The term $\alpha' = 1 - (1-\alpha)^{1/n}$ is computed. The value of $(1 - \alpha'/2)$ is the normal cumulative distribution value, P, and the value of $z_{1-\alpha'/2}$ is calculated or taken from cumulative normal distribution tables. For a mean value of m, the values of a and b are computed where:

$$a = m - \sigma * z_{1-\alpha'/2}$$
$$b = m + \sigma * z_{1-\alpha'/2}$$

Any observation that does not lie in the interval a to b is rejected. The method does assume a normal distribution and the values of μ, mean of the data, and s, standard deviation of the data, are reasonable estimates of m and σ. Therefore, care must be taken to ensure the elimination of outliers is justifiable. As stated in Sections 3 and 4, [ ] for the ABB-NV correlation and [ ] for the ABB-TV correlation. [ ] correlation database had M/P CHF ratio values [ ] the standard deviation, s. In addition, [ ] the standard deviation away from the mean.

6.1.2 Normality Tests

The W and D' tests, Reference 14, were used to evaluate the assumption of a normal distribution For individual tests with less than 50 test points, the W test is applied. The test statistic W is computed as:

$$W = b^2 / S^2$$

where: $S^2 = \sum_{i=1}^{n} (x_i - \bar{x})^2$

$b = \sum_{i=1}^{k} a_{n-i+1} (x_{n-i+1} - x_i)$ x_i in ascending order

a_i from Table 1, Reference 14

k = n/2 if n is even and k = (n-1)/2 if n is odd.

The value of W is compared with percentage points of the distribution of W for the P value set to 0.05 from Table 2 of Reference 14. Small values of W indicate non-normality. For combined tests or individual tests with $n \geq 50$, the D' normality test is applied. The test statistic D' is computed as:

$$D' = T / S$$

where: $S = [\sum_{i=1}^{n} (x_i - \bar{x})^2]^{0.5}$

$T = \sum_{i=1}^{n} \{i - (n+1)/2\} x_i$ x_i in ascending order

The calculated value of D' is compared with the percentage points of the distribution of D' from Table 5 of Reference 14. The D' test indicates non-normality if the calculated value of D' falls outside of the range established from Table 5 for P value set to 0.025 and 0.975. These tests were selected since they are considered to be more rigorous compared to other normality tests, such as the Kolmogorov-Smirnov test.

6.1.3 Statistical Tests for Comparison of Data Groups

Statistical tests were performed to determine whether data groups could be considered to come from one population.. The Bartlett test for homogeneity of variances and the t-test, for 2 groups, or the F-test, for multiple groups are applied to determine if data groups can be combined. For the groups that pass the analysis of variance tests, the normality tests are applied to check the assumption of normality. If the combined group pass the normality test, Owen's one-sided tolerance limit factor, Reference 11, is used to compute the 95/95 DNBR limit. If the data in the combined group fail the normality test, the Kruskal-Wallis One Way Analysis of Variance by Ranks test is used to check the null hypotheses that the medians, or averages, of the tests or groups are the same. If the combined group fails the normality test, a distribution-free one-sided 95/95 limit is determined, Chapter 2 of Reference 12. A brief description of the comparison tests is given below:

6.1.3.1 Homogeneity of Variances

One of the most used tests for examining the homogeneity of a set of variances is Bartlett's test (Reference 15). Bartlett showed that for a set of variances estimated from K independent samples from normal distributions having a common variance σ^2, a quantity M/C would have a distribution satisfactorily approximated by the χ^2 distribution. Specifically:

$$M = N \ln \{ N^{-1} \sum_{t=1}^{K} \nu_t s_t^2 \} - \sum_{t=1}^{K} \nu_t \ln s_t^2$$

$$C = 1 + \frac{1}{3(K-1)} \left\{ \sum_{t=1}^{K} \frac{1}{\nu_t} - \frac{1}{N} \right\} \text{, where}$$

s_t^2 is an estimate of variance for test section t based on degrees of freedom ν_t,

K is the number of test sections,

$N = \sum_{t=1}^{K} \nu_t$,

and the quantity M/C is distributed approximately as χ^2 with K-1 degrees of freedom.

6.1.3.2 Test for Equality of Means for Two Data Groups - Unpaired t-Test

When data from two groups passed the test for homogeneity of variances, the t-Test was employed to test the hypothesis that $\mu_1 - \mu_2 = 0.0$ or that $\mu_1 = \mu_2$ where μ_1 is the mean from data group 1 and μ_2 is the mean from data group 2. From Reference 16, the test statistic t is calculated with the expression:

$$t = \frac{\mu_1 - \mu_2}{s_o\,(\,1/n1 + 1/n2\,)^{0.5}}$$

where $$s_o^2 = \frac{\sum_{j=1}^{n1} (x_{1j} - \mu_1)^2 + \sum_{j=1}^{n2} (x_{2j} - \mu_2)^2}{n1 + n2 - 2}$$ is a "pooled" estimate

The computed value of t is compared with the value $t_{\alpha/2,\, n1+n2-2}$ in a table of percentiles of the t distribution for α set to 0.05. The hypothesis that $\mu_1 = \mu_2$ is rejected if the computed value of t is larger then the value of $t_{\alpha/2,\, n1+n2-2}$.

6.1.3.3 Test for Equality of Means for Multiple Data Groups – ANOVA F-Test

An analysis of variance test was performed to test the equality of means and determine whether the data from multiple tests or groups could be pooled. One of the usual techniques for examining the equality of means determined in an experimental study is a particular form of the F-test. In this technique, two mean squares are found, call them S_1, the between test section mean square and S_2, the within test section mean square. If K is the number of test sections, n_t the number of data for test section t and N is the total number of data,

$$S_1 = \frac{\sum_{t=1}^{K} n_t\,(\bar{X}_t - \bar{\bar{X}})^2}{K - 1}, \text{ and}$$

$$S_2 = \frac{\sum_{t=1}^{K} \{ \sum_{i=1}^{n_t} (X_{ti} - \bar{X}_t)^2 \}}{N - K}$$

In these expressions X_{ti} is an individual datum for test section t, $\bar{X}_t$ is the mean value of X for test section t, and $\bar{\bar{X}}$ is the grand mean for all data. Under the hypotheses of normality, homogeneity of variance and equality of means, S_1 and S_2 are independent estimates of the variance, σ^2 , due to random deviation from the true grand mean. Therefore the ratio:

$F = S_1 / S_2$ should follow the F distribution with degrees of freedom,
$\nu_1 = K\text{-}1$ and $\nu_2 = N\text{-}K$.

The calculated value of F is compared with the value of $F_{1-\alpha}(\nu_1, \nu_2)$ for α set to 0.05. Should the test section means not be equal, S_1 will contain additional components of variance. Therefore, large values of F require the rejection of the hypothesis of equality among the means of the tests or groups.

6.1.3.4 Distribution Free Comparison of Average Performance

For comparison of tests or multiple groups that failed the Bartlett test for equal variance or the D' test for normality, the Kruskal-Wallis One Way Analysis of Variance by Ranks test, References 12 and 17 is used. The level of significance of the test, α, is selected to be 0.05. The $\chi^2_{1-\alpha}$ value for K-1 = degrees of freedom is taken from a Table of the percentiles of the χ^2 distribution. The data from all tests or groups are ranked from lowest to highest The H statistic is then calculated with the equation:

$$H = \frac{12}{N(N+1)} * \sum_{i=1}^{K} \frac{R_i^2}{n_i} - 3*(N+1)$$

where R_i is the sum of the ranks for the ith test, n_i is the number of points in test i and N is the total number of points. If $H > \chi^2_{1-\alpha}$, one rejects the hypothesis that the averages are the same.

6.1.4 One-sided 95/95 DNBR Limit

All data from the correlation and validation databases should be considered in the establishment of the one-sided 95/95 DNBR tolerance limit. Therefore, the comparison tests are performed on the combined data sets prior to the determination of the 95/95 DNBR limit. If not all of the data passed the analysis of variance tests, the data were grouped into subsets or classes of tests and the 95/95 DNBR limit was established for each class. The computed 95/95 DNBR limit for the class of data provides 95% probability at the 95% confidence level that a rod in that class having that DNBR will not experience CHF. The most conservative limit determined for any class is then applied to the entire correlation data set. For normally distributed groups, Owen's one-sided tolerance limit factor, Reference 11, is used to compute the 95/95 DNBR limit For groups that are not normally distributed, a distribution-free or nonparametric limit, from Chapter 2 of Reference 12, is established.

6.1.4.1 Normally Distributed 95/95 DNBR Limit

The mean and standard deviation of the ratio of measured to ABB-NV or ABB-TV predicted CHF are computed for each data group or class of data that pass the comparison tests and D' normality test. This group can include all data from the correlation database and validation database or a subset of that data. A 95/95 DNBR limit is evaluated for each group based on the following formulas:

$$DNBR_{95/95} = \frac{1}{\overline{X} - KS}$$

$$K = \frac{1.645 + 1.645\left[1 - \left(1 - \frac{2.706}{2(N-1)}\right) \bullet \left(1 - \frac{1}{N}\right)\right]^{\frac{1}{2}}}{1 - \frac{2.706}{2(N-1)}}$$

where: $\overline{X}$ = mean of ratio of measured to predicted CHF

S = standard deviation of measured to predicted CHF

K = 95/95 confidence multiplier (Expression given in Ref. 16, Practically equivalent to Owen's tables in Ref. 11)

N = number of data points

6.1.4.2 Distribution Free 95/95 Limit

For data groups that do not pass the D' normality test, a distribution free one-sided 95/95 limit is established. Table A-31 of Reference 12 gives the largest value of m such that one can assert with 95% confidence that 95% of the population lies above the m^{th} smallest value of X_i where X_i is an individual test run value of the ratio of measured to ABB-NV or ABB-TV predicted CHF in the non-normally distributed group.

As stated earlier, if all of the data in the combined correlation and validation database could not be pooled, the most conservative 95/95 limit for any subset of that data is the specified limit for the correlation. As a check on the limit, the total number of test points that fall below the limit are also identified.

6.1.5 Graphical Verification

After the determination of the 95/95 DNBR limit for the correlation, scatter plots are then generated for each of the variables in the correlation to examine the correlation for trends or regions of non-conservatism. The M/P CHF ratio is plotted as a function of pressure, local mass velocity, local quality, heated hydraulic diameter, distance from bottom of adjacent upstream grid, and heated length from BOHL to location of CHF. The DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points.

6.2 ABB-NV Correlation Statistical Evaluation and 95/95 DNBR Limit

The W and D' normality tests and comparison tests were performed to determine if the ABB-NV correlation and validation data were random samples from one or more populations and whether the data from individual tests and the combination of tests were normally distributed. As stated in Section 6.1, parametric comparison tests were performed to determine if data from the different test sections were poolable, then normality tests were performed on the pooled data. If the pooled data failed the normality test, nonparametric tests were performed to check the hypothesis that the averages for the pooled tests are the same. The data were examined in the following order:

1.) [

] The mean and standard deviation for the ratio of measured to ABB-NV predicted CHF are shown in Table 3-2 for the correlation database and Table 3-3 for the validation database. The correlation database has 528 points and the validation database has 187 points or 26% of the total points within the range of applicability. The Bartlett test and t-Test was applied to the data in the correlation database and validation database to verify that these data came from the same population(s). [

] The results from the tests are summarized in Table 6.2-1. [

]

2.) The second comparison made on the data was performed to examine if there is a bias in the correlation for bundle array. [

] These results of the comparison tests are summarized in Table 6.2-1. [

]

3.) Since no bias is observed between the correlation database and verification database or due to bundle array geometry, a multiple data analysis was performed on all of the test section data, [ ] The results of the parametric comparison tests are given in Table 6.2-2. Based upon these results, it is concluded that not all test sections have the same variance or mean, although the data barely failed the Bartlett test. This is not a surprising result for a large, 14 test sections, and diverse database with a small standard deviation. [

]

A typical distribution for the combined data is illustrated in Figures 6.2-1 and 6.2-2. Figure 6.2-1 presents a histogram of the combined correlation and validation data with the normal distribution for the data mean and standard deviation. Figure 6.2-2 is the probability plot of the data compared to the line representing the area of the gaussian distribution. [

]

5.) [

]

The DNBR limit of 1.13 for the most non-conservative data is applicable for the entire database. A plot of the measured CHF versus the ABB-NV predicted CHF for all the test data is given in Figure 6.2-3, along with the DNBR limit curve. The DNBR limit of 1.13 is equivalent to a value of 0.885 for the M/P CHF ratio. It is noted that for the entire database, eighteen test points, or 2.5% of the data fall below the $M/P_{95/95}$ limit of 0.885. [

].

The data are then examined graphically in order to check for any deviation as a function of the correlation variables. The plots of the M/P CHF ratio as a function of pressure, local mass velocity, local quality, heated hydraulic diameter, distance from bottom of adjacent upstream grid, DG, and heated length from BOHL to location of CHF, HL, are shown in Figures 6.2-4 through 6.2-9. The DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points. For information, the correlation, or source, data and validation data are identified in the plots even though the data were combined in the determination of the one-sided DNBR limit. There are no observed adverse trends on any of the plots.

Based upon the results of the statistical tests applied to the ABB-NV database and the scatter plot analysis, the one-sided 95/95 DNBR limit is determined to be 1.13. The applicable parameter ranges for the ABB-NV correlation are given in Table 6.2-6.

TABLE 6.2-1

COMPARISON TESTS

ABB-NV CORRELATION AND VALIDATION DATABASE
FUEL BUNDLE ARRAY FOR CORRELATION DATA

Bartlett Test Results – ABB-NV Data

Database	N	Mean	s	K	M	C	M/C	$\gamma^2_{.95}$	Pass Test
Correlation	528	1.0045	0.0615						
Validation	187	1.0040	0.0570						
Combined	715	1.0044	0.0603	2	1.637	1.002	1.6337	3.84	Yes
14x14 C	226	1.0044	0.0604						
16x16 C	302	1.0046	0.0624						
Correlation	528	1.0045	0.0615	2	0.252	1.002	0.2515	3.84	Yes

t-Test Results - ABB-NV Data

Database	N	Mean, μ	s	μ1 - μ2	s_o	t	$t_{.975,713}$	Pass Test
Correlation	528	1.0045	0.0615					
Validation	187	1.0040	0.0570					
Combined	715	1.0044	0.0603	0.00053	0.0604	0.103	1.9600	Yes
14x14 C	226	1.0044	0.0604				$t_{.975,526}$	
16x16 C	302	1.0046	0.0624					
Correlation	528	1.0045	0.0615	0.00015	0.0616	0.028	1.9600	Yes

Kruskal-Wallis Variance By Ranks Test Results - ABB-NV

Database	N	Mean, μ	s	K	H	$\gamma^2_{.95}$	Test
Correlation	528	1.0045	0.0615				
Validation	187	1.0040	0.0570				
Combined	715	1.0044	0.0603	2	0.00822	3.84	Yes
14x14 C	226	1.0044	0.0604				
16x16 C	302	1.0046	0.0624				
Correlation	528	1.0045	0.0615	2	0.0649	3.84	Yes

TABLE 6.2-2

PARAMETRIC COMPARISON TESTS
COMBINED CORRELATION AND VALIDATION DATABASE

Test No.	Bundle Array	Rod Diam. ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	Axial Shape	N	ABB-NV M/P Mean, μ	M/P s
18	14x14	0.440	48	16.0	Yes	Uniform	52	[	]
21	14x14	0.440	84	16.0	No	Uniform	34		
36	14x14	0.440	84	18.25	Yes	Uniform	45		
38	14x14	0.440	150	17.4	Yes	Uniform	38		
41	16x16	0.382	84	17.4	Yes	Uniform	40		
43	16x16	0.382	84	14.3	Yes	Uniform	50		
47	16x16	0.382	150	14.3	Yes	Uniform	57		
48	16x16	0.382	84	14.3	No	Uniform	55		
51	16x16	0.382	84	14.3	Yes	Uniform	49		
52	16x16	0.382	84	14.3	Yes	Uniform	49		
58	14x14	0.440	150	17.4	Yes	1.68 TP	57		
59	16x16	0.382	150	14.2	Yes	1.46 Cosine	73		
69	14x14	0.440	150	17.4	Yes	1.68 TP	48		
73	16x16	0.382	150	15.7	Yes	Yes	68		
ALL							715	1.0044	0.0603

Bartlett Test Results - ABB-NV Data

Database	N	Mean, μ	s	K	M	C	M/C	$\gamma^2_{.95}$	Pass Test
ALL	715	1.0044	0.0603	14	22.658	1.0074	22.4916	22.36	No

F-Test Results - ABB-NV Data

Database	n_1	n_2	S_1	S_2	S_1 / S_2	$F_{.95}(n_1, n_2)$	Pass Test
ALL	13	701	0.03724	0.00302	12.3458	1.64	No

TABLE 6.2-3

COMPARISON TESTS FOR POOLED SUBSETS
ABB-NV DATABASE

Bartlett Test Results - ABB-NV Data

Database	N	Mean, μ	s	K	M	C	M/C	$\gamma^2_{.95}$

F-Test Results - ABB-NV Data

Database	n_1	n_2	S_1	S_2	S_1 / S_2	$F_{.95}(n_1, n_2)$	Pass Test

t-Test Results - ABB-NV Data

Database	N	$\mu1 - \mu2$	s_o	t	$t_{.975,132}$	Pass Test

Kruskal-Wallis Variance By Ranks Test Results - Subsets 1 & 2

Database	K	H	$\gamma^2_{.95}$	Pass Test

[ ]
[ ]
[ ]
[ ]

TABLE 6.2-4

W AND D' NORMALITY TESTS – ABB-NV DATA

Data	N	Mean, μ	D' Calculated	D' P=.025	D' P=.975	Pass Test
Test 18	52					
Test 47	57					
Test 48	55					
Test 51	50					
Test 58	57					
Test 59	73					
Test 60	67					
Test 66	67					
Test 73	68					
Test 43	50					
14x14	226					
16x16	302					
Correlation	528					
Validation	187					
All	715					
[ ]	258					
[ ]	399					
[ ]	166					
[ ]	134					

Data	N	Mean, μ	*W* Calculated	*W* P=.05	Pass Test
Test 21	34				
Test 36	45				
Test 38	38				
Test 41	40				
Test 51	49				
Test 52	49				
Test 69	48				

[ ]
[ ]
[ ]
[ ]

TABLE 6.2-5

DETERMINATION OF $DNBR_{95}$ LIMIT FOR POOLED DATA
ABB-NV DATABASE

TABLE 6.2-6

PARAMETER RANGES FOR THE ABB-NV CORRELATION

Parameter	Minimum	Maximum
Pressure (psia)	1750	2415
Local Coolant Quality	-0.14	0.22
Local Mass velocity (Mlbm/hr-ft^2)	0.86	3.16
Heated Hydraulic Diameter Ratio, Dhm/Dh	0.679	1.08
Heated Length, HL (inches)	48	150
Distance From Grid, DG (inches)	8	18.86

FIGURE 6.2-1

DISTRIBUTION OF M/P CHF RATIO
FOR ABB-NV CORRELATION
COMBINED CORRELATION AND VALIDATION DATABASE

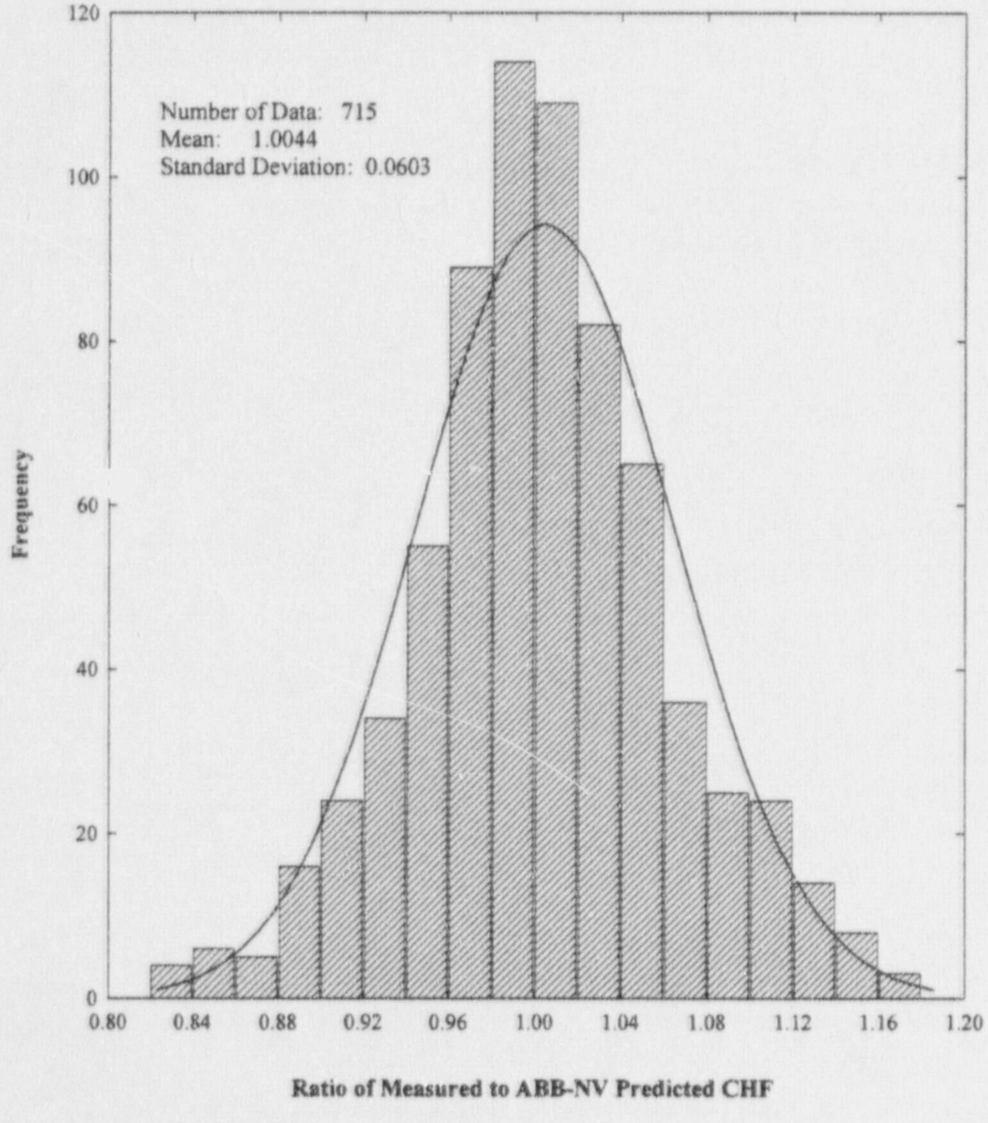


FIGURE 6.2-2

NORMAL PROBABILITY PLOT OF M/P CHF RATIO
FOR ABB-NV CORRELATION
COMBINED CORRELATION AND VALIDATION DATABASE

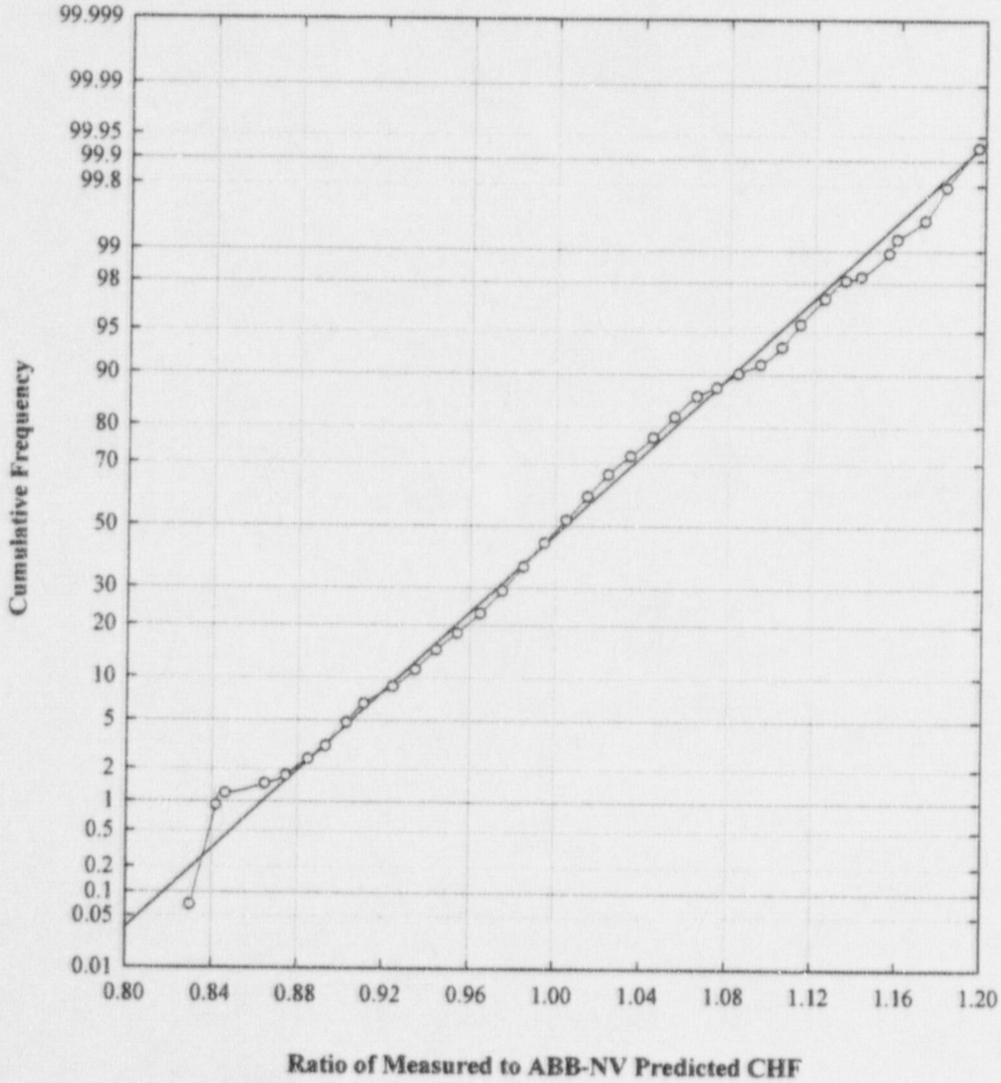


FIGURE 6.2-3

MEASURED AND PREDICTED CRITICAL HEAT FLUXES ABB-NV CORRELATION

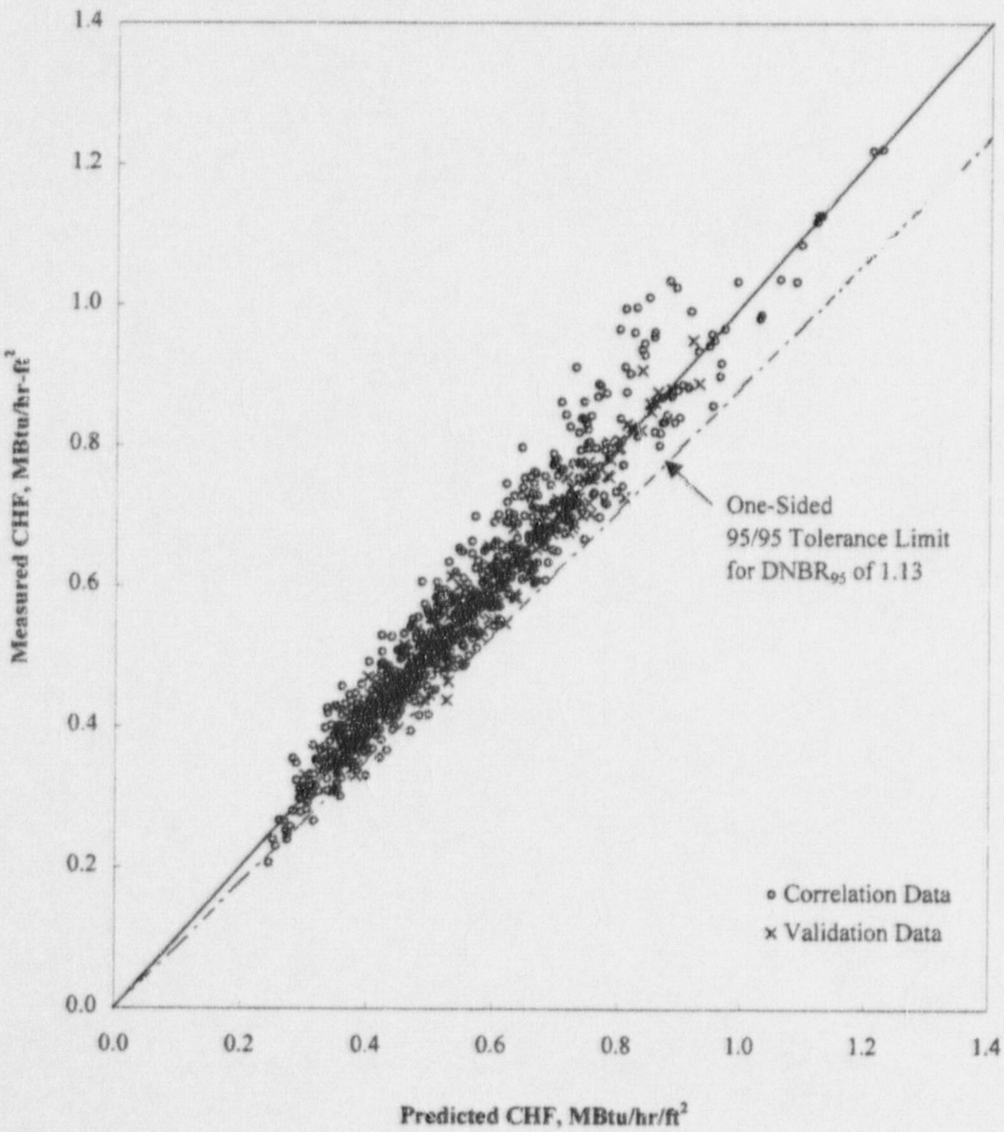
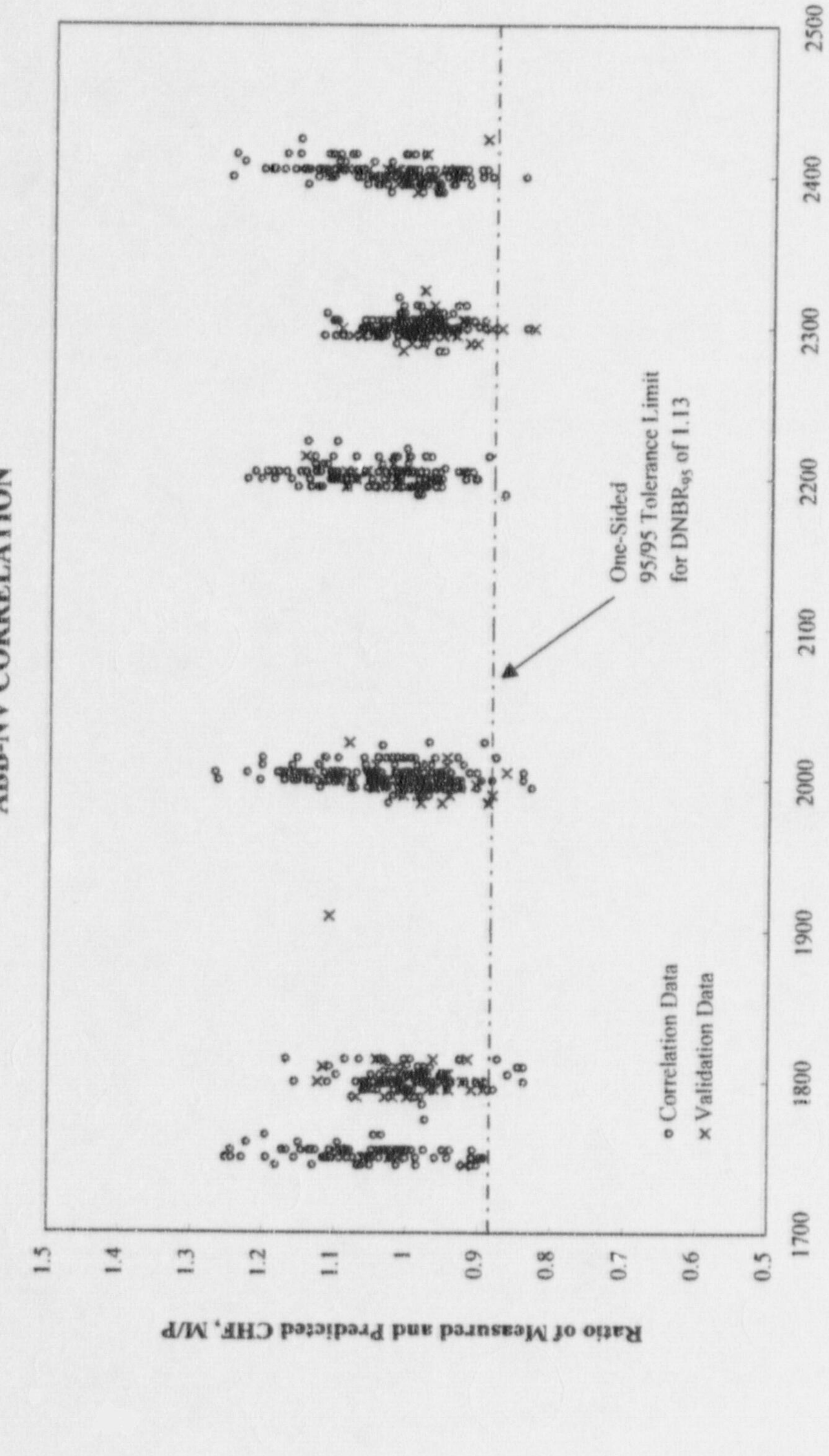


FIGURE 6.2-4

VARIATION OF M/P CHF RATIO WITH PRESSURE
ABB-NV CORRELATION



NON-PROPRIETARY INFORMATION
ABB COMBUSTION ENGINEERING, INC,

FIGURE 6.2-5

**VARIATION OF M/P CHF RATIO WITH MASS VELOCITY
ABB-NV CORRELATION**

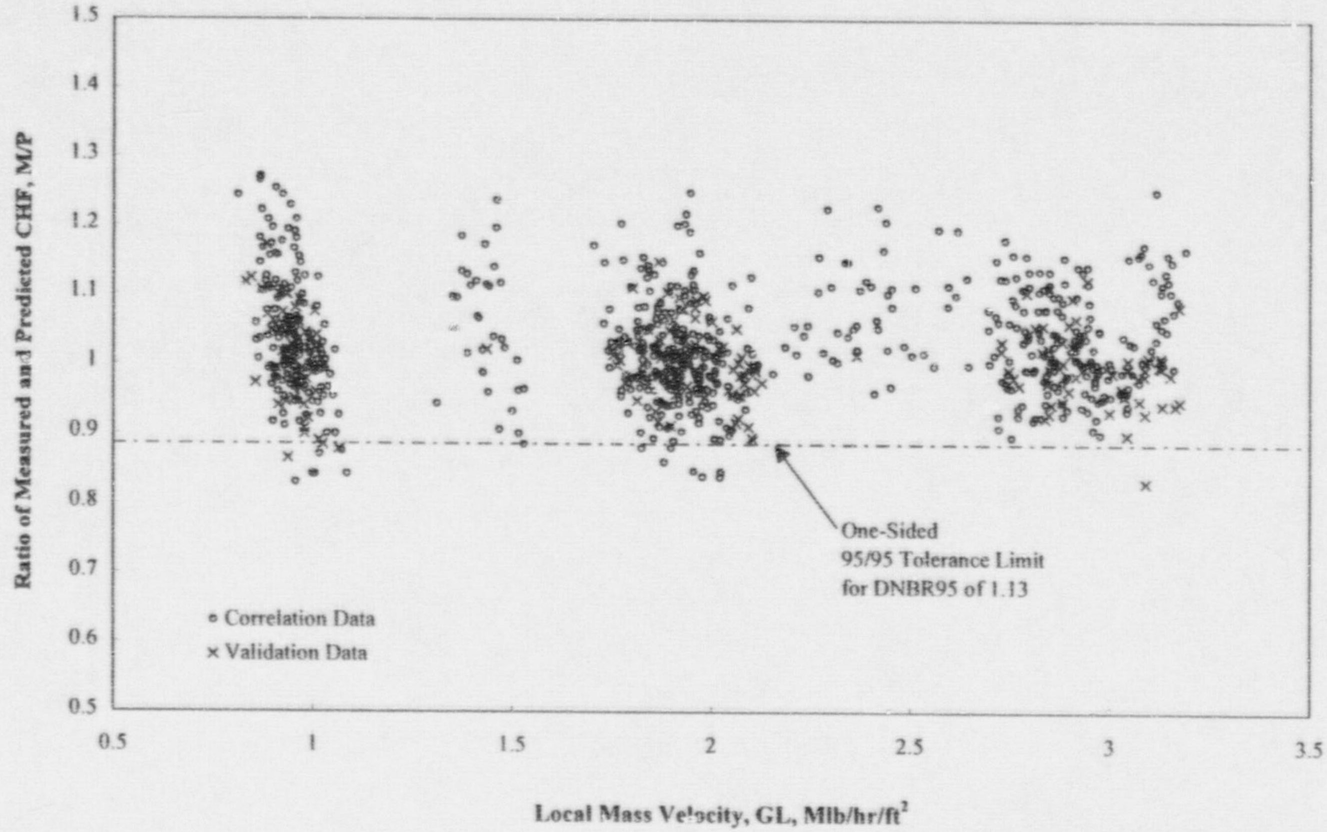


FIGURE 6.2-6

VARIATION OF M/P CHF RATIO WITH LOCAL QUALITY
ABB-NV CORRELATION

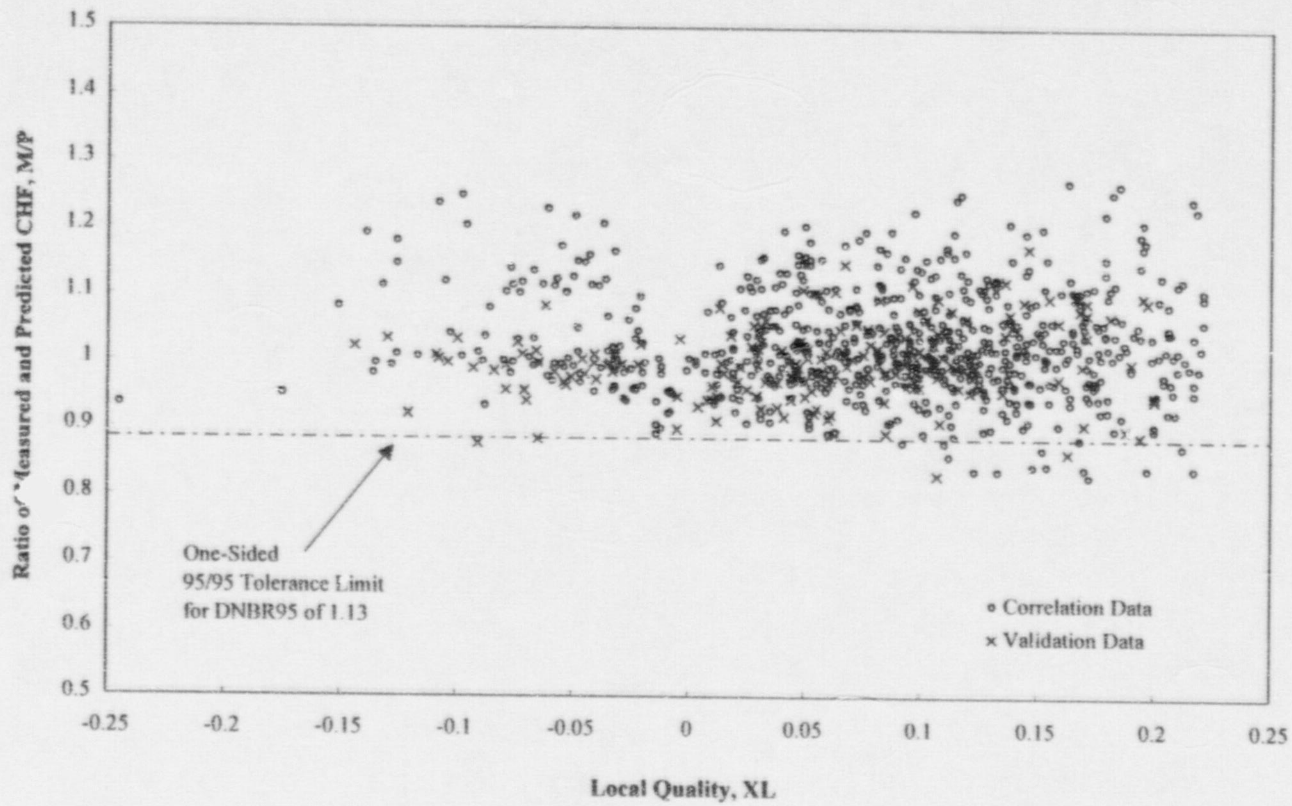


FIGURE 6.2-7

VARIATION OF M/P CHF RATIO WITH HEATED HYDRAULIC DIAMETER RATIO
ABB-NV CORRELATION

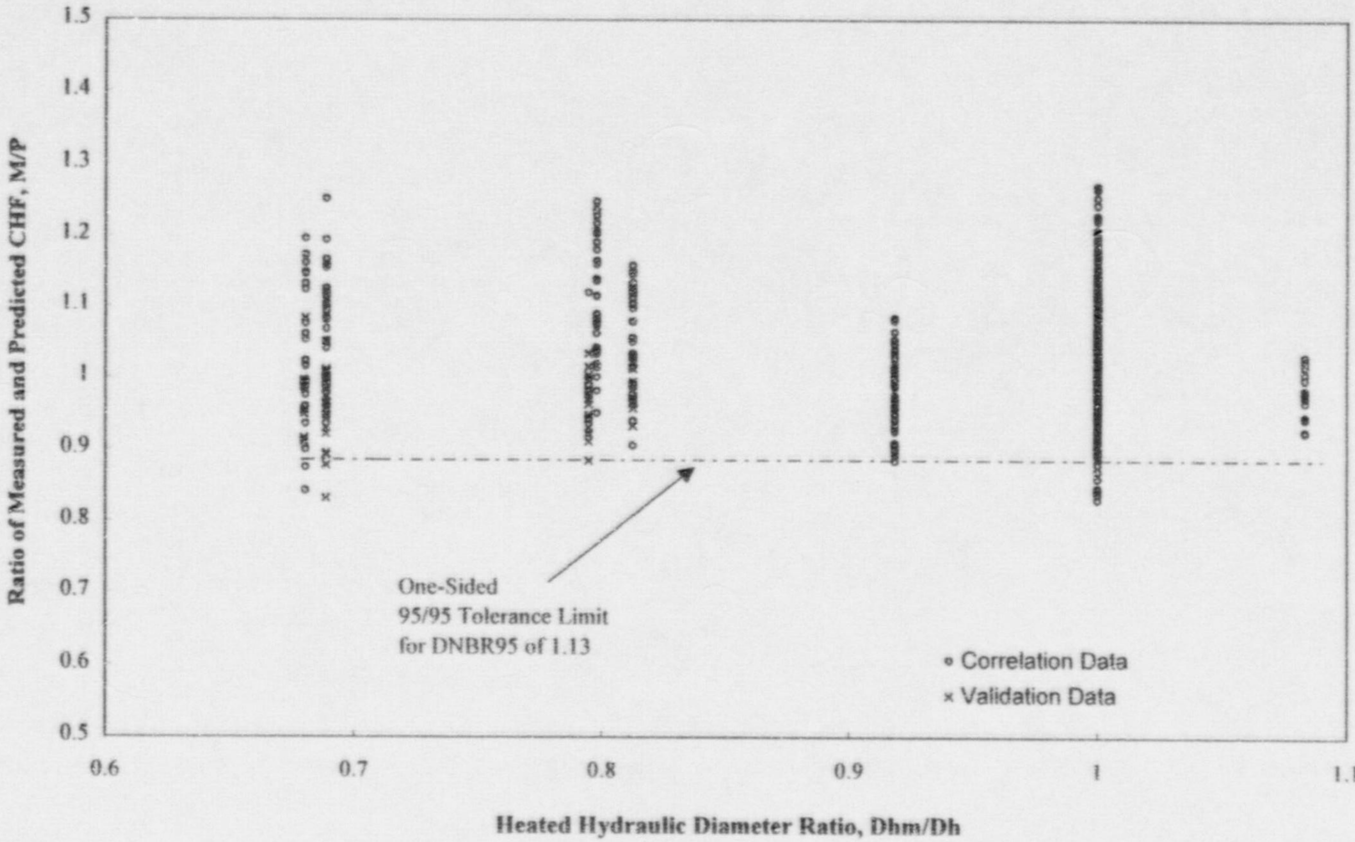


FIGURE 6.2-8

VARIATION OF M/P CHF RATIO WITH DISTANCE FROM GRID ABB-NV CORRELATION

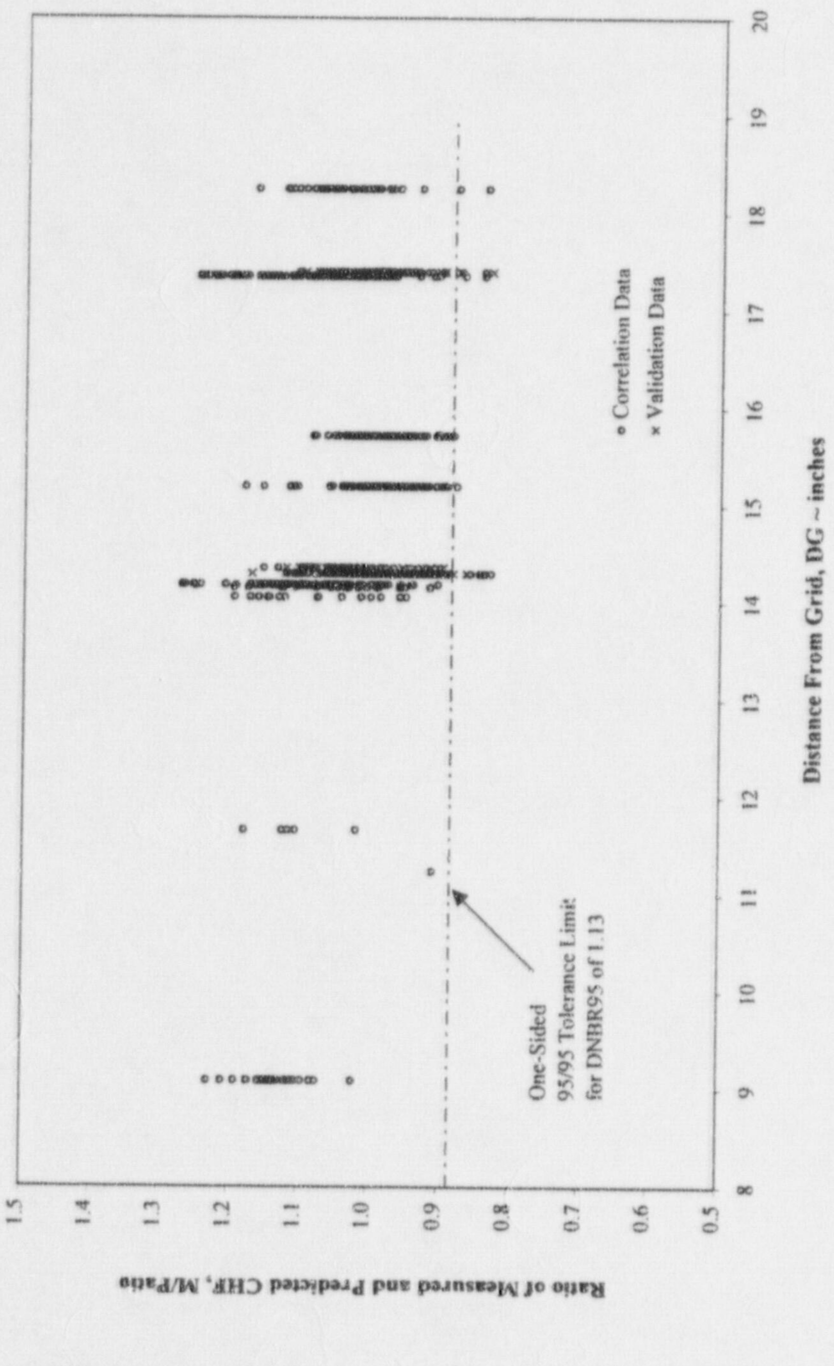
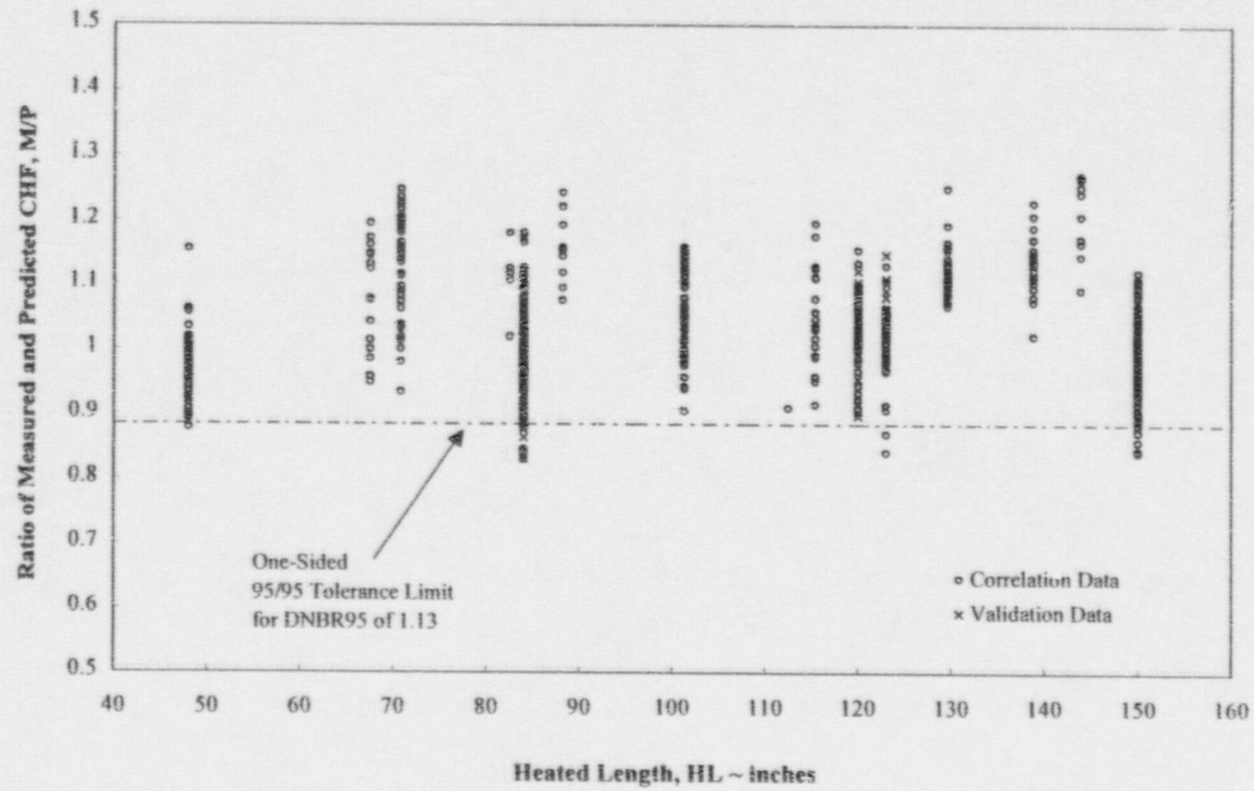


FIGURE 6.2-9

VARIATION OF M/P CHF RATIO WITH HEATED LENGTH ABB-NV CORRELATION



6.3 ABB-TV Correlation Statistical Evaluation and 95/95 DNBR Limit

Following the methods applied to the ABB-NV data in Section 6.2, [

] The mean and standard deviation for the ratio of measured to ABB-TV predicted CHF are shown in Table 4-2 for the correlation database and Table 4-3 for the validation database. The correlation database has 234 points and the validation database has 62 points or 21% of the total points within the range of applicability. The Bartlett test and t-Test were applied to the data in the correlation database and validation database to verify that these data came from the same population(s). The results from the tests are summarized in Table 6.3-1. [

]

Since no bias is observed between the correlation database and verification database, a multiple data analysis was performed on all of the test section data. The results of the comparison tests are given in Table 6.3-2. Based upon the results of the parametric tests, one would conclude that all test sections have the same variance and mean. The W and D' normality tests were then applied to the data from each test section and each set of data, as shown in Table 6.3.3. [

] Based upon the results from all tests, it is concluded all the data for the ABB-TV correlation came from the same population and the data are combined to determine the one-sided 95/95 DNBR tolerance limit.

[

] A typical distribution for the combined data is illustrated in Figures 6.3-1 and 6.3-2. Figure 6.3-1 presents a histogram of the combined correlation and validation data with the normal distribution for the data mean and standard deviation. Figure 6.3-2 is a probability plot of the data compared to the line representing the area of the gaussian distribution. [

]

[

], the 95/95 DNBR limit for the ABB-TV correlation is set to 1.13, the value determined for the ABB-NV correlation in Section 6.2. A plot of the measured CHF versus the ABB-TV predicted CHF for all the test data is given in Figure 6.3-3, along with the DNBR limit curve. The DNBR limit of 1.13 is equivalent to a value of 0.885 for the M/P CHF ratio. It is noted that for the entire database, five test points, or 1.7% of the data fall below the $M/P_{95/95}$ limit of 0.885.

The data are then examined graphically in order to check for any deviation as a function of the correlation variables. The plots of the M/P CHF ratio as a function of pressure, local mass velocity, local quality, heated hydraulic diameter, distance from bottom of adjacent upstream grid, and heated length from BOHL to location of CHF are shown in Figures 6.3-4 through 6.3-9. The DNBR limit is also shown on these plots to show the number of test points that fall below the limit and the location of those points. For information, the correlation, or source, data and validation data are identified in the plots even though the data were combined based upon the results of the analysis of variance test results. There are no observed adverse trends on any of the plots.

Based upon the results of the statistical tests applied to the ABB-TV database and the scatter plot analysis, the one-sided 95/95 DNBR limit is set to be the same as the ABB-NV correlation, 1.13. The applicable parameter ranges for the ABB-TV correlation are given in Table 6.3-5.

TABLE 6.3-1

COMPARISON TESTS

ABB-TV CORRELATION AND VALIDATION DATABASE

Bartlett Test Results - ABB-TV Data

Database	N	Mean, μ	s	K	M	C	M/C	$\gamma^2_{.95}$	Pass Test
Correlation	234	1.0002	0.0486						
Validation	62	0.9974	0.0477						
Combined	296	0.9996	0.0483	2	0.033	1.0046	0.0328	3.84	Yes

t-Test Results - ABB-TV Data

Database	N	Mean, μ	s	μ1 - μ2	s_o	t	$t_{.975,294}$	Pass Test
Correlation	234	1.0002	0.0486					
Validation	62	0.9974	0.0477					
Combined	296	0.9996	0.0483	0.00272	0.0484	0.394	1.9600	Yes

Kruskal-Wallis Variance By Ranks Test Results - ABB-TV

Database	N	Mean. μ	s	K	H	$\gamma^2_{.95}$	Pass Test
Correlation	234	1.0002	0.0486				
Validation	62	0.9974	0.0477				
Combined	296	0.9996	0.0483	2	0.298	3.84	Yes

TABLE 6.3-2

PARAMETRIC COMPARISON TESTS
COMBINED CORRELATION AND VALIDATION DATABASE

Test No.	Bundle Array	Rod Diam. ~ in.	Heated Length ~ in.	Grid Spacing ~ in.	Guide Tube	Axial Shape	N	ABB-NV M/P Mean, μ	ABB-NV M/P s
91 C	14x14	0.440	136.7	18.86	No	Uniform	73		
92 C	14x14	0.440	136.7	18.86	Yes	Uniform	79		
93 C	14x14	0.440	136.7	18.86	Yes	1.47 Cosine	82		
91 V	14x14	0.440	136.7	18.86	No	Uniform	20		
92 V	14x14	0.440	136.7	18.86	Yes	Uniform	22		
93 V	14x14	0.440	136.7	18.86	Yes	1.47 Cosine	20		
ALL							296	0.9996	0.0483

Bartlett Test Results - ABB-TV Data

Database	N	Mean. μ	s	K	M	C	M/C	$\gamma^2_{.95}$	Pass Test
ALL	296	0.9996	0.0483	5	3.8026	1.01257	3.7555	11.07	Yes

F-Test Results - ABB-TV Data

Database	n_1	n_2	S_1	S_2	S_1 / S_2	$F_{.95}(n_1, n_2)$	Pass Test
ALL	5	290	0.00321	0.00232	1.3837	2.21	Yes

Kruskal-Wallis Variance By Ranks Test Results - ABB-TV Data

Database	K	H	$\gamma^2_{.95}$	Pass Test
ALL	5	6.837	11.07	Yes

TABLE 6.3-3

W AND D' NORMALITY TESTS – ABB-TV DATA

Data	N	Mean, μ	D' Calculated	D' P=.025	D' P=.975	Pass Test
Test 91C	73	[				]
Test 92 C	79					
Test 93 C	82					
Correlation	234					
Validation	62					
Test 91 All	93					
Test 92 All	101					
Test 93 All	102					
All	296					

Data	N	Mean, μ	*W* Calculated	*W* P=.05	Pass Test
Test 91	20	[			]
Test 92	22				
Test 93	20				

TABLE 6.3-4

DETERMINATION OF $DNBR_{95}$ LIMIT FOR POOLED DATA
ABB-TV DATABASE

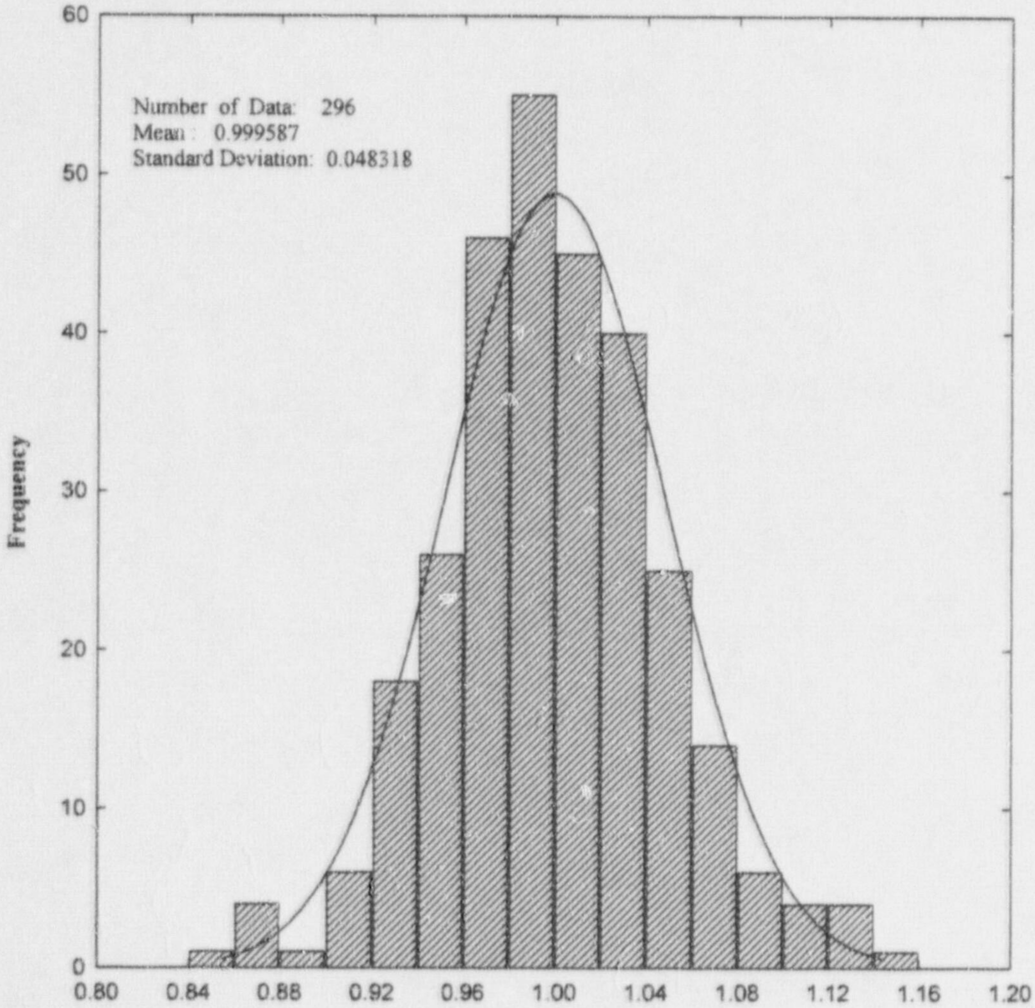
TABLE 6.3-5

PARAMETER RANGES FOR THE ABB-TV CORRELATION

Parameter	Minimum	Maximum
Pressure (psia)	1500	2415
Local Coolant Quality	-0.10	0.225
Local Mass velocity (Mlbm/hr-ft^2)	0.90	3.40
Heated Hydraulic Diameter Ratio, Dhm/Dh	0.679	1.00
Heated Length, HL (inches)	48	136.7
Distance From Grid, DG (inches)	8	18.86

FIGURE 6.3-1

DISTRIBUTION OF M/P CHF RATIO
FOR ABB-TV CORRELATION
COMBINED CORRELATION AND VALIDATION DATABASE



Ratio of Measured to ABB-TV Predicted CHF

FIGURE 6.3-2

NORMAL PROBABILITY PLOT OF M/P CHF RATIO
FOR ABB-TV CORRELATION
COMBINED CORRELATION AND VALIDATION DATABASE

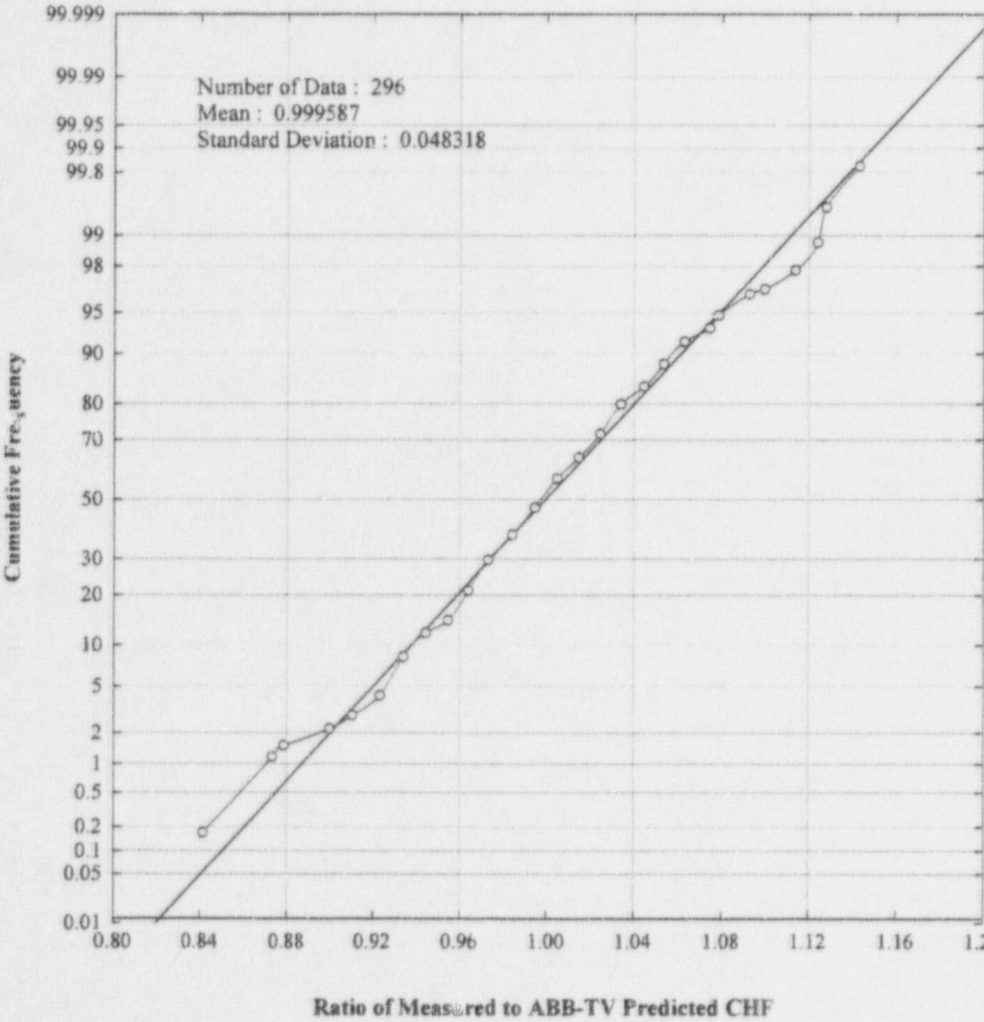


FIGURE 6.3-3

MEASURED AND PREDICTED CRITICAL HEAT FLUXES
ABB-TV CORRELATION

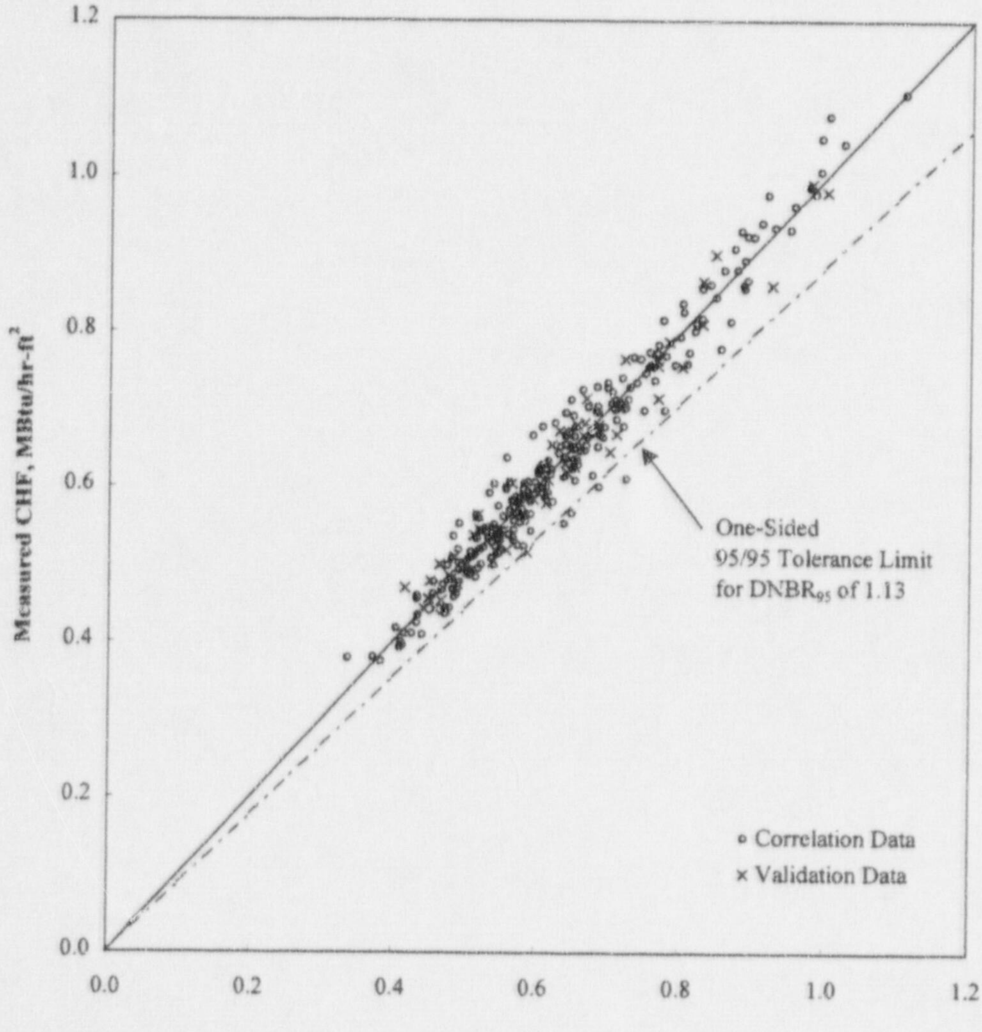


FIGURE 6.3-4

VARIATION OF M/P CHF RATIO WITH PRESSURE
ABB-TV CORRELATION

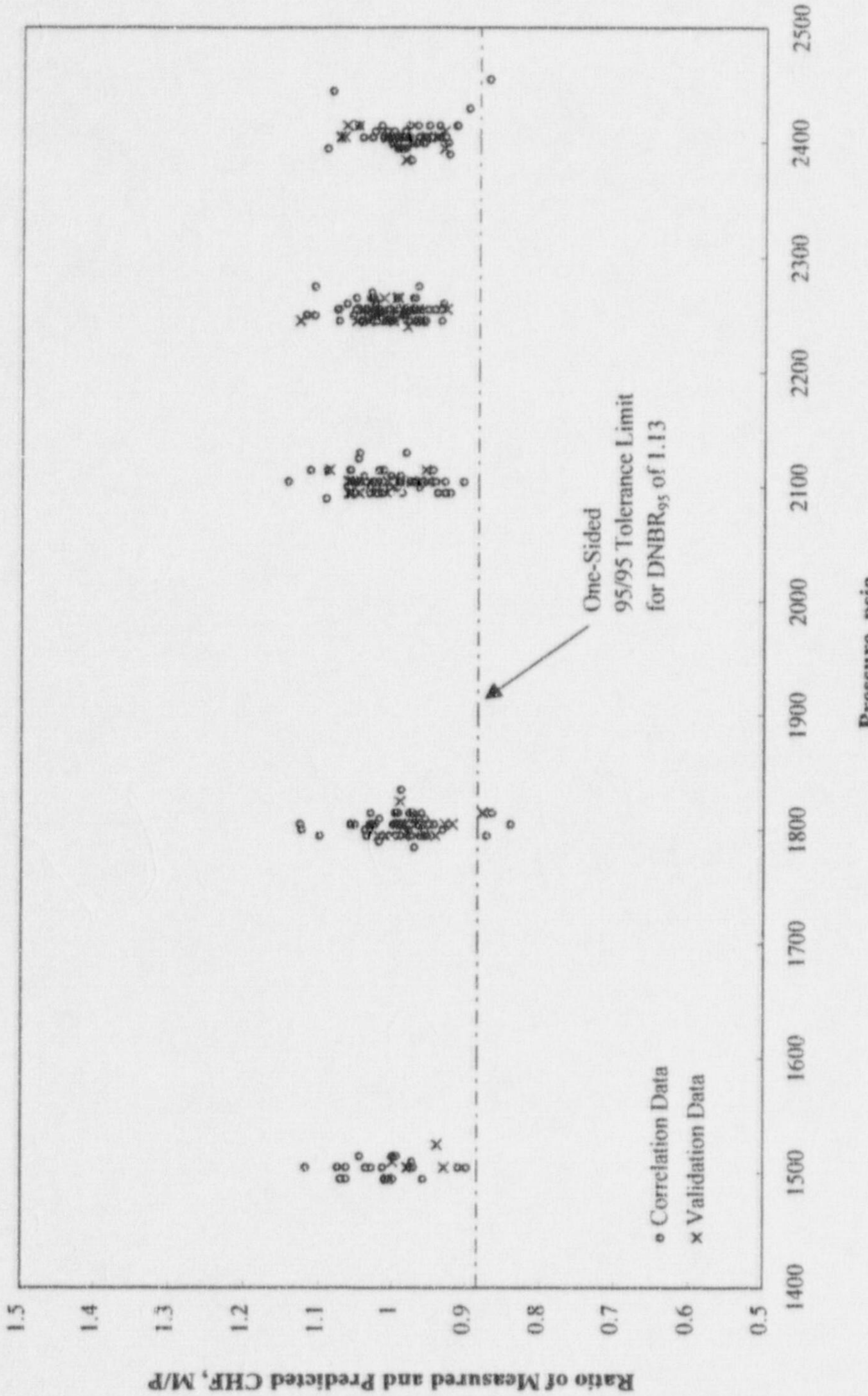


FIGURE 6.3-5

VARIATION OF M/P CHF RATIO WITH MASS VELOCITY ABB-TV CORRELATION

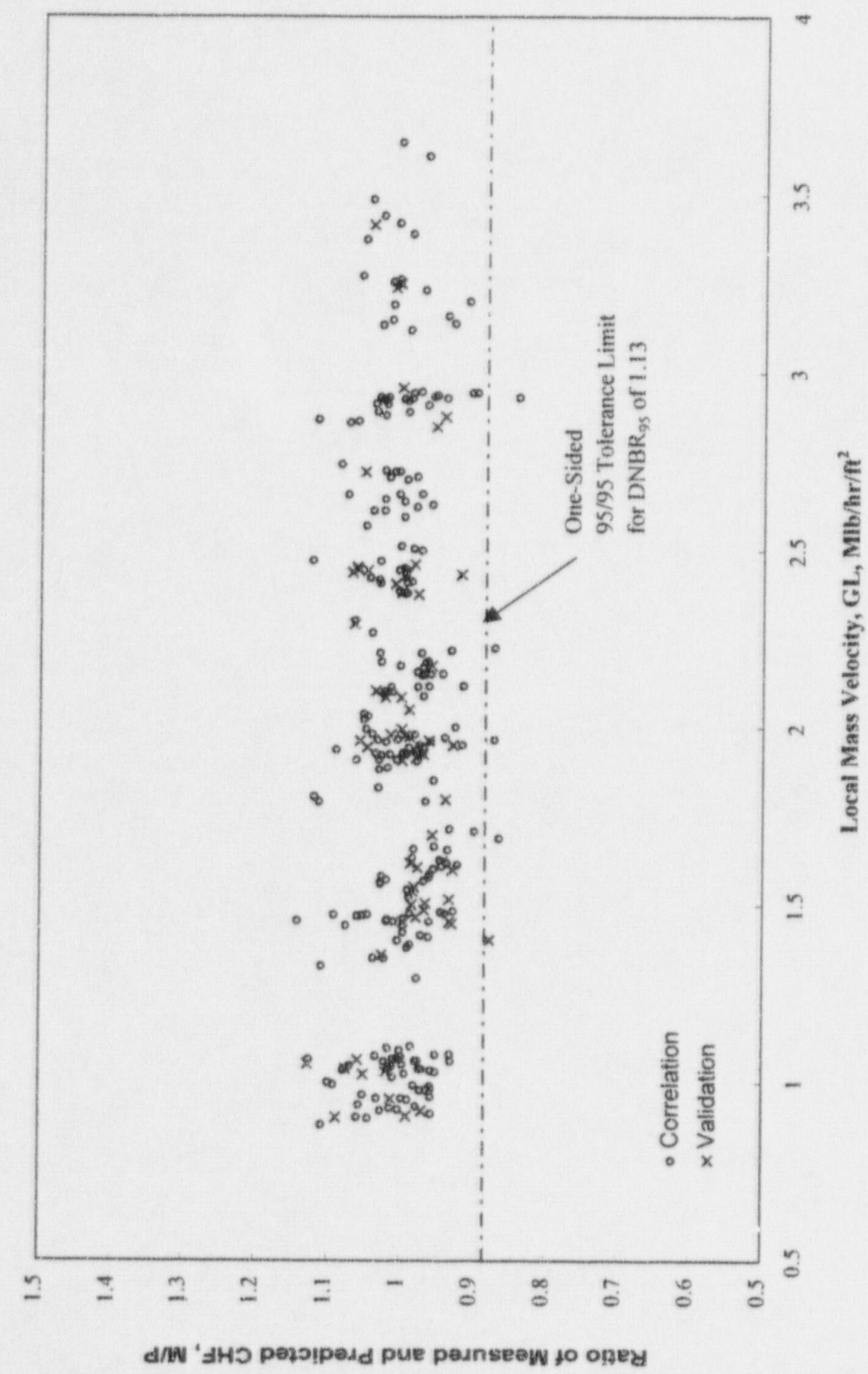


FIGURE 6.3-6

VARIATION OF M/P CHF RATIO WITH LOCAL QUALITY
ABB-TV CORRELATION

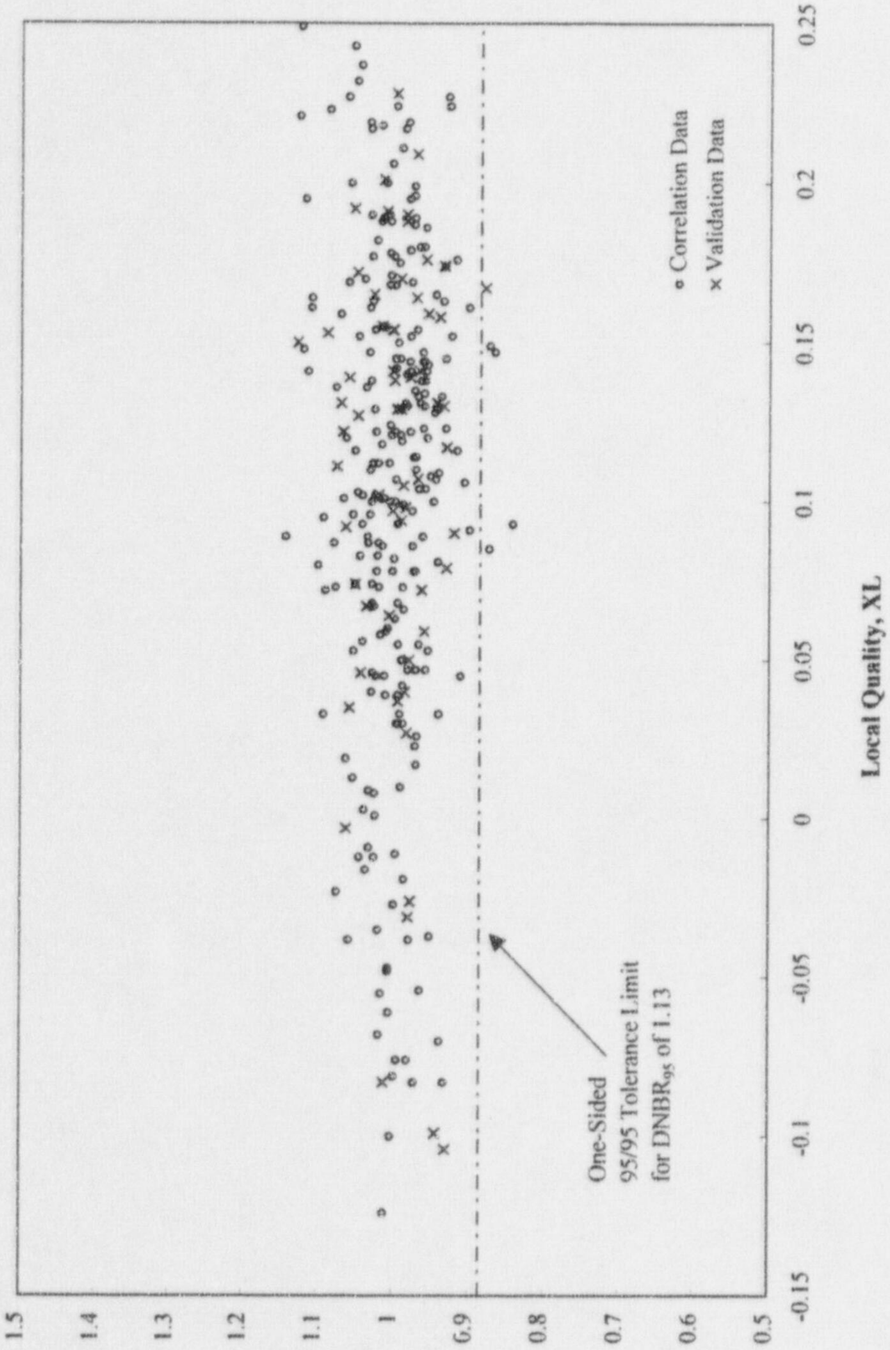


FIGURE 6.3-7

VARIATION OF M/P CHF RATIO WITH HEATED HYDRAULIC DIAMETER RATIO
ABB-TV CORRELATION

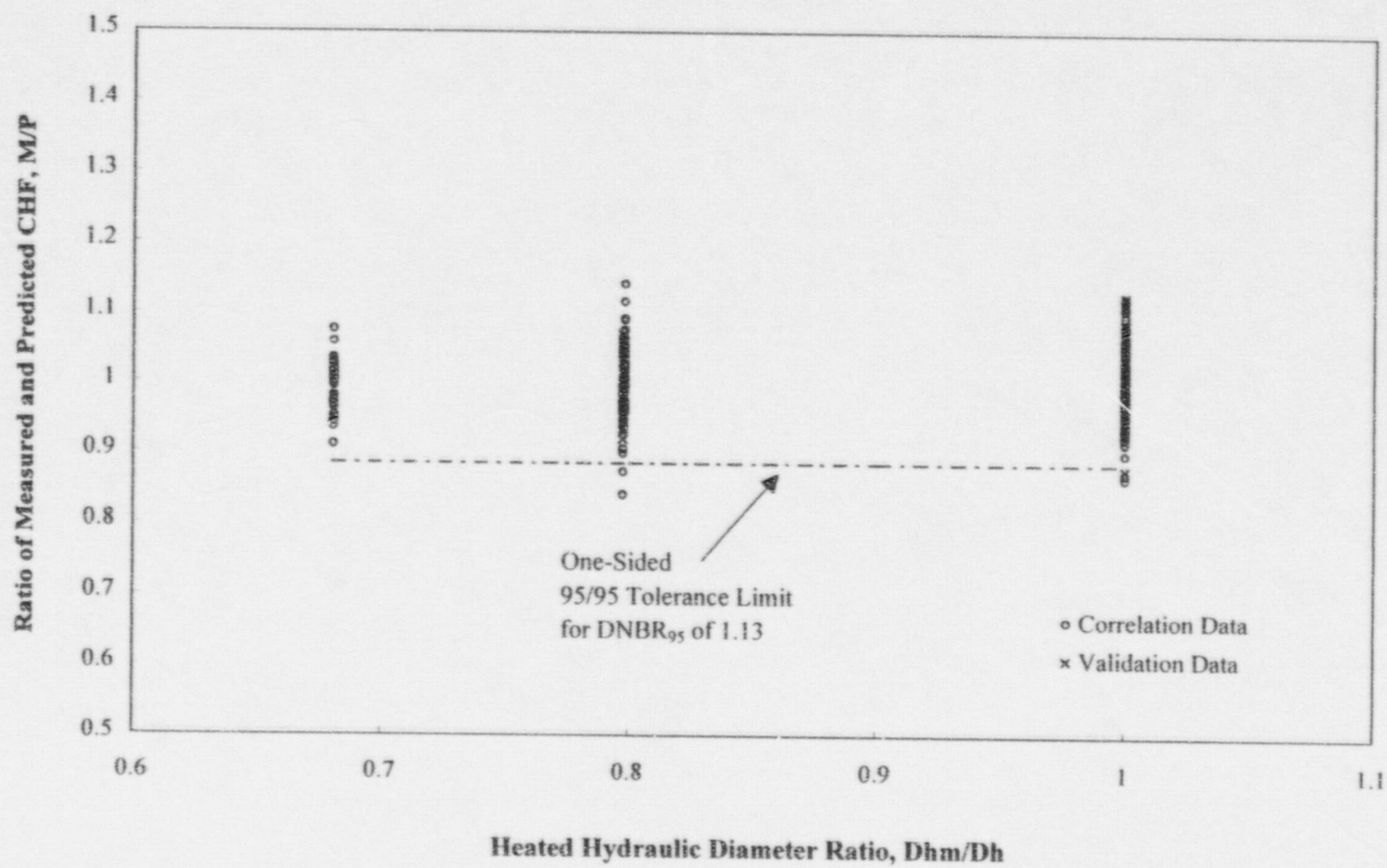


FIGURE 6.3-8

VARIATION OF M/P CHF RATIO WITH DISTANCE FROM GRID
ABB-TV CORRELATION

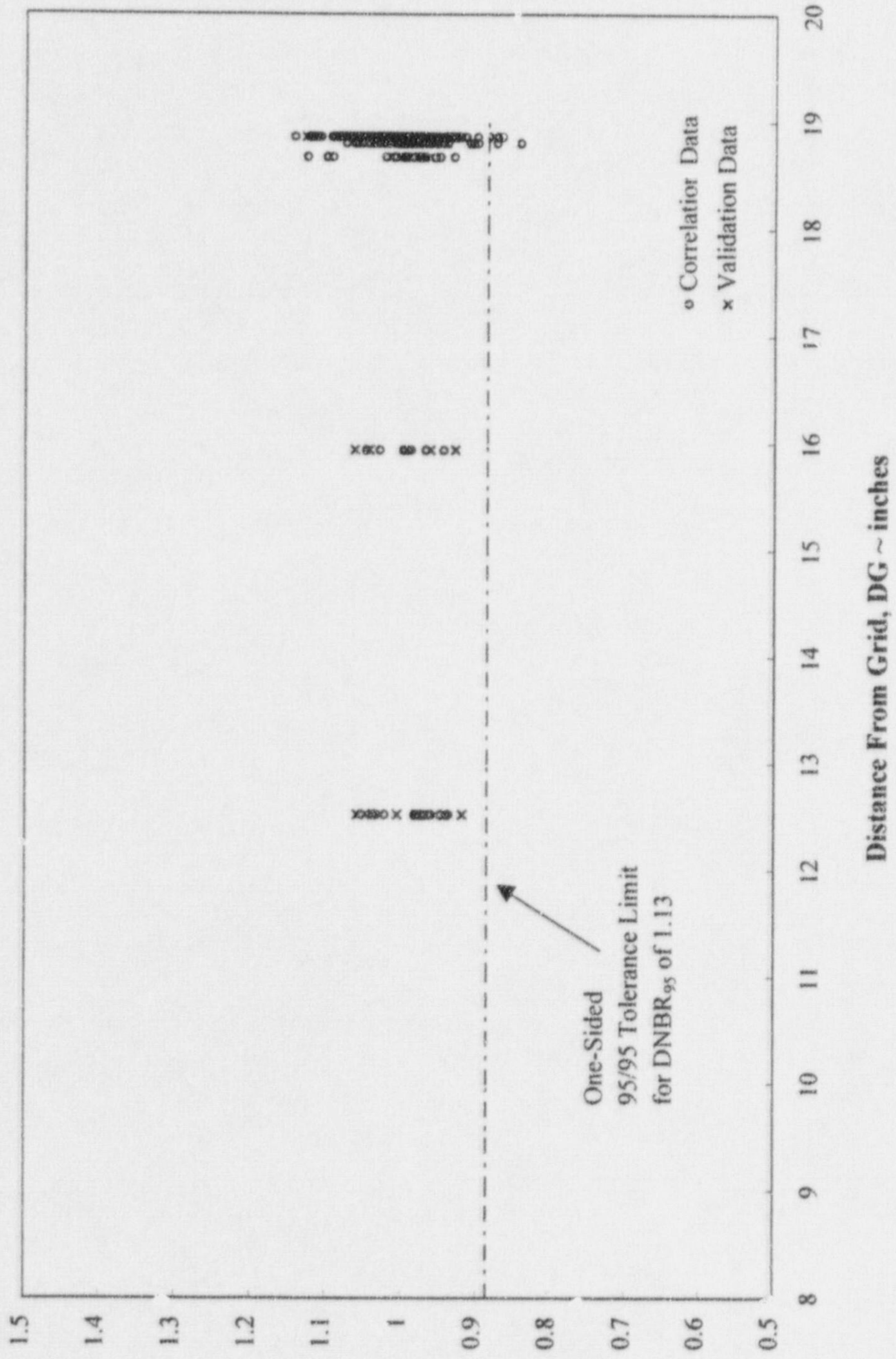
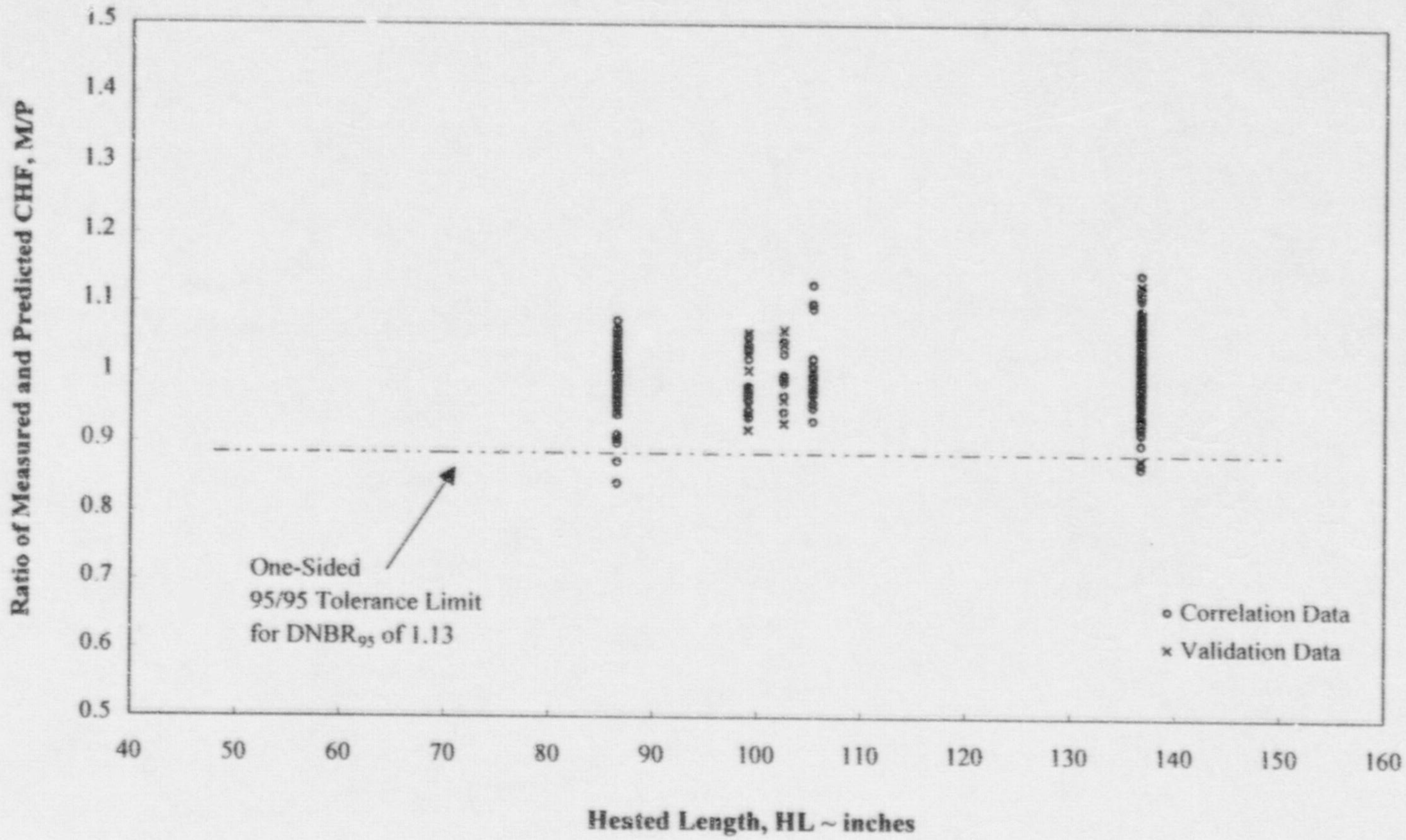


FIGURE 6.3-9

VARIATION OF M/P CHF RATIO WITH HEATED LENGTH
ABB-TV CORRELATION



7.0 Application of Correlations in Reloads

The CE-1 CHF correlation (References 1 and 2) is included in the TORC code (References 4 and 5) and the CETOP-D code (Reference 6) for use in thermal hydraulic calculations for reload analysis. Methods for reload application using the CE-1 CHF correlation in TORC and CETOP-D are discussed in various NRC approved topical reports, including the setpoints topical (Reference 18) and the ESCU topical (Reference 19) for plants with analog protection systems, the MSCU topical for plants with digital protection systems (Reference 20), the rod bow topical reports (References 21, 22, and 23), the loss of flow topical for treatment of statistical convolution (Reference 24), and the inert rod topical (Reference 25).

The impact of using either the ABB-NV and/or the ABB-TV CHF correlations instead of the CE-1 CHF correlation in reload analysis is discussed in Section 7.1. The approach for using ABB-NV along with ABB-TV in transition cores where Turbo mixing vane fuel is implemented is discussed in Section 7.2.

7.1 Impact of ABB-NV and ABB-TV on Existing Topical Reports

A summary of the impact of the ABB-NV and ABB-TV CHF correlations on existing topical reports is given in the following Sections.

7.1.1 Application of New CHF Correlations with TORC and CETOP-D Codes

Options to the TORC and CETOP-D codes will allow TORC and CETOP-D to use the ABB-NV and/or ABB-TV CHF correlations in DNBR calculations. The topical reports described in References 4 to 6 for the TORC and CETOP-D codes will remain valid with the application of the new CHF correlations. The approvals for the use of the CETOP-D codes, defined in Reference 6, are given in safety evaluation reports, Reference 28. The TORC code is used in reloads to perform detailed modeling of the core and the hot assembly and to determine minimum DNBR in the hot assembly. The CETOP-D code is a fast running tool, which is used in reload analysis to calculate the minimum DNBR in the hot subchannel.

While the TORC code can be applied directly in the reload analyses (Reference 18), typically the TORC code is used to benchmark the CETOP-D DNBR results so the CETOP-D code can be used in analyses for setpoints and transient evaluations over state parameter operating space. This benchmarking methodology, which is described in Reference 6, will not change due to the application of the ABB-NV and/or ABB-TV CHF correlations. [

].

7.1.2 Impact on Setpoints Report

The setpoints topical described in Reference 18 remains valid with the application of the new CHF correlations. [

]

[

]

7.1.3 Impact on ESCU and MSCU Reports

TORC-generated system parameter uncertainties using the ABB-NV and/or ABB-TV CHF correlations will be incorporated in the overall uncertainty analysis according to the methods of References 19 (ESCU for plants with analog protection systems) or Reference 20 (MSCU for plants with digital protection systems). Reference 26 provides further detail on the SCU methodology supporting the ESCU and MSCU reports.

[

]

The use of the probability density function for the new CHF correlations will result in a SCU 95/95 DNBR SAFDL which is smaller compared to the SAFDL calculated using CE-1 values due to the improvement in CHF statistics for the new CHF correlations. Uncertainties associated with system parameters will be calculated using the new CHF correlations and incorporated into the overall SCU analysis according to the methods described in References 19 and 20. Initially Utilities may elect to not take credit for a calculated improvement in the SCU 95/95 DNBR SAFDL in order to simplify the reload analysis.

7.1.4 Impact on Rod Bow Reports

In the rod bow reports (References 21 to 23), the CHF statistics for the CE-1 correlation are used to convolute with the probability density function for the rod bow closure data and with the rod bow effect model based on rod bow CHF tests, to determine rod bow DNB penalty versus burnup. The mean and variance for subset 1, defined in Section 7.1.3, which supports the 95/95 DNBR limit for the new CHF correlations will be applied instead of the CE-1 CHF statistics in the rod bow DNB penalty evaluation. The methodology defined in References 21 to 23 for evaluating the rod bow DNB penalty shall remain applicable.

[

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[

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[

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7.1.5 Impact on Inert Replacement Rod Report

The methodology defined in Reference 25 for using inert replacement rods as amended by the NRC safety evaluation will be applied in the same manner for the new CHF correlations. The form of the cold wall term for the new CHF correlations is the same as the CE-1 cold wall term. The addition of the special cold wall test (Test 73) to the ABB-NV database demonstrated that the cold wall term was not needed to correct the cold wall effect for subchannels with unheated replacement rods (See Section 3). However, to utilize the same methodology defined in

Reference 25, ABB will continue to conservatively apply the cold wall term for the new CHF correlations for a subchannel with an unheated replacement rod.

7.1.6 Impact on Loss of Flow Report

The Loss of Flow analysis will apply the new CHF correlations according to the same methodology defined in Reference 24. In this case, the fuel damage probability distribution at the 95% confidence level will be based on the new CHF correlations instead of CE-1. The probability of fuel damage will be based on the mean and increased variance for subset 1, defined in Section 7.1.3, which supports the 95/95 DNBR limit for the new CHF correlations.

7.1.7 HID-1 Grid Spacing DNB Penalty

In Reference 27, the NRC imposed a 0.01 penalty on the DNBR limit for ABB CE 16x16 fuel due to a difference in grid spacing between the reactor fuel (15.7 inches) and the DNB test section (14.2 inches). This penalty was applied since the CE-1 correlation did not contain a term to adjust for grid spacing effects on CHF. The new CHF correlations now include a grid term to correct for grid spacing effects therefore no DNB penalty is required, so none will be applied to the 1.13 DNBR limit for the new CHF correlations.

7.2 Application of ABB-NV and ABB-TV CHF Correlations in Transition Cores

This section will treat application of the ABB-NV CHF correlation and the ABB-TV CHF correlation in transition core situations.

7.2.1 Application of ABB-NV Correlation in Non-Mixing Vane Grid Transition Cores

Sections in Supplement 2-P-A of Reference 18 describe ABB CE's approach to analysis of transition cores containing non-mixing grid fuel assemblies. These methods remain applicable with application of the ABB-NV CHF correlation in DNBR reload analysis as described in Section 7.1. The ABB-NV CHF correlation may be applied in DNBR reload analysis provided the conditions for fuel assembly and grid compatibility discussed in Reference 18 are met. In particular, it is noted that the ABB-NV CHF correlation was developed from a series of CHF tests that included non-mixing vane grids with grid loss coefficients covering the range of grid loss coefficients used in developing the CE-1 correlation. Furthermore, as Reference 18 shows, TORC is acceptable for predicting the hydraulic conditions in adjacent assemblies with significantly different grids.

The application of the ABB-NV CHF correlation and codes, setpoints and uncertainty analyses, as described in Sections 7.1.1 to 7.1.3, will be the same for transition cores containing non-mixing grid fuel assemblies.

7.2.2 Application of New CHF Correlations in Transition to Turbo Fuel Cores

As Turbo fuel is introduced to reactor, transition cores will exist in which ABB Turbo mixing vane grid fuel assemblies are co-resident with ABB non-mixing vane grid fuel assemblies. [

]

14x14 dual bundle test results, described in Section A.4 of Reference 18 Supplement 2-P, demonstrate the accurate prediction of axial flow redistribution by the TORC code. The dual bundle test model consisted of two full scale fuel assemblies of the same basic geometry but containing grids with different hydraulic characteristics located in the upper portions of the assemblies. One of the fuel assemblies is a Turbo fuel assembly, [

] The other fuel assembly was an ABB non-mixing vane grid fuel assembly. Comparison of the flow split between assemblies showed good agreement between TORC predictions and measurements. It was concluded that TORC accurately predicts the flow conditions in adjacent fuel bundles that contain grids with significantly different designs and loss coefficients.

TORC is capable of accurately predicting hydraulic conditions in a transition core composed of both Turbo fuel assemblies and non-mixing vane grid fuel assemblies. Consequently, the TORC thermal hydraulic reload analysis methods as described in Section 7.1 will be used with the ABB-TV and ABB-NV CHF correlations for Turbo and non-mixing grid fuel assemblies. [

]

In the transition cores where Turbo fuel is implemented, ABB and its utility partners may elect to forego crediting the DNBR margin gains associated with Turbo to simplify the reload analyses in transition cores. A margin neutral approach may be adopted in which a TORC analysis would be performed to show that improvements in CHF due to the mixing vane grids more than compensates for any decrease in predicted DNBR due to flow diversion from Turbo to adjacent non-mixing vane grid fuel assemblies. For a full core of Turbo fuel assemblies, the entire DNBR margin benefit would then be credited in the reload analysis. If the margin neutral approach is not used for the transition cores, then a detailed TORC analysis will be performed each cycle to credit the full benefit of the Turbo grids minus the transition core penalty due to flow diversion.

The application of the ABB-NV and ABB-TV CHF correlations and codes, setpoints and uncertainty analyses, as described in Sections 7.1.1 to 7.1.3, will be the same for transition cores containing Turbo and non-mixing grid fuel assemblies.

8.0 Conclusions

The following conclusions and restrictions apply for the ABB-NV and ABB-TV CHF correlations:

1. Analysis of the ABB-NV and ABB-TV correlations and the source and validation data indicates that a minimum DNBR limit of 1.13 will provide a 95% probability with 95% confidence of not experiencing CHF on a rod showing the limiting value.

2. Statistical tests support the evaluation of the 95/95 DNBR limit of the ABB-NV and ABB-TV correlations.

3. The ABB-NV and ABB-TV correlations must be used in conjunction with the TORC code since the correlations were developed based on TORC and the associated TORC input specifications. The correlations may also be used in the CETOP-D code in support of reload design calculations.

4. The ABB-NV and ABB-TV correlations must also be used with the ABB optimized F_C shape factor to correct for non-uniform axial power shapes.

5. The range of applicability of the ABB-NV and ABB-TV correlations:

Parameter	**ABB-NV Range**	**ABB-TV Range**
Pressure (psia)	1750 to 2415	1500 to 2415
Local mass velocity (Mlbm/hr-ft^2)	0.8 to 3.16	0.90 to 3.40
Local quality	-0.14 to 0.22	-0.10 to 0.225
Heated length, inlet to CHF location (in)	48 to 150	48 to 136.7
Grid spacing (in)	8 to 18.86	8 to 18.86
Heated hydraulic diameter ratio, Dhm/Dh	0.679 to 1.08	0.679 to 1.00

9.0 References

1. CENPD-162-P-A, "C-E Critical Heat Flux, Critical Heat Flux Correlation for C-E Fuel Assemblies with Standard Spacer Grids, Part 1 Uniform Axial Power Distribution," September 1976.

2. CENPD-207-P-A, "C-E Critical Heat Flux, Critical Heat Flux Correlation for C-E Fuel Assemblies with Standard Spacer Grids, Part 2 Nonuniform Axial Power Distribution," December 1984.

3. Barnett, P. G., "An Investigation into the Validity of Certain Hypotheses Implied by Various Burnout Correlations", AEEW-R214, 1963.

4. CENPD-161-P-A, "TORC Code, A Computer Code for Determining the Thermal Margin of a Reactor Core," April 1986.

5. CENPD-206-P-A, "TORC Code, Verification and Simplified Modeling Methods", June 1981.

6. CETOP-D Reports:
   a.) CEN-191(B)-P, "CETOP-D Code Structure and Modeling Methods for Calvert Cliffs Units 1 and 2," December 1981.
   b.) CEN-160(S)-P Rev. 1-P, "CETOP Code Structure and Modeling Methods for San Onofre Nuclear Generating Station Units 2 and 3," September 1981.
   c.) CEN-214(A)-P, "CETOP-D Code Structure and Modeling Methods for Arkansas Nuclear One – Unit 2," July 1982.

7. CE NPSD-729-P, "CE-X1 Critical Heat Flux Correlation for Westinghouse 17x17 and 15x15 Fuel", March, 1992.

8. CE NPSD-785-P, "ABB-X2 Critical Heat Flux Correlation for ABB 17x17 and 16x16 Standard and Intermediate Mixing Grid Fuel", December, 1994.

9. Karoutas, Z. E., et al., "Supporting Test Data and Analysis for ABB CE's Turbo™ PWR Fuel Design", 12th annual KAIF/KNS meeting in Seoul Korea, April, 1997.

10. Tong, L. S., Boiling Crisis and Critical Heat Flux, U. S. Atomic Energy Commission, 1972, pp. 54-55.

11. Owen, D. B., "Factors for On-sided Tolerance Limits and for Variable Sampling Plans", SC-R-607, March 1963.

12. Natrella, M. G., Experimental Statistics, National Bureau of Standards handbook 91, Issued August, 1963, Reprinted October, 1966 with corrections.

13. Young, H. D., Statistical Treatment of Experimental Data, McGraw-Hill, pp. 76-80.

9.0 References (Cont'd)

14. ANSI N15.151974, "American National Standard Assessment of the Assumption of Normality (Employing Individual Observed Values)", October, 1973.

15. Pearson, E. S., and Hartley, H. O., Biometrika Tables for Statisticians, Vol. I, Third Edition, Cambridge, 1966, pp. 63-66 and Table 7.

16. Crow, E. L., Davis, F. A., and Maxfield, M. W., Statistics Manual, Dover Publications, 1960.

17. Siegal, S., and Castellan, Jr., N. J., Nonparametric Statistics for the Behavioral Sciences, 2nd Edition, McGraw-Hill, 1988, pp. 128-137 & 206-216.

18. CENPD-199-P Rev. 1-P-A, Supplement 2-P, "CE Setpoint Methodology", September 1997.

19. CEN-348(B)-P-A Supplement 1-P-A, "Extended Statistical Combination of Uncertainties", January 1997.

20. CEN-356(V)-P-A Revision 1-P-A, "Modified Statistical Combination of Uncertainties," May 1988.

21. CENPD-225-P-A, "Fuel and Poison Rod Bowing," June 1983.

22. CEN-289(A)-P, "Revised Rod Bow Penalties for Arkansas Nuclear One Unit 2," December 1984.

23. Letter, Robert S. Lee (NRC) to John M. Griffin (AP&L), Enclosure 2, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Amendment No. 66 to Facility Operating License No. NPF-6, Arkansas Power & Light Company, Arkansas Nuclear One, Unit 2, Docket No. 50-368," May 7, 1985.

24. CENPD-183-A "Loss of Flow – CE Methods for Loss of Flow Analysis", June 1984.

25. CENPD-289-P-A, "Use of Inert Replacement Rods in ABB CENF Fuel Assemblies", expected June 1999.

26. CEN-124(B)-P, "Statistical Combination of Uncertainties, Part 2", January 1980.

27. NUREG-0712, Supplement 4, "Safety Evaluation Report Related to the Operation of San Onofre Nuclear Generating Station Units 2 and 3", Docket Numbers 50-361 and 50-362, Pages 4-1 and 4-2, January 1982.

9.0 References (Cont'd)

28. Approval of CETOP-D Reports:
    a.) Safety Evaluation Report Supporting Ammendment No. 71 to License No. DPR-53 for Calvert Cliffs Unit1, Docket 50-317, Section 2.1.2.
    b.) Safety Evaluation Report, NUREG-0712 Supplement 4 for San Onofre Generating Station Units 2 and 3, Docket Nos. 50-361 and 50-362, Section 4.4.6.1.
    c.) Safety Evaluation Report Supporting Ammendment No. 26 to License No. NPF-6 for Arkansas Nuclear One Unit 2, Docket 50-368, Section 2-3.

Appendix A ABB-NV DATABASE

A detailed summary of the ABB-NV Correlation Database is shown in Table A-1 and the Validation Database is shown in Table A-2. The tables in this appendix summarize the raw data from Columbia data files, the test geometry information needed for the correlation development, and the predicted local coolant conditions taken from the TORC runs. The tabulation presented here gives the data from all CHF experiments with test sections described in Table 2-1 for which the system pressure was greater than 1740 psia and the test section average mass velocity was greater than 0.80 Mlbm/hr-ft^2. Repeat runs in the correlation database, identified in bold Italics, were eliminated in the correlation codes along with points outside the correlation parameter limits. Nomenclature for heading abbreviations in Appendices A and C are defined below:

TS	=	Test Section Number
TD	=	Test Section Type (UN is Uniform Shape without Guide Tube, UT is Uniform Shape with Guide Tube, NT is Non-Uniform Shape with Guide Tube)
Pr	=	Test Section Pressure (psia)
Tin	=	Test Section Inlet Temperature (°F)
Gavg	=	Average Test Section Mass Velocity (Mlbm/hr-ft^2)
Qavg	=	Test Section Critical Bundle Average Heat Flux (MBtu/hr-ft^2)
DROD	=	Primary DNB Rod Thermocouple Number
DCH	=	TORC Subchannel Number Where Local Coolant Conditions are Selected
GL	=	Local Mass Velocity in CHF Channel (Mlbm/hr-ft^2)
XL	=	Local Quality in CHF Channel
hfg	=	Latent Heat of Vaporization (Btu/lbm)
CHFM	=	Measured CHF (MBtu/hr-ft^2)
F_C	=	Non-uniform Shape Factor = 1.00 for Uniform Axial Power Shape Based on C_{OPT} for Non-uniform Axial Power Shape
GS	=	Nominal Grid Spacing (in)
HL	=	Heated Length to CHF Site (in)
DG	=	Distance from Bottom of Grid to CHF Site (in)
De	=	Wetted Hydraulic Diameter of CHF Channel (in)
Dh	=	Heated Hydraulic Diameter of CHF Channel (in)
Dhm	=	Heated Hydraulic Diameter of Matrix Channel (in)

TABLE A-1

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
18UT	16																	
18UT	17																	
18UT	18																	
18UT	19																	
18UT	20																	
18UT	21																	
18UT	22																	
18UT	23																	
18UT	24																	
18UT	25																	
18UT	26																	
18UT	27																	
18UT	28																	
18UT	29																	
18UT	30																	
18UT	31																	
18UT	32																	
18UT	33																	
18UT	34																	
18UT	35																	
18UT	36																	
18UT	37																	
18UT	38																	
18UT	39																	
18UT	40																	
18UT	41																	
18UT	42																	
18UT	43																	
18UT	44																	
18UT	45																	
18UT	46																	
18UT	47																	
18UT	48																	
18UT	49																	
18UT	50																	
18UT	51																	
18UT	52																	
18UT	53																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
18UT	54																	
18UT	55																	
18UT	56																	
18UT	57																	
18UT	58																	
18UT	59																	
18UT	60																	
18UT	81																	
18UT	82																	
18UT	83																	
18UT	84																	
18UT	85																	
18UT	86																	
18UT	87																	
21UN	13																	
21UN	14																	
21UN	15																	
21UN	16																	
21UN	17																	
21UN	18																	
21UN	19																	
21UN	20																	
21UN	21																	
21UN	22																	
21UN	23																	
21UN	24																	
21UN	25																	
21UN	26																	
21UN	27																	
21UN	28																	
21UN	29																	
21UN	30																	
21UN	31																	
21UN	32																	
21UN	33																	
21UN	34																	
21UN	35																	
21UN	36																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
21UN	37																	
21UN	38																	
21UN	*39*																	
21UN	40																	
21UN	41																	
21UN	42																	
21UN	43																	
21UN	44																	
21UN	45																	
21UN	46																	
21UN	47																	
21UN	48																	
21UN	49																	
21UN	50																	
21UN	51																	
21UN	52																	
21UN	53																	
21UN	54																	
21UN	55																	
36UT	105																	
36UT	106																	
36UT	107																	
36UT	108																	
36UT	109																	
36UT	110																	
36UT	111																	
36UT	112																	
36UT	113																	
36UT	114																	
36UT	115																	
36UT	116																	
36UT	117																	
36UT	118																	
36UT	119																	
36UT	120																	
36UT	*121*																	
36UT	*122*																	
36UT	*123*																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
36UT	124																	
36UT	125																	
36UT	126																	
36UT	127																	
36UT	128																	
36UT	129																	
36UT	***130***																	
36UT	***131***																	
36UT	***132***																	
36UT	***133***																	
36UT	134																	
36UT	135																	
36UT	136																	
36UT	137																	
36UT	138																	
36UT	139																	
36UT	140																	
36UT	141																	
36UT	142																	
36UT	143																	
36UT	144																	
36UT	145																	
36UT	146																	
36UT	147																	
36UT	148																	
36UT	149																	
36UT	220																	
36UT	***221***																	
36UT	***222***																	
36UT	223																	
36UT	***224***																	
36UT	***225***																	
36UT	***226***																	
36UT	227																	
36UT	228																	
36UT	***229***																	
36UT	230																	
36UT	***231***																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
36UT	232																	
36UT	233																	
36UT	*234*																	
36UT	*261*																	
36UT	262																	
36UT	263																	
36UT	*264*																	
36UT	*265*																	
36UT	266																	
36UT	267																	
36UT	268																	
36UT	*269*																	
36UT	*270*																	
36UT	*271*																	
36UT	272																	
36UT	*273*																	
36UT	*274*																	
36UT	*275*																	
38UT	18																	
38UT	19																	
38UT	20																	
38UT	21																	
38UT	22																	
38UT	23																	
38UT	24																	
38UT	25																	
38UT	26																	
38UT	27																	
38UT	28																	
38UT	29																	
38UT	30																	
38UT	31																	
38UT	32																	
38UT	33																	
38UT	34																	
38UT	35																	
38UT	36																	
38UT	37																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
38UT	38																	
38UT	39																	
38UT	40																	
38UT	41																	
38UT	42																	
38UT	43																	
38UT	44																	
38UT	45																	
38UT	46																	
38UT	47																	
38UT	48																	
38UT	49																	
38UT	50																	
38UT	51																	
38UT	52																	
38UT	53																	
38UT	54																	
38UT	55																	
38UT	56																	
38UT	57																	
38UT	58																	
38UT	59																	
38UT	60																	
38UT	61																	
38UT	62																	
38UT	63																	
47UT	18																	
47UT	19																	
47UT	20																	
47UT	21																	
47UT	22																	
47UT	23																	
47UT	24																	
47UT	26																	
47UT	27																	
47UT	29																	
47UT	30																	
47UT	31																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
47UT	33																	
47UT	34																	
47UT	35																	
47UT	36																	
47UT	39																	
47UT	40																	
47UT	41																	
47UT	42																	
47UT	43																	
47UT	44																	
47UT	45																	
47UT	47																	
47UT	48																	
47UT	49																	
47UT	50																	
47UT	51																	
47UT	52																	
47UT	53																	
47UT	54																	
47UT	55																	
47UT	56																	
47UT	57																	
47UT	58																	
47UT	59																	
47UT	60																	
47UT	62																	
47UT	63																	
47UT	64																	
47UT	65																	
47UT	66																	
47UT	67																	
47UT	69																	
47UT	70																	
47UT	71																	
47UT	73																	
47UT	75																	
47UT	81																	
47UT	82																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
47UT	83																	
47UT	84																	
47UT	85																	
47UT	86																	
47UT	88																	
47UT	89																	
47UT	90																	
47UT	91																	
47UT	92																	
47UT	95																	
47UT	96																	
47UT	97																	
47UT	98																	
47UT	*101*																	
47UT	102																	
47UT	184																	
47UT	185																	
47UT	186																	
47UT	187																	
47UT	188																	
47UT	189																	
47UT	190																	
47UT	191																	
47UT	192																	
47UT	193																	
48UN	29																	
48UN	30																	
48UN	31																	
48UN	32																	
48UN	33																	
48UN	34																	
48UN	35																	
48UN	36																	
48UN	37																	
48UN	38																	
48UN	40																	
48UN	41																	
48UN	43																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
48UN	44																	
48UN	45																	
48UN	46																	
48UN	47																	
48UN	48																	
48UN	49																	
48UN	50																	
48UN	53																	
48UN	54																	
48UN	55																	
48UN	56																	
48UN	57																	
48UN	58																	
48UN	59																	
48UN	60																	
48UN	61																	
48UN	62																	
48UN	63																	
48UN	64																	
48UN	65																	
48UN	66																	
48UN	67																	
48UN	70																	
48UN	*71*																	
48UN	72																	
48UN	75																	
48UN	*75*																	
48UN	76																	
48UN	77																	
48UN	78																	
48UN	79																	
48UN	80																	
48UN	81																	
48UN	82																	
48UN	83																	
48UN	84																	
48UN	85																	
48UN	86																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
48UN	87																	
48UN	88																	
48UN	90																	
48UN	91																	
48UN	95																	
48UN	96																	
48UN	97																	
48UN	98																	
48UN	99																	
48UN	100																	
48UN	101																	
48UN	102																	
48UN	103																	
48UN	104																	
48UN	105																	
48UN	106																	
48UN	107																	
48UN	108																	
48UN	109																	
48UN	111																	
48UN	*115*																	
52UT	*23*																	
52UT	24																	
52UT	*25*																	
52UT	26																	
52UT	27																	
52UT	28																	
52UT	29																	
52UT	30																	
52UT	*31*																	
52UT	*32*																	
52UT	*33*																	
52UT	34																	
52UT	35																	
52UT	36																	
52UT	*37*																	
52UT	38																	
52UT	39																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
52UT	43																	
52UT	44																	
52UT	45																	
52UT	46																	
52UT	48																	
52UT	49																	
52UT	50																	
52UT	51																	
52UT	55																	
52UT	*56*																	
52UT	*57*																	
52UT	58																	
52UT	59																	
52UT	60																	
52UT	61																	
52UT	64																	
52UT	65																	
52UT	66																	
52UT	67																	
52UT	68																	
52UT	69																	
52UT	70																	
52UT	71																	
52UT	74																	
52UT	75																	
52UT	76																	
52UT	77																	
52UT	78																	
52UT	*79*																	
52UT	80																	
52UT	81																	
52UT	82																	
52UT	83																	
52UT	84																	
52UT	86																	
52UT	88																	
52UT	89																	
52UT	90																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
52UT	91																	
52UT	92																	
52UT	93																	
52UT	94																	
52UT	96																	
52UT	***97***																	
52UT	98																	
52UT	107																	
52UT	***108***																	
52UT	109																	
52UT	***110***																	
52UT	***111***																	
52UT	112																	
52UT	113																	
52UT	***114***																	
52UT	***116***																	
52UT	117																	
52UT	***118***																	
52UT	119																	
52UT	***120***																	
52UT	121																	
52UT	122																	
52UT	***123***																	
52UT	***124***																	
52UT	125																	
52UT	***126***																	
52UT	***127***																	
52UT	***128***																	
52UT	***129***																	
52UT	130																	
52UT	***131***																	
73UT	18																	
73UT	19																	
73UT	20																	
73UT	21																	
73UT	***22***																	
73UT	23																	
73UT	24																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
73UT	25																	
73UT	26																	
73UT	27																	
73UT	28																	
73UT	29																	
73UT	30																	
73UT	31																	
73UT	32																	
73UT	33																	
73UT	34																	
73UT	35																	
73UT	36																	
73UT	37																	
73UT	39																	
73UT	40																	
73UT	41																	
73UT	42																	
73UT	43																	
73UT	44																	
73UT	45																	
73UT	46																	
73UT	47																	
73UT	48																	
73UT	49																	
73UT	50																	
73UT	51																	
73UT	52																	
73UT	53																	
73UT	54																	
73UT	55																	
73UT	56																	
73UT	57																	
73UT	58																	
73UT	59																	
73UT	60																	
73UT	61																	
73UT	62																	
73UT	63																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
73UT	64																	
73UT	65																	
73UT	*66*																	
73UT	67																	
73UT	68																	
73UT	69																	
73UT	70																	
73UT	71																	
73UT	72																	
73UT	73																	
73UT	74																	
73UT	75																	
73UT	76																	
73UT	77																	
73UT	78																	
73UT	79																	
73UT	80																	
73UT	81																	
73UT	82																	
73UT	83																	
73UT	84																	
73UT	85																	
73UT	86																	
73UT	87																	
73UT	88																	
73UT	89																	
73UT	90																	
58NT	1																	
58NT	2																	
58NT	3																	
58NT	4																	
58NT	5																	
58NT	6																	
58NT	7																	
58NT	8																	
58NT	9																	
58NT	10																	
58NT	11																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
58NT	12																	
58NT	13																	
58NT	14																	
58NT	15																	
58NT	16																	
58NT	17																	
58NT	18																	
58NT	19																	
58NT	20																	
58NT	21																	
58NT	22																	
58NT	23																	
58NT	24																	
58NT	25																	
58NT	26																	
58NT	27																	
58NT	28																	
58NT	29																	
58NT	30																	
58NT	31																	
58NT	32																	
58NT	33																	
58NT	34																	
58NT	35																	
58NT	36																	
58NT	37																	
58NT	38																	
58NT	39																	
58NT	40																	
58NT	41																	
58NT	42																	
58NT	43																	
58NT	44																	
58NT	45																	
58NT	46																	
58NT	47																	
58NT	48																	
58NT	49																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
58NT	50																	
58NT	51																	
58NT	52																	
58NT	53																	
58NT	54																	
58NT	55																	
58NT	56																	
58NT	57																	
58NT	64																	
58NT	65																	
58NT	66																	
58NT	67																	
58NT	68																	
58NT	69																	
58NT	70																	
58NT	71																	
59NT	15																	
59NT	16																	
59NT	17																	
59NT	18																	
59NT	19																	
59NT	20																	
59NT	21																	
59NT	22																	
59NT	23																	
59NT	24																	
59NT	25																	
59NT	26																	
59NT	27																	
59NT	28																	
59NT	29																	
59NT	30																	
59NT	31																	
59NT	32																	
59NT	33																	
59NT	34																	
59NT	35																	
59NT	36																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
59NT	37																	
59NT	38																	
59NT	39																	
59NT	40																	
59NT	41																	
59NT	42																	
59NT	*50*																	
59NT	51																	
59NT	52																	
59NT	53																	
59NT	54																	
59NT	55																	
59NT	56																	
59NT	57																	
59NT	58																	
59NT	59																	
59NT	60																	
59NT	61																	
59NT	62																	
59NT	63																	
59NT	64																	
59NT	65																	
59NT	66																	
59NT	67																	
59NT	68																	
59NT	69																	
59NT	70																	
59NT	71																	
59NT	72																	
59NT	73																	
59NT	74																	
59NT	75																	
59NT	76																	
59NT	77																	
59NT	78																	
59NT	79																	
59NT	80																	
59NT	81																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
59NT	82																	
59NT	83																	
59NT	84																	
59NT	85																	
59NT	87																	
59NT	88																	
59NT	89																	
59NT	90																	
59NT	92																	
59NT	94																	
59NT	96																	
59NT	97																	
59NT	99																	
59NT	100																	
59NT	101																	
59NT	102																	
59NT	103																	
59NT	104																	
59NT	105																	
59NT	106																	
59NT	107																	
59NT	108																	
59NT	110																	
60NT	9																	
60NT	10																	
60NT	11																	
60NT	12																	
60NT	13																	
60NT	14																	
60NT	15																	
60NT	16																	
60NT	17																	
60NT	*18*																	
60NT	19																	
60NT	20																	
60NT	21																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
60NT	22																	
60NT	23																	
60NT	24																	
60NT	25																	
60NT	26																	
60NT	27																	
60NT	28																	
60NT	29																	
60NT	30																	
60NT	31																	
60NT	32																	
60NT	33																	
60NT	34																	
60NT	35																	
60NT	37																	
60NT	38																	
60NT	39																	
60NT	40																	
60NT	43																	
60NT	44																	
60NT	45																	
60NT	46																	
60NT	47																	
60NT	48																	
60NT	***49***																	
60NT	50																	
60NT	51																	
60NT	52																	
60NT	53																	
60NT	54																	
60NT	55																	
60NT	56																	
60NT	57																	
60NT	58																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
60NT	59																	
60NT	60																	
60NT	61																	
60NT	62																	
60NT	63																	
60NT	64																	
60NT	65																	
60NT	66																	
60NT	67																	
60NT	68																	
60NT	69																	
60NT	70																	
60NT	71																	
60NT	72																	
60NT	73																	
60NT	74																	
60NT	78																	
60NT	79																	
60NT	80																	
60NT	81																	
60NT	82																	
60NT	83																	
60NT	84																	
60NT	85																	
60NT	86																	
60NT	87																	
60NT	88																	
66NT	15																	
66NT	16																	
66NT	17																	
66NT	18																	
66NT	19																	
66NT	*20*																	
66NT	21																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
66NT	22																	
66NT	24																	
66NT	*25*																	
66NT	*26*																	
66NT	27																	
66NT	28																	
66NT	29																	
66NT	30																	
66NT	31																	
66NT	34																	
66NT	33																	
66NT	35																	
66NT	36																	
66NT	38																	
66NT	39																	
66NT	40																	
66NT	41																	
66NT	42																	
66NT	43																	
66NT	44																	
66NT	45																	
66NT	46																	
66NT	47																	
66NT	48																	
66NT	49																	
66NT	50																	
66NT	51																	
66NT	52																	
66NT	53																	
66NT	54																	
66NT	55																	
66NT	56																	
66NT	58																	
66NT	59																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
66NT	60																	
66NT	61																	
66NT	63																	
66NT	***64***																	
66NT	65																	
66NT	66																	
66NT	***68***																	
66NT	69																	
66NT	70																	
66NT	71																	
66NT	72																	
66NT	73																	
66NT	74																	
66NT	75																	
66NT	76																	
66NT	77																	
66NT	78																	
66NT	79																	
66NT	***80***																	
66NT	81																	
66NT	***82***																	
66NT	83																	
66NT	***84***																	
66NT	85																	
66NT	86																	
66NT	87																	
66NT	88																	
66NT	89																	
66NT	90																	
66NT	91																	
66NT	92																	
66NT	93																	
66NT	94																	
66NT	95																	

TABLE A-1 Continued

ABB-NV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	Dc	Dh	Dhm
66NT	96																	
66NT	97																	
66NT	98																	
66NT	99																	
66NT	100																	
66NT	101																	
66NT	102																	
66NT	103																	
66NT	104																	
66NT	***105***																	
66NT	106																	
66NT	107																	

Bold & Italic Test Runs are Repeat Points Dropped From Correlation Development

TABLE A-2

ABB-NV Validation Datab. e

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
41UT	9																	
41UT	10																	
41UT	11																	
41UT	12																	
41UT	13																	
41UT	14																	
41UT	16																	
41UT	17																	
41UT	18																	
41UT	20																	
41UT	21																	
41UT	22																	
41UT	24																	
41UT	25																	
41UT	26																	
41UT	28																	
41UT	29																	
41UT	30																	
41UT	31																	
41UT	32																	
41UT	33																	
41UT	35																	
41UT	36																	
41UT	37																	
41UT	39																	
41UT	59																	
41UT	60																	
41UT	61																	
41UT	62																	
41UT	63																	
41UT	64																	
41UT	65																	
41UT	66																	
41UT	67																	

TABLE A-2 Continued

ABB-NV Validation Database

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
41UT	71																	
41UT	72																	
41UT	73																	
41UT	74																	
41UT	75																	
41UT	76																	
41UT	77																	
41UT	78																	
41UT	79																	
41UT	80																	
41UT	81																	
41UT	82																	
41UT	83																	
41UT	84																	
41UT	85																	
43UT	19																	
43UT	20																	
43UT	21																	
43UT	22																	
43UT	23																	
43UT	24																	
43UT	25																	
43UT	26																	
43UT	27																	
43UT	28																	
43UT	29																	
43UT	30																	
43UT	31																	
43UT	33																	
43UT	32																	
43UT	34																	
43UT	35																	
43UT	36																	
43UT	37																	

TABLE A-2 Continued

ABB-NV Validation Database

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
43UT	38																	
43UT	39																	
43UT	40																	
43UT	41																	
43UT	42																	
43UT	43																	
43UT	44																	
43UT	45																	
43UT	46																	
43UT	48																	
43UT	59																	
43UT	60																	
43UT	61																	
43UT	62																	
43UT	63																	
43UT	64																	
43UT	65																	
43UT	66																	
43UT	67																	
43UT	68																	
43UT	72																	
43UT	73																	
43UT	74																	
43UT	75																	
43UT	76																	
43UT	77																	
43UT	79																	
43UT	80																	
43UT	81																	
43UT	83																	
43UT	84																	
43UT	85																	
43UT	87																	
43UT	88																	

TABLE A-2 Continued

ABB-NV Validation Database

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
43UT	89																	
43UT	107																	
43UT	108																	
43UT	109																	
43UT	110																	
43UT	117																	
43UT	121																	
43UT	122																	
43UT	123																	
51UT	9																	
51UT	10																	
51UT	11																	
51UT	12																	
51UT	13																	
51UT	14																	
51UT	15																	
51UT	16																	
51UT	17																	
51UT	18																	
51UT	19																	
51UT	20																	
51UT	21																	
51UT	22																	
51UT	23																	
51UT	24																	
51UT	25																	
51UT	26																	
51UT	27																	
51UT	28																	
51UT	29																	
51UT	30																	
51UT	31																	
51UT	32																	
51UT	33																	

TABLE A-2 Continued

ABB-NV Validation Database

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
51UT	34																	
51UT	35																	
51UT	36																	
51UT	37																	
51UT	38																	
51UT	39																	
51UT	40																	
51UT	41																	
51UT	42																	
51UT	43																	
51UT	44																	
51UT	45																	
51UT	46																	
51UT	47																	
51UT	48																	
51UT	49																	
51UT	50																	
51UT	51																	
51UT	52																	
51UT	53																	
51UT	54																	
51UT	58																	
51UT	60																	
51UT	61																	
51UT	62																	
51UT	63																	
51UT	64																	
51UT	65																	
51UT	66																	
51UT	67																	
51UT	68																	
51UT	69																	
51UT	70																	
51UT	71																	

TABLE A-2 Continued

ABB-NV Validation Database

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
51UT	72																	
51UT	73																	
51UT	74																	
51UT	75																	
51UT	76																	
69NT	8																	
69NT	9																	
69NT	10																	
69NT	11																	
69NT	12																	
69NT	13																	
69NT	14																	
69NT	15																	
69NT	16																	
69NT	17																	
69NT	18																	
69NT	19																	
69NT	20																	
69NT	21																	
69NT	22																	
69NT	23																	
69NT	24																	
69NT	25																	
69NT	26																	
69NT	27																	
69NT	28																	
69NT	29																	
69NT	30																	
69NT	31																	
69NT	32																	
69NT	33																	
69NT	34																	
69NT	35																	
69NT	36																	

TABLE A-2 Continued

ABB-NV Validation Database

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
69NT	37																	
69NT	38																	
69NT	39																	
69NT	40																	
69NT	41																	
69NT	42																	
69NT	43																	
69NT	44																	
69NT	45																	
69NT	46																	
69NT	47																	
69NT	48																	
69NT	49																	
69NT	50																	
69NT	51																	
69NT	52																	
69NT	53																	
69NT	54																	
69NT	55																	

Appendix B ABB-NV STATISTICAL OUTPUT

A detailed summary of the statistical output of the ABB-NV correlation is given in Table B-1. For each test run in Table B-1, the values for the correlation variables, the measured CHF and ABB-NV predicted CHF are given, along with the valued for the M/P CHF ratio. For Table B-1, CHFM is multiplied by F_c. The repeat test runs and any test runs with variables outside the correlation parameter range are removed from Table B-1. The individual test section, database, Subset, and overall statistics are given at the end of the output in Table B-1. Nomenclature for heading abbreviations in Appendices B and D are defined below:

TS	=	Test Section Number
TD	=	Test Section Type (UN is Uniform Shape without Guide Tube, UT is Uniform Shape with Guide Tube, NT is Non-Uniform Shape with Guide Tube)
Pr	=	Test Section Pressure (psia)
GL	=	Local Mass Velocity in CHF Channel (Mlbm/hr-ft^2)
XL	=	Local Quality in CHF Channel
GS	=	Nominal Grid Spacing (in)
HL	=	Heated Length to CHF Site (in)
DG	=	Distance from Bottom of Grid to CHF Site (in)
Dh	=	Heated Hydraulic Diameter of CHF Channel (in)
Dhm	=	Heated Hydraulic Diameter of Matrix Channel (in)
CHFM	=	Measured CHF multiplied by F_C (MBtu/hr-ft^2),
F_C	=	Non-uniform Shape Factor = 1.00 for Uniform Axial Power Shape Based on C_{OPT} for Non-uniform Axial Power Shape
CHFP	=	ABB-NV Predicted CHF, Appendix B (MBtu/hr-ft^2) ABB-TV Predicted CHF, Appendix D (MBtu/hr-ft^2)

TABLE B-1

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
18UT	16												
18UT	17												
18UT	18												
18UT	19												
18UT	20												
18UT	21												
18UT	22												
18UT	23												
18UT	24												
18UT	25												
18UT	26												
18UT	27												
18UT	28												
18UT	29												
18UT	30												
18UT	31												
18UT	32												
18UT	33												
18UT	34												
18UT	35												
18UT	36												
18UT	37												
18UT	38												
18UT	39												
18UT	40												
18UT	41												
18UT	42												
18UT	43												
18UT	44												
18UT	45												
18UT	46												
18UT	47												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
18UT	48												
18UT	49												
18UT	50												
18UT	51												
18UT	52												
18UT	53												
18UT	54												
18UT	55												
18UT	56												
18UT	57												
18UT	58												
18UT	59												
18UT	60												
18UT	81												
18UT	82												
18UT	83												
18UT	84												
18UT	85												
18UT	86												
18UT	87												
21UN	13												
21UN	14												
21UN	15												
21UN	16												
21UN	17												
21UN	18												
21UN	19												
21UN	20												
21UN	21												
21UN	22												
21UN	23												
21UN	24												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
21UN	25												
21UN	26												
21UN	27												
21UN	28												
21UN	29												
21UN	30												
21UN	31												
21UN	32												
21UN	33												
21UN	34												
21UN	35												
21UN	36												
21UN	37												
21UN	38												
21UN	40												
21UN	44												
21UN	47												
21UN	48												
21UN	50												
21UN	51												
21UN	53												
21UN	54												
36UT	105												
36UT	106												
36UT	107												
36UT	108												
36UT	109												
36UT	110												
36UT	111												
36UT	112												
36UT	114												
36UT	115												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
36UT	116												
36UT	117												
36UT	118												
36UT	119												
36UT	120												
36UT	124												
36UT	125												
36UT	129												
36UT	134												
36UT	135												
36UT	136												
36UT	138												
36UT	140												
36UT	141												
36UT	142												
36UT	143												
36UT	144												
36UT	145												
36UT	146												
36UT	147												
36UT	148												
36UT	149												
36UT	220												
36UT	223												
36UT	227												
36UT	228												
36UT	230												
36UT	232												
36UT	233												
36UT	262												
36UT	263												
36UT	266												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
36UT	267												
36UT	268												
36UT	272												
38UT	18												
38UT	19												
38UT	20												
38UT	21												
38UT	22												
38UT	23												
38UT	24												
38UT	25												
38UT	26												
38UT	27												
38UT	28												
38UT	29												
38UT	30												
38UT	31												
38UT	32												
38UT	33												
38UT	34												
38UT	35												
38UT	36												
38UT	37												
38UT	38												
38UT	39												
38UT	40												
38UT	41												
38UT	42												
38UT	43												
38UT	44												
38UT	45												
38UT	46												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
38UT	47												
38UT	48												
38UT	49												
38UT	51												
38UT	52												
38UT	56												
38UT	57												
38UT	60												
38UT	63												
47UT	19												
47UT	20												
47UT	21												
47UT	23												
47UT	24												
47UT	26												
47UT	27												
47UT	29												
47UT	30												
47UT	31												
47UT	33												
47UT	34												
47UT	35												
47UT	36												
47UT	40												
47UT	42												
47UT	43												
47UT	44												
47UT	45												
47UT	47												
47UT	48												
47UT	49												
47UT	50												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
47UT	51												
47UT	52												
47UT	53												
47UT	54												
47UT	62												
47UT	63												
47UT	64												
47UT	67												
47UT	69												
47UT	70												
47UT	71												
47UT	73												
47UT	75												
47UT	82												
47UT	83												
47UT	85												
47UT	89												
47UT	90												
47UT	92												
47UT	95												
47UT	96												
47UT	97												
47UT	98												
47UT	102												
47UT	184												
47UT	185												
47UT	186												
47UT	187												
47UT	188												
47UT	189												
47UT	190												
47UT	191												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
47UT	192												
47UT	193												
48UN	29												
48UN	30												
48UN	31												
48UN	32												
48UN	33												
48UN	34												
48UN	35												
48UN	36												
48UN	37												
48UN	38												
48UN	40												
48UN	41												
48UN	43												
48UN	44												
48UN	45												
48UN	46												
48UN	47												
48UN	48												
48UN	49												
48UN	50												
48UN	53												
48UN	54												
48UN	55												
48UN	56												
48UN	57												
48UN	58												
48UN	60												
48UN	61												
48UN	62												
48UN	63												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
48UN	64												
48UN	65												
48UN	66												
48UN	67												
48UN	70												
48UN	72												
48UN	76												
48UN	77												
48UN	78												
48UN	79												
48UN	80												
48UN	81												
48UN	82												
48UN	83												
48UN	84												
48UN	85												
48UN	86												
48UN	87												
48UN	88												
48UN	90												
48UN	91												
43UN	103												
48UN	104												
48UN	105												
48UN	106												
52UT	24												
52UT	26												
52UT	27												
52UT	28												
52UT	29												
52UT	30												
52UT	34												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
52UT	35												
52UT	36												
52UT	38												
52UT	39												
52UT	43												
52UT	44												
52UT	45												
52UT	46												
52UT	55												
52UT	58												
52UT	59												
52UT	60												
52UT	61												
52UT	64												
52UT	65												
52UT	66												
52UT	67												
52UT	68												
52UT	69												
52UT	70												
52UT	71												
52UT	74												
52UT	75												
52UT	88												
52UT	89												
52UT	90												
52UT	92												
52UT	93												
52UT	94												
52UT	95												
52UT	96												
52UT	98												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
52UT	107												
52UT	109												
52UT	112												
52UT	113												
52UT	117												
52UT	119												
52UT	121												
52UT	122												
52UT	125												
52UT	130												
73UT	18												
73UT	19												
73UT	20												
73UT	21												
73UT	23												
73UT	24												
73UT	25												
73UT	26												
73UT	27												
73UT	28												
73UT	29												
73UT	30												
73UT	31												
73UT	32												
73UT	33												
73UT	34												
73UT	35												
73UT	36												
73UT	37												
73UT	39												
73UT	40												
73UT	41												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
73UT	42												
73UT	43												
73UT	45												
73UT	46												
73UT	47												
73UT	48												
73UT	49												
73UT	50												
73UT	51												
73UT	52												
73UT	53												
73UT	54												
73UT	55												
73UT	56												
73UT	57												
73UT	58												
73UT	59												
73UT	60												
73UT	61												
73UT	62												
73UT	63												
73UT	64												
73UT	65												
73UT	67												
73UT	68												
73UT	69												
73UT	70												
73UT	72												
73UT	73												
73UT	74												
73UT	75												
73UT	76												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
73UT	77												
73UT	78												
73UT	79												
73UT	80												
73UT	81												
73UT	82												
73UT	83												
73UT	84												
73UT	85												
73UT	86												
73UT	87												
73UT	88												
73UT	89												
73UT	90												
58NT	1												
58NT	2												
58NT	3												
58NT	4												
58NT	5												
58NT	6												
58NT	7												
58NT	8												
58NT	9												
58NT	10												
58NT	11												
58NT	12												
58NT	13												
58NT	14												
58NT	15												
58NT	16												
58NT	17												
58NT	18												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
58NT	19												
58NT	20												
58NT	21												
58NT	22												
58NT	23												
58NT	24												
58NT	25												
58NT	26												
58NT	27												
58NT	28												
58NT	29												
58NT	30												
58NT	32												
58NT	33												
58NT	38												
58NT	39												
58NT	40												
58NT	41												
58NT	42												
58NT	43												
58NT	44												
58NT	45												
58NT	46												
58NT	48												
58NT	49												
58NT	50												
58NT	51												
58NT	52												
58NT	53												
58NT	54												
58NT	55												
58NT	56												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
58NT	57												
58NT	64												
58NT	65												
58NT	66												
58NT	67												
58NT	68												
58NT	71												
59NT	15												
59NT	16												
59NT	17												
59NT	18												
59NT	19												
59NT	20												
59NT	21												
59NT	23												
59NT	24												
59NT	25												
59NT	26												
59NT	27												
59NT	28												
59NT	29												
59NT	30												
59NT	31												
59NT	32												
59NT	33												
59NT	34												
59NT	35												
59NT	36												
59NT	37												
59NT	38												
59NT	39												
59NT	41												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
59NT	42												
59NT	51												
59NT	52												
59NT	53												
59NT	54												
59NT	55												
59NT	58												
59NT	59												
59NT	60												
59NT	61												
59NT	62												
59NT	63												
59NT	64												
59NT	65												
59NT	66												
59NT	67												
59NT	68												
59NT	69												
59NT	70												
59NT	71												
59NT	72												
59NT	73												
59NT	74												
59NT	75												
59NT	76												
59NT	77												
59NT	78												
59NT	79												
59NT	80												
59NT	81												
59NT	82												
59NT	83												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
59NT	84												
59NT	85												
59NT	87												
59NT	88												
59NT	89												
59NT	90												
59NT	92												
59NT	94												
59NT	96												
59NT	97												
59NT	99												
59NT	100												
59NT	101												
59NT	106												
59NT	107												
59NT	110												
60NT	9												
60NT	10												
60NT	11												
60NT	12												
60NT	13												
60NT	14												
60NT	15												
60NT	16												
60NT	17												
60NT	19												
60NT	20												
60NT	21												
60NT	22												
60NT	23												
60NT	24												
60NT	25												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
60NT	26												
60NT	27												
60NT	28												
60NT	29												
60NT	30												
60NT	31												
60NT	32												
60NT	33												
60NT	34												
60NT	35												
60NT	37												
60NT	38												
60NT	39												
60NT	40												
60NT	47												
60NT	48												
60NT	50												
60NT	51												
60NT	52												
60NT	53												
60NT	54												
60NT	55												
60NT	56												
60NT	57												
60NT	58												
60NT	59												
60NT	60												
60NT	61												
60NT	62												
60NT	63												
60NT	64												
60NT	66												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
60NT	67												
60NT	68												
60NT	69												
60NT	70												
60NT	71												
60NT	72												
60NT	73												
60NT	74												
60NT	78												
60NT	79												
60NT	80												
60NT	81												
60NT	82												
60NT	83												
60NT	84												
60NT	85												
60NT	86												
60NT	87												
60NT	88												
66NT	15												
66NT	16												
66NT	17												
66NT	18												
66NT	19												
66NT	21												
66NT	22												
66NT	24												
66NT	27												
66NT	28												
66NT	29												
66NT	30												
66NT	31												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
66NT	34												
66NT	33												
66NT	35												
66NT	36												
66NT	38												
66NT	39												
66NT	40												
66NT	41												
66NT	42												
66NT	43												
66NT	44												
66NT	45												
66NT	46												
66NT	47												
66NT	48												
66NT	49												
66NT	50												
66NT	51												
66NT	52												
66NT	53												
66NT	54												
66NT	55												
66NT	56												
66NT	58												
66NT	59												
66NT	60												
66NT	61												
66NT	63												
66NT	65												
66NT	66												
66NT	73												
66NT	74												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
66NT	75												
66NT	76												
66NT	77												
66NT	78												
66NT	79												
66NT	81												
66NT	83												
66NT	88												
66NT	89												
66NT	92												
66NT	93												
66NT	94												
66NT	95												
66NT	96												
66NT	97												
66NT	98												
66NT	99												
66NT	100												
66NT	101												
66NT	102												
66NT	103												
66NT	104												
41UT	9												
41UT	10												
41UT	11												
41UT	12												
41UT	13												
41UT	14												
41UT	16												
41UT	17												
41UT	18												
41UT	20												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
41UT	21												
41UT	22												
41UT	24												
41UT	25												
41UT	26												
41UT	28												
41UT	29												
41UT	30												
41UT	31												
41UT	32												
41UT	33												
41UT	35												
41UT	36												
41UT	37												
41UT	39												
41UT	71												
41UT	72												
41UT	73												
41UT	74												
41UT	75												
41UT	76												
41UT	[illegible]												
41UT	[illegible]												
41UT	79												
41UT	80												
41UT	81												
41UT	82												
41UT	83												
41UT	84												
41UT	85												
43UT	19												
43UT	20												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
43UT	21												
43UT	22												
43UT	23												
43UT	24												
43UT	25												
43UT	26												
43UT	27												
43UT	28												
43UT	29												
43UT	30												
43UT	31												
43UT	33												
43UT	32												
43UT	34												
43UT	35												
43UT	36												
43UT	37												
43UT	38												
43UT	39												
43UT	40												
43UT	41												
43UT	42												
43UT	43												
43UT	44												
43UT	45												
43UT	46												
43UT	48												
43UT	59												
43UT	72												
43UT	73												
43UT	74												
43UT	75												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
43UT	76												
43UT	77												
43UT	79												
43UT	80												
43UT	81												
43UT	83												
43UT	84												
43UT	85												
43UT	87												
43UT	88												
43UT	89												
43UT	108												
43UT	110												
43UT	117												
43UT	121												
43UT	122												
51UT	9												
51UT	10												
51UT	11												
51UT	12												
51UT	13												
51UT	14												
51UT	15												
51UT	16												
51UT	17												
51UT	18												
51UT	19												
51UT	20												
51UT	21												
51UT	22												
51UT	23												
51UT	24												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
51UT	25												
51UT	26												
51UT	27												
51UT	28												
51UT	29												
51UT	30												
51UT	31												
51UT	32												
51UT	33												
51UT	34												
51UT	35												
51UT	36												
51UT	37												
51UT	38												
51UT	39												
51UT	40												
51UT	41												
51UT	42												
51UT	43												
51UT	44												
51UT	45												
51UT	58												
51UT	60												
51UT	67												
51UT	68												
51UT	69												
51UT	70												
51UT	71												
51UT	72												
51UT	73												
51UT	74												
51UT	75												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
51UT	76												
69NT	8												
69NT	9												
69NT	10												
69NT	11												
69NT	12												
69NT	13												
69NT	14												
69NT	15												
69NT	16												
69NT	17												
69NT	18												
69NT	19												
69NT	20												
69NT	21												
69NT	22												
69NT	23												
69NT	24												
69NT	25												
69NT	26												
69NT	27												
69NT	28												
69NT	29												
69NT	30												
69NT	31												
69NT	32												
69NT	33												
69NT	34												
69NT	35												
69NT	36												
69NT	37												
69NT	38												

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
69NT	39												
69NT	40												
69NT	41												
69NT	42												
69NT	43												
69NT	44												
69NT	45												
69NT	46												
69NT	47												
69NT	48												
69NT	49												
69NT	50												
69NT	51												
69NT	52												
69NT	53												
69NT	54												
69NT	55												

CORRELATION DATA

ALL DATA NP = 528 AVG = 1.00450826 SDF = 0.06150885

TABLE B-1 Continued

Statistical Output of ABB-NV Correlation

VALIDATION DATA

ALL DATA NP = 187 AVG = 1.00397991 SDF = 0.05698663

Appendix C ABB-TV DATABASE

A detailed summary of the ABB-TV Correlation Database is shown in Table C-1 and the Validation Database is shown in Table C-2. The tables in this appendix summarize the raw data from Columbia data files, the test geometry information needed for the correlation development, and the predicted local coolant conditions taken from the TORC runs. The tabulation presented here gives the data from all CHF experiments with test sections described in Table 2-2 for which the system pressure was greater than 1490 psia and the test section average mass velocity was greater than 0.80 Mlbm/hr-ft^2. Repeat runs in the correlation database, identified in bold Italics, were eliminated in the correlation codes along with points outside the correlation parameter limits.

TABLE C-1

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
91UN	38																	
91UN	39																	
91UN	40																	
91UN	42																	
91UN	43																	
91UN	*44*																	
91UN	45																	
91UN	46																	
91UN	47																	
91UN	48																	
91UN	50																	
91UN	51																	
91UN	54																	
91UN	78																	
91UN	*79*																	
91UN	80																	
91UN	89																	
91UN	90																	
91UN	91																	
91UN	92																	
91UN	93																	
91UN	94																	
91UN	95																	
91UN	96																	
91UN	99																	
91UN	100																	
91UN	101																	
91UN	104																	
91UN	106																	
91UN	107																	
91UN	108																	
91UN	109																	
91UN	110																	
91UN	112																	

TABLE C-1 - Continued

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
91UN	113																	
91UN	114																	
91UN	115																	
91UN	116																	
91UN	117																	
91UN	118																	
91UN	119																	
91UN	120																	
91UN	121																	
91UN	123																	
91UN	124																	
91UN	126																	
91UN	127																	
91UN	128																	
91UN	129																	
91UN	130																	
91UN	131																	
91UN	133																	
91UN	136																	
91UN	*140*																	
91UN	141																	
91UN	142																	
91UN	143																	
91UN	144																	
91UN	145																	
91UN	146																	
91UN	147																	
91UN	148																	
91UN	149																	
91UN	151																	
91UN	155																	
91UN	156																	
91UN	157																	
91UN	158																	

TABLE C-1 - Continued

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gsvg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
91UN	159																	
91UN	160																	
91UN	161																	
91UN	162																	
91UN	165																	
91UN	166																	
91UN	167																	
91UN	168																	
91UN	169																	
91UN	171																	
91UN	172																	
91UN	173																	
91UN	174																	
91UN	176																	
91UN	177																	
91UN	178																	
91UN	179																	
92UT	59																	
92UT	60																	
92UT	61																	
92UT	62																	
92UT	***63***																	
92UT	65																	
92UT	66																	
92UT	69																	
92UT	70																	
92UT	71																	
92UT	72																	
92UT	74																	
92UT	75																	
92UT	***81***																	
92UT	82																	
92UT	83																	
92UT	85																	

TABLE C-1 - Continued

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
92UT	87																	
92UT	88																	
92UT	89																	
92UT	90																	
92UT	91																	
92UT	93																	
92UT	94																	
92UT	95																	
92UT	96																	
92UT	97																	
92UT	***98***																	
92UT	99																	
92UT	100																	
92UT	101																	
92UT	102																	
92UT	103																	
92UT	***104***																	
92UT	105																	
92UT	106																	
92UT	108																	
92UT	109																	
92UT	110																	
92UT	***112***																	
92UT	113																	
92UT	***114***																	
92UT	115																	
92UT	116																	
92UT	118																	
92UT	***119***																	
92UT	120																	
92UT	121																	
92UT	122																	
92UT	123																	
92UT	151																	

TABLE C-1 - Continued

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
92UT	152																	
92UT	153																	
92UT	154																	
92UT	157																	
92UT	158																	
92UT	160																	
92UT	162																	
92UT	163																	
92UT	164																	
92UT	165																	
92UT	166																	
92UT	167																	
92UT	168																	
92UT	170																	
92UT	171																	
92UT	172																	
92UT	*173*																	
92UT	174																	
92UT	177																	
92UT	178																	
92UT	179																	
92UT	180																	
92UT	182																	
92UT	183																	
92UT	184																	
92UT	185																	
92UT	186																	
92UT	187																	
92UT	188																	
92UT	189																	
92UT	190																	
92UT	191																	
92UT	192																	
92UT	194																	

TABLE C-1 - Continued

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
92UT	195																	
92UT	196																	
92UT	197																	
92UT	198																	
92UT	200																	
92UT	***201***																	
92UT	202																	
93NT	37																	
93NT	38																	
93NT	39																	
93NT	40																	
93NT	41																	
93NT	42																	
93NT	43																	
93NT	45																	
93NT	46																	
93NT	47																	
93NT	49																	
93NT	50																	
93NT	***57***																	
93NT	58																	
93NT	59																	
93NT	60																	
93NT	61																	
93NT	62																	
93NT	65																	
93NT	66																	
93NT	67																	
93NT	69																	
93NT	72																	
93NT	74																	
93NT	75																	
93NT	76																	
93NT	77																	

TABLE C-1 - Continued

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_c	GS	HL	DG	De	Dh	Dhm
93NT	81																	
93NT	82																	
93NT	83																	
93NT	84																	
93NT	85																	
93NT	86																	
93NT	87																	
93NT	88																	
93NT	89																	
93NT	90																	
93NT	91																	
93NT	92																	
93NT	93																	
93NT	94																	
93NT	95																	
93NT	96																	
93NT	97																	
93NT	*110*																	
93NT	111																	
93NT	112																	
93NT	113																	
93NT	114																	
93NT	115																	
93NT	116																	
93NT	117																	
93NT	118																	
93NT	119																	
93NT	120																	
93NT	121																	
93NT	122																	
93NT	123																	
93NT	124																	
93NT	*125*																	
93NT	*132*																	

TABLE C-1 - Continued

ABB-TV Correlation Database - Primary Point Data

TS TD	Run	Pr	Tin	Gavg	Qavg	DROD	DCH	GL	XL	hfg	CHFM	F_C	GS	HL	DG	De	Dh	Dhm
93NT	133																	
93NT	134																	
93NT	135																	
93NT	137																	
93NT	138																	
93NT	139																	
93NT	140																	
93NT	141																	
93NT	142																	
93NT	143																	
93NT	144																	
93NT	145																	
93NT	146																	
93NT	147																	
93NT	148																	
93NT	150																	
93NT	154																	
93NT	155																	
93NT	156																	
93NT	157																	
93NT	158																	
93NT	159																	
93NT	160																	
93NT	164																	
93NT	165																	
93NT	166																	

Bold & Italic Test Runs are Repeat Points Dropped From Correlation Development

Appendix D ABB-TV STATISTICAL OUTPUT

A detailed summary of the statistical output of the ABB-TV correlation is given in Table D-1. For each test run in Table D-1, the values for the correlation variables, the measured CHF and ABB-TV predicted CHF are given, along with the valued for the M/P CHF ratio. For Table D-1, CHFM is multiplied by F_c. Data from the correlation database are identified with the letter C and data from the validation database are identified with the letter V. The repeat test runs and any test runs with variables outside the correlation parameter range are removed from Table D-1. The individual test section, database and overall statistics are given at the end of the output in Table D-1.

TABLE D-1

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
91UN C	38												
91UN C	39												
91UN C	42												
91UN C	43												
91UN C	45												
91UN C	46												
91UN C	47												
91UN C	48												
91UN C	50												
91UN C	51												
91UN C	54												
91UN C	78												
91UN C	80												
91UN C	89												
91UN C	90												
91UN C	91												
91UN C	95												
91UN C	96												
91UN C	99												
91UN C	100												
91UN C	101												
91UN C	104												
91UN C	106												
91UN C	107												
91UN C	108												
91UN C	109												
91UN C	110												
91UN C	112												
91UN C	113												
91UN C	114												
91UN C	115												
91UN C	116												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
91UN C	117												
91UN C	118												
91UN C	119												
91UN C	120												
91UN C	121												
91UN C	123												
91UN C	124												
91UN C	127												
91UN C	128												
91UN C	129												
91UN C	130												
91UN C	131												
91UN C	133												
91UN C	136												
91UN C	141												
91UN C	144												
91UN C	145												
91UN C	146												
91UN C	149												
91UN C	151												
91UN C	155												
91UN C	156												
91UN C	157												
91UN C	158												
91UN C	159												
91UN C	160												
91UN C	161												
91UN C	162												
91UN C	165												
91UN C	166												
91UN C	167												
91UN C	168												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dlam	CHFM	CHFP	M/P - 1	M/P
91UN C	169												
91UN C	171												
91UN C	172												
91UN C	173												
91UN C	174												
91UN C	176												
91UN C	177												
91UN C	178												
91UN C	179												
91UN V	41												
91UN V	49												
91UN V	52												
91UN V	53												
91UN V	97												
91UN V	98												
91UN V	102												
91UN V	103												
91UN V	105												
91UN V	111												
91UN V	122												
91UN V	125												
91UN V	134												
91UN V	135												
91UN V	150												
91UN V	152												
91UN V	163												
91UN V	164												
91UN V	170												
91UN V	175												
92UT C	61												
92UT C	62												
92UT C	65												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
92UT C	69												
92UT C	70												
92UT C	71												
92UT C	72												
92UT C	74												
92UT C	75												
92UT C	82												
92UT C	83												
92UT C	85												
92UT C	87												
92UT C	88												
92UT C	90												
92UT C	91												
92UT C	93												
92UT C	94												
92UT C	95												
92UT C	96												
92UT C	97												
92UT C	99												
92UT C	100												
92UT C	101												
92UT C	102												
92UT C	103												
92UT C	105												
92UT C	106												
92UT C	108												
92UT C	109												
92UT C	110												
92UT C	113												
92UT C	115												
92UT C	116												
92UT C	118												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
92UT C	120												
92UT C	121												
92UT C	122												
92UT C	123												
92UT C	151												
92UT C	152												
92UT C	153												
92UT C	154												
92UT C	157												
92UT C	158												
92UT C	160												
92UT C	162												
92UT C	163												
92UT C	164												
92UT C	165												
92UT C	166												
92UT C	167												
92UT C	168												
92UT C	170												
92UT C	171												
92UT C	172												
92UT C	174												
92UT C	177												
92UT C	178												
92UT C	179												
92UT C	180												
92UT C	182												
92UT C	183												
92UT C	184												
92UT C	185												
92UT C	186												
92UT C	187												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
92UT C	188												
92UT C	189												
92UT C	190												
92UT C	191												
92UT C	192												
92UT C	194												
92UT C	195												
92UT C	196												
92UT C	197												
92UT C	198												
92UT C	200												
92UT C	202												
92UT V	64												
92UT V	67												
92UT V	68												
92UT V	73												
92UT V	80												
92UT V	84												
92UT V	86												
92UT V	92												
92UT V	107												
92UT V	111												
92UT V	117												
92UT V	150												
92UT V	155												
92UT V	156												
92UT V	159												
92UT V	161												
92UT V	169												
92UT V	175												
92UT V	176												
92UT V	181												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
92UT V	193												
92UT V	199												
93NT C	37												
93NT C	38												
93NT C	39												
93NT C	40												
93NT C	41												
93NT C	42												
93NT C	43												
93NT C	45												
93NT C	46												
93NT C	47												
93NT C	49												
93NT C	50												
93NT C	58												
93NT C	59												
93NT C	60												
93NT C	61												
93NT C	62												
93NT C	65												
93NT C	66												
93NT C	67												
93NT C	69												
93NT C	72												
93NT C	74												
93NT C	75												
93NT C	76												
93NT C	77												
93NT C	81												
93NT C	82												
93NT C	83												
93NT C	84												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
93NT C	85												
93NT C	87												
93NT C	88												
93NT C	89												
93NT C	90												
93NT C	91												
93NT C	92												
93NT C	93												
93NT C	94												
93NT C	95												
93NT C	96												
93NT C	97												
93NT C	111												
93NT C	112												
93NT C	113												
93NT C	114												
93NT C	115												
93NT C	116												
93NT C	117												
93NT C	118												
93NT C	119												
93NT C	120												
93NT C	121												
93NT C	122												
93NT C	123												
93NT C	124												
93NT C	133												
93NT C	134												
93NT C	135												
93NT C	137												
93NT C	138												
93NT C	139												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
93NT C	140												
93NT C	141												
93NT C	142												
93NT C	143												
93NT C	144												
93NT C	145												
93NT C	146												
93NT C	147												
93NT C	148												
93NT C	150												
93NT C	154												
93NT C	155												
93NT C	156												
93NT C	157												
93NT C	158												
93NT C	159												
93NT C	160												
93NT C	164												
93NT C	165												
93NT C	166												
93NT V	35												
93NT V	36												
93NT V	44												
93NT V	48												
93NT V	63												
93NT V	64												
93NT V	68												
93NT V	70												
93NT V	71												
93NT V	73												
93NT V	78												
93NT V	79												

TABLE D-1 Continued

Statistical Output of ABB-TV Correlation

TS TD	Run	Pr	GL	XL	GS	HL	DG	Dh	Dhm	CHFM	CHFP	M/P - 1	M/P
93NT V	80												
93NT V	149												
93NT V	151												
93NT V	152												
93NT V	153												
93NT V	161												
93NT V	162												
93NT V	163												

CORRELATION DATABASE

ALL DATA NP= 234 AVG = 1.00015667 SDF = 0.04856979

VALIDATION DATABASE

ALL DATA NP= 62 AVG = 0.99743881 SDF = 0.04768478

COMBINED DATABASE

ALL DATA NP= 296 AVG = 0.99958739 SDF = 0.04831811

Appendix E ABB CHF TEST GEOMETRIES

The test section radial and axial geometries for the tests used in the development and validation of the ABB-NV correlation are shown in Figures E-1 through E-32. The axial relative power input into the TORC code for the non-uniform tests are shown in Table E-1. The test section radial and axial geometries for the tests used in the development and validation of the ABB-TV correlation are shown in Figures E-33 through E-37. The axial relative power input into the TORC code for the non-uniform test is shown in Table E-2. The test section radial and axial geometries for the special ABB-NV tests are shown in Figures E-14 and E-38 through E-41.

TABLE E-1

TORC Axial Power Distribution Input For ABB-NV Non-uniform Tests

Test 58		Test 59		Test 60		Test 66	
x/L	Rel. Power	x/L	Rel. Power	x/L	Rel. Power	x/L	Rel. Power

TABLE E-2

TORC Axial Power Distribution Input For ABB-TV Non-uniform Test

Test 93

x/L	Rel. Power

E-3

Appendix E Figures

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