REACTOR ENGINEERING

TU ELECTRIC
Generating Division

RXE-88-102-NP, Sup.1

TUE-1 DNB CORRELATION

SUPPLEMENT 1

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ABSTRACT

A study has been performed to extend the application of the TUE-1 Departure from Nucleate Boiling (DNB) correlation to [ ]. The TUE-1 DNB correlation was developed at TU Electric using the Columbia University DNB data base, VIPRE-01 thermal-hydraulic code, and the Statistical Analysis System. The original data base for the TUE-1 correlation consisted of 934 data points representative of Westinghouse 15x15 and 17x17 fuel with R-type mixing vane grids. In this supplement, DNB test data representative of [ ] were analyzed to validate the TUE-1 correlation for use with [

].

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CHAPTER 1

INTRODUCTION

1.1 Purpose

[

] This supplement describes the analysis of additional experimental DNB test data which [

]

TU Electric presented the TUE-1 DNB correlation in Reference 1. The original TUE-1 correlation data base consisted of 934 experimental data points representative of Westinghouse 15x15 and 17x17 R-grid fuel. The TUE-1 DNB correlation 95/95 DNBR limit was evaluated to be 1.16, based on statistical analyses of the experimental data predictions. [

]

1.2 Intended Applications

TU Electric intends to employ the TUE-1 DNB correlation for licensing and safety calculations using the VIPRE-01 thermal-hydraulic code (Reference 7). The applications of the TUE-1 correlation will include DNB-related calculations required for core safety limit curve calculations, reactor protection system setpoint analysis, and safety analyses for normal operation and DNB-limited events.

1.3 Methodology

A VIPRE-01 thermal-hydraulic model represented the [ ] fuel which was used to obtain the DNB data. This model is consistent with the model used in the analysis of the original correlation data base. The TUE-1 Minimum Departure from Nucleate Boiling Ratio (MDNBR) predictions for the new data were examined using several statistical tests. First, the [ ] data base was tested for normality using the D' test. Then, statistical combinability tests were performed to [

]. The following statistical analyses were then performed on the expanded correlation data base, which consists of the original data and the additional [ ]:

1) The expanded data base was tested for normality using the D' test.

2) Statistical combinability tests were performed to determine [

]. Subgroups that were tested included uniform and nonuniform axial heat flux profiles, bundle arrays (15x15 or 17x17), heated lengths, subchannel hydraulic diameters, grid spacing, subchannel types (typical and thimble cells), and fuel rod diameters.

3) Scatter plots of predicted MDNBR versus independent variables (such as heat flux, local quality, and pressure) were examined to determine if the correlation is biased over the range of any independent variable.

4) The 95/95 DNBR limit for the expanded data base was calculated using the Owen's one-sided tolerance factor.

CHAPTER 2

[ ] DATA BASE

2.1 Data Selection

The data selected for this evaluation are from the [ ]. This test section has a configuration representative of [ ] fuel assembly with a [ ] inch fuel rod outside diameter The [ ] test section data base consists of [ ] data points. The characteristics of the [ ] test section and the range of experimental operating conditions are shown in Table 2-1. For comparison, the range of operating conditions for the original experimental data used to develop the TUE-1 DNB correlation is also shown in Table 2-1.

Figure 2-1 shows the channel and rod layout for test section [ ] with radial power factors.

2.2 Data Elimination

One data point was excluded from the analysis because it was evaluated to be a statistical outlier. This exclusion is based on the same data elimination technique, Chauvenet's Criterion, that was applied to the original experimental data base. Chauvenet's Criterion is discussed in detail in Reference 1.

TABLE 2-1

Comparison of the [ ] Data and the Original Data

	[ ] Data Test Section [ ]	Original Data
Pressure (psia)	[	1485 to 2435
Inlet Mass Flux (Mlbm/hr-ft2)		0.93 to 3.53
Local Quality		-0.15 to 0.30
Local Heat Flux (MBTU/hr-ft2)		0.14 to 1.15
Inlet Subcooling (Btu/lbm)		30 to 350
Mixing Vane Grid Spacing (in)		20 to 32
Heated Length (in)		96 to 168
Rod Diameter (in)		0.374 to 0.422
Wetted Hydraulic Equivalent Dia (in)		0.37 to 0.51
Heated Hydraulic Equivalent Dia (in)		0.46 to 0.58
Axial Heat Flux		uniform, cos(u), (u)sin(u)
Assembly-Average Grid Loss Coef	]	1.20 to 1.90

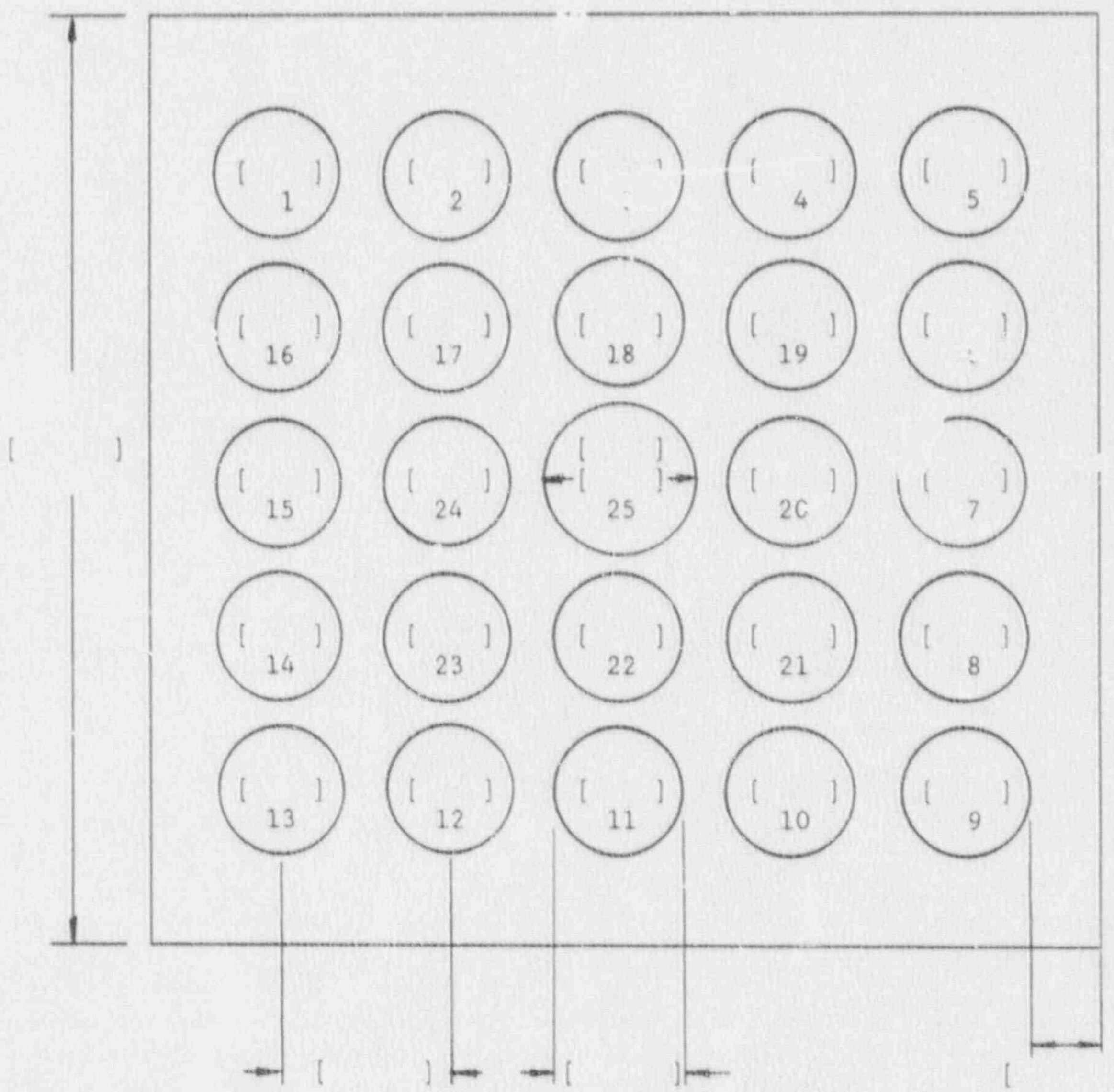

FIGURE 2-1

Test Assembly Geometry and Radial Power Distribution

NOTE: The decimal numbers inside the rods denote the radial power factor and the integer numbers inside the rods denote the rod number.

CHAPTER 3

MDNBR CALCULATIONS

3.1 Computer Code

The VIPRE-01 computer code (Reference 7), modified to include the TUE-1 DNB correlation, was used to predict the thermal-hydraulic conditions and MDNBR for the analysis of the test data.

3.2 VIPRE-01 Subchannel Model

The thermal-hydraulic model for the [ ] test section is consistent with the model used in developing the TUE-1 correlation (Reference 1). Similar to the thermal-hydraulic model used for the TUE-1 correlation development, the model for the [ ] test section is a full model of the whole test section; all 36 subchannels and all 25 rods (24 heated and 1 unheated) are explicitly modeled. The axial noding scheme provides for finer mesh spacing in the regions where the MDNBR occurs. Figures 3-1 and 3-2 show the axial noding and the channel and rod layout used for the VIPRE-01 model.

A conservative ABETA value of 0.02, as recommended by EPRI (Reference 6), is used for the turbulent crossflow mixing coefficient.

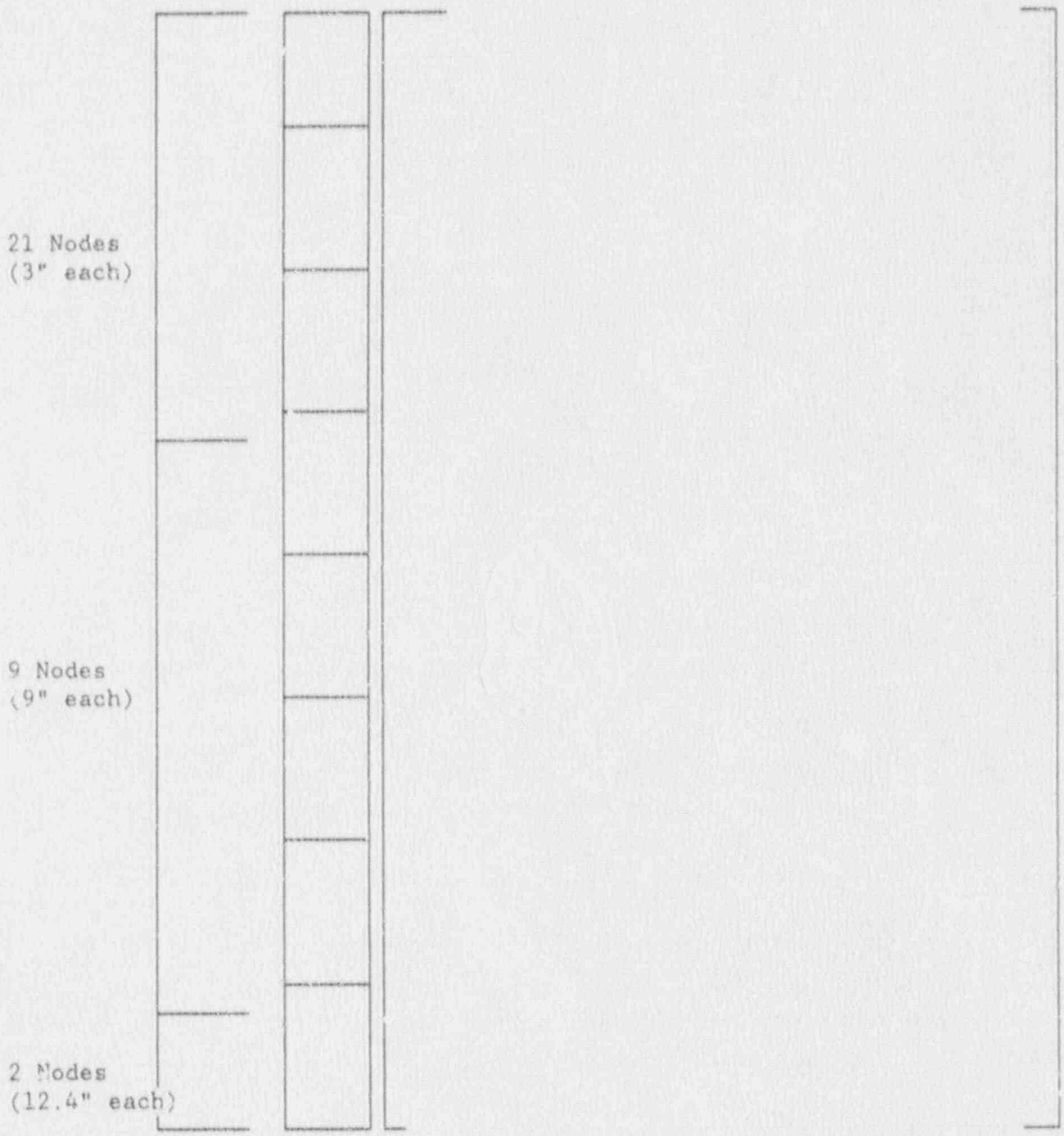

FIGURE 3-1

Axial Noding Configuration for [ ] Data

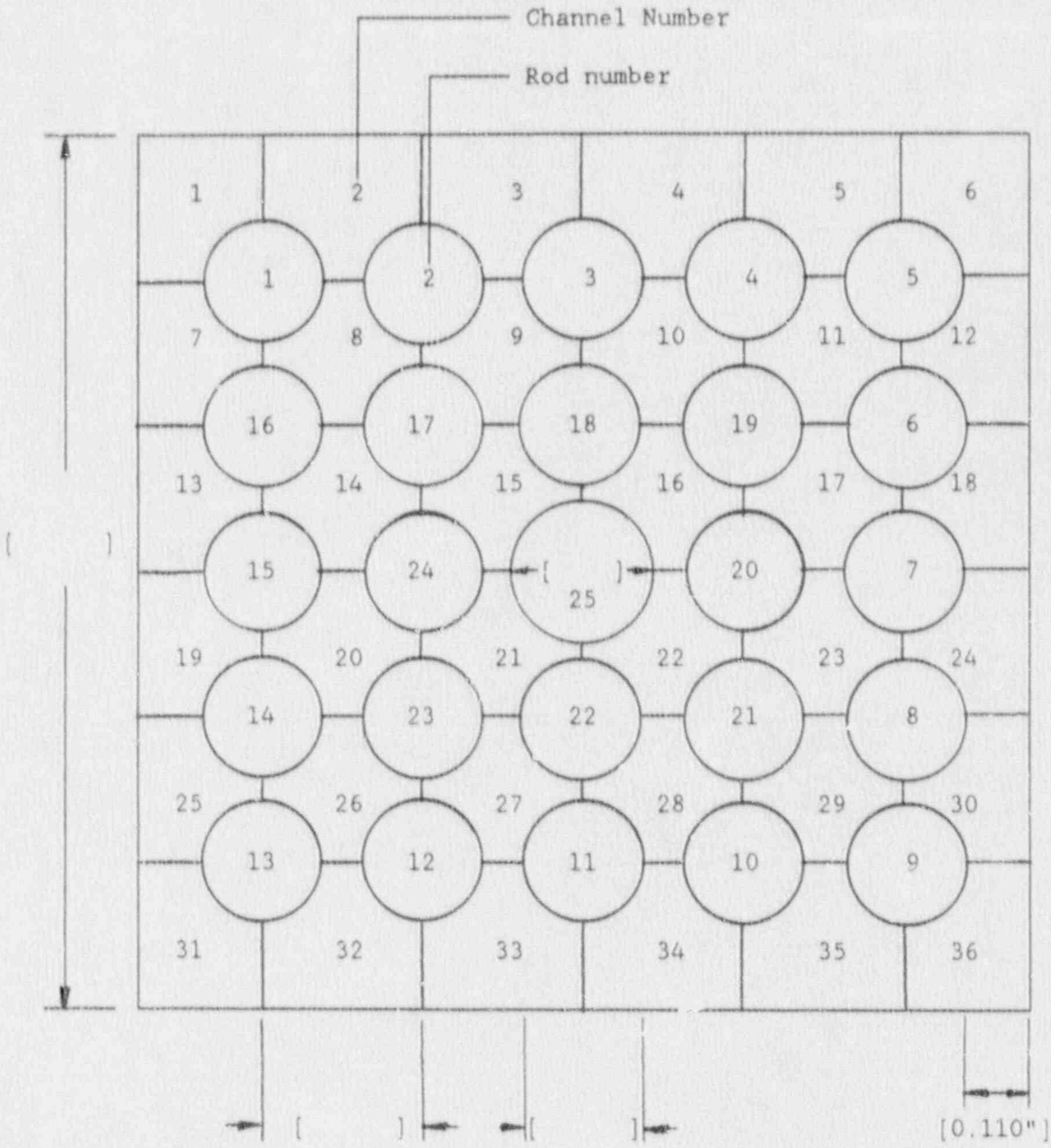

FIGURE 3-2

Channel and Rod Layout for [ ] Data

CHAPTER 4

STATISTICAL EVALUATION

4.1 [ ] Data

A listing of the calculated MDNBRs and corresponding local conditions for each [ ] data point is provided in Appendix A. By application of the D' test (Reference 3), the data was determined to be normally distributed. The mean and standard deviation for the MDNBR predictions were evaluated to be [ ] and [ ], respectively.

4.2 [ ]

[ ] The F-test and t-test (Reference 4) were used to test the equality of the variance and the mean, respectively, consistent with the methods used in Reference 1. [ ]

[ ]

The results of the comparison are shown in Table 4-1. [

]

4.3 Data Plots

To determine if the correlation describes the DNB phenomenon for the expanded data set accurately and without any bias, scatter plots are examined. Scatter plots of predicted DNB heat flux vs local heat flux and of predicted MDNBR versus system pressure, local quality, and local mass flux are shown in Figures 4-1, 4-2, 4-3, and 4-4, respectively. Visual examination of these plots shows that [

]

4.4 95/95 DNBR Limit for the Expanded TUE-1 Data Base

The 95/95 DNBR limit for the expanded TUE-1 data base is calculated as follows:

(i) The D' test (Reference 3 is used to test the expanded data set .or normality.

The results of the D' test indicate that the [

]

(ii) A mean and standard deviation of [ ], respectively, are calculated for the expanded data base. Because the data base is normally distributed, Owen's one-sided tolerance limit factor (Reference 5) is used to calculate the 95/95 DNBR limit, as shown below.

$$95/95 \text{ DNBR Limit} = m + s * K(n, 95\%, 95\%)$$

where: m is the sample mean

s is the sample standard deviation

K(n,95%,95%) is the Owen's one-sided tolerance limit factor for calculating a 95/95 limit for a sample set of size n.

The Owen's factor for a sample size of [

]

TABLE 4-1

Statistical Analysis Summary

[ ]

Figure 4-1

Predicted DNB Heat Flux s Local Heat Flux

for [ ] Data

[ ]

Figure 4-2

Predicted DNB Heat Flux vs Local Heat Flux

for Expanded Data Set

Figure 4-3

MDNBR vs System Pressure

Figure 4-3

MDNBR vs System Pressure

Figure 4-4

MDNBR vs Local Quality

Figure 4-4

MDNBR vs Local Quality

Figure 4-5

MDNBR vs Local Mass Flux

CHAPTER 5

CONCLUSION

This supplement provides the justification for the use of the TUE-1 DNB correlation for [ ] fuel assemblies. The methodology employed one DNB test section of [ ] and the subchannel analysis computer code VIPRE-01. The thermal-hydraulic model for this test section is consistent with the model used in the analysis of the original data. Statistical analyses [

].

CHAPTER 6

REFERENCES

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2. [ ]

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4. Bernard Ostle and Richard Mensing, "Statistics in Research", 3rd ed., Iowa State University Press, 1982.

5. SCR-607, D.B. Owen, "Factor for One-Sided Tolerance Limits and for Variables Sampling Plans", Sandia National Laboratory, 1958.

6. EPRI-NP-2609, "Parametric Study of CHF Data", Vol.2, "Generalized Subchannel CHF Correlation for PWR and BWR Fuel Assemblies", Page 2-38, Project 813, Jan. 1983.

7. EPRI NP-2511-CCM, Rev.2, "VIPRE-01: A Thermal-Hydraulic Code for Reactor Cores"., July 1985.

APPENDIX A

[ ] DNB DATA SUMMARY

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