ENCLOSURE

Evaluation of Westinghouse Report on "Effect on CHF of A Partially Bowed Heated Rod In A Cold Wall Thimble Cell Geometry"

Summary of Report

This report describes tests to determine the effects of a bowed rod on critical heat flux (CHF). The tests were done with a heated rod bowed to 85 percent of the maximum possible closure and the bowed rod was adjacent to a thimble tube. Figure 1 shows the position of the bowed rod relative to the other rods in the bundle and Figure 2 shows the method of maintaining the bowed geometry throughout the test.

The test bundle consisted of 15 electrically heated rods and 1 unheated rod which simulated a control rod guide thimble. The bundle had a non-uniform radial power distribution with the 12 outer rods having less power than the 3 inner rods. The thimble was attached to the grid in the same manner as in a reactor core. The bowed heater rod had its point of maximum bow at the midpoint between the two topmost mixing vane grids, 136 inches above the beginning of the test section heated length. The axial heat flux distribution was, as shown in Figure 3, non-uniform with an approximate u sin u distribution.

The test method consisted of obtaining CHF data on the bowed geometry for inlet conditions which match inlet conditions for the tests in reference 1 (The tests of reference 1 had no intentional bow). The measured-to-predicted critical heat flux ratio ($^M/P$) was obtained for each test and a new parameter, δ_{pB}, was defined such that

$$\delta_{PB} = \frac{\{^M/P\}_{\text{no bow}} - (^M/P)_{\text{BOW}}}{\{^M/P\}_{\text{no bow}}}$$

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The parameter δ_{P8} is a measure of the effect of a partially bowed rod on CHF. δ_{P8} was found to scatter about zero for tests at 1500 and 1800 PSIA but was greater than zero for tests at 2100 and 2400 PSIA. The partial bow parameter was also found to be a function of the mass flux.

The value of the bow effect at a closure of 1.0 is the contact penalty as previously defined(4) at limiting conditions of heat flux and pressure. The bow penalty obtained from the 85% closure data yield values of 11.4% for all loops in service and 14% for the loss of flow accident and for one-loop-out-of-service analyses. Based on data reported by other investigators(3) a bow penalty of zero percent will be used for bow magnitude less than or equal to 50%. Linear interpolation will be used to calculate the bow penalty between 50% and 85% and between 85% and 100% gap closure. The resultant bow penalty as a function of gap closure is shown in Figure 4.

Summary of Staff Evaluation

To obtain reliable CHF data on a partially bowed geometry is an extremely difficult task because of the possible influence of the restraints required to maintain the desired bowed geometry. For this reason, the supports and restraints used by Westinghouse to obtain 85% closure with a bowed rod were analyzed for possible influence on the CHF data.

The thermocouple used to detect CHF at the bow location was at the elevation of maximum bow. The special support grid used to maintain the desired bow was 1/2 inch downstream of the elevation of maximum bow. Simple finning analyses show that the possible finning effects of the support pins in the grid did not extend more than approximately 1/4 inch from the pins. Therefore, there should be no increase in observed CHF due to the influence of the special support grids. There may be some hydrodynamic effects which extended as much as 1/2 inch below the grid but these effects would have resulted in a reduced value of the indicated CHF. Therefore, the Westinghouse method of maintaining the bowed geometry for the tests is acceptable.

The parameter which characterizes the effect of a partially bowed rod on CHF, δ_{PB}, was found to be a function of pressure and mass flux. An attempt to correlate δ_{PB} in terms of the bow penalty for rods bowed to contact resulted in the relation

$$\delta_{PB} = F_{PB} \; (S_{BOW})_{CORR}$$

where $(\delta_{BOW})_{CORR}$ is the bow contact penalty obtained in reference 2. The F_{PB} obtained from this correlation had a correlation coefficient of -0.5. Therefore the F_{PB} correlation reported in the bow report is unacceptable.

The correlation of δ_{PB} with mass flux for the two high pressure data sets gives a much better fit than the F_{PB} correlation. The partial bow correlation corrects all the high pressure data in such a manner that the data is distributed like a repeat set of non-bowed data. This is shown by testing for a significant difference between the corrected data and another, unbowed, data set. The t-statistic for comparing the two means is 0.1435 with 58 degrees of freedom; the probability of a deviation greater than t is between 0.8 and 0.9. Therefore, the partial bow correlation is acceptable.

The use of the data of reference 3 to justify no bow penalty for channel closure less than or equal to 50% is acceptable because the typical cell contact bow results presented were the same as the results for tests conducted on similar Westinghouse geometries. Thus, while critical heat flux is sensitive to differences in test section geometry, the bow effect is not.

Staff Position

The letter report on CHF with partial rod bow provides an acceptable data base for CHF on rods bowed to 85% of the bow necessary for contact. Further, the relation for bow penalty as a function of gap closure, given in Figure 4 is an acceptable bow penalty for use on Westinghouse fuel designs.

References

1. Motley, F.E. and Codek, F.F., "DNB Test Results for R-Grid Thimble Cold Wall Cells", WCAP-7958-A1-A, January, 1975.

2. Nagino, Y., et.al., "Rod Bowed to Contact Departure from Nucleate Boiling Tests in Coldwall Thimble Cell Geometry", Jour. of Nuclear Science and Technology, 15 [8], pp. 568 - 573, August, 1978.

3. Markowski, E.S., et.al., "Effect of Rod Bowing on CHF in PWR Fuel Assemblies", ASME Paper 77-HT-91.

4. Letter, C. Eicheldinger to D.F. Ross, NS-CE-1161, August 13, 1976.

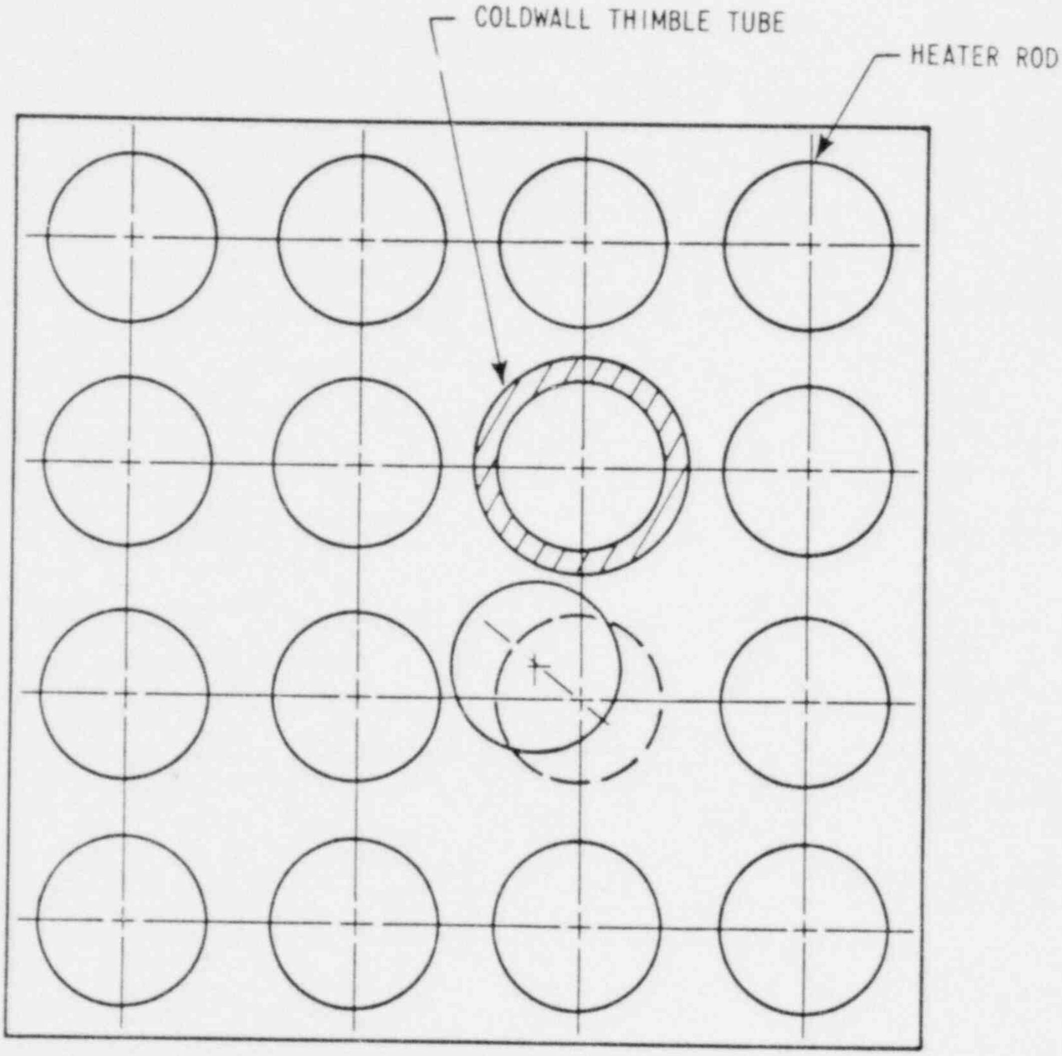

Figure 1 Partial Rod Bow Test Section, 85 Percent Closure

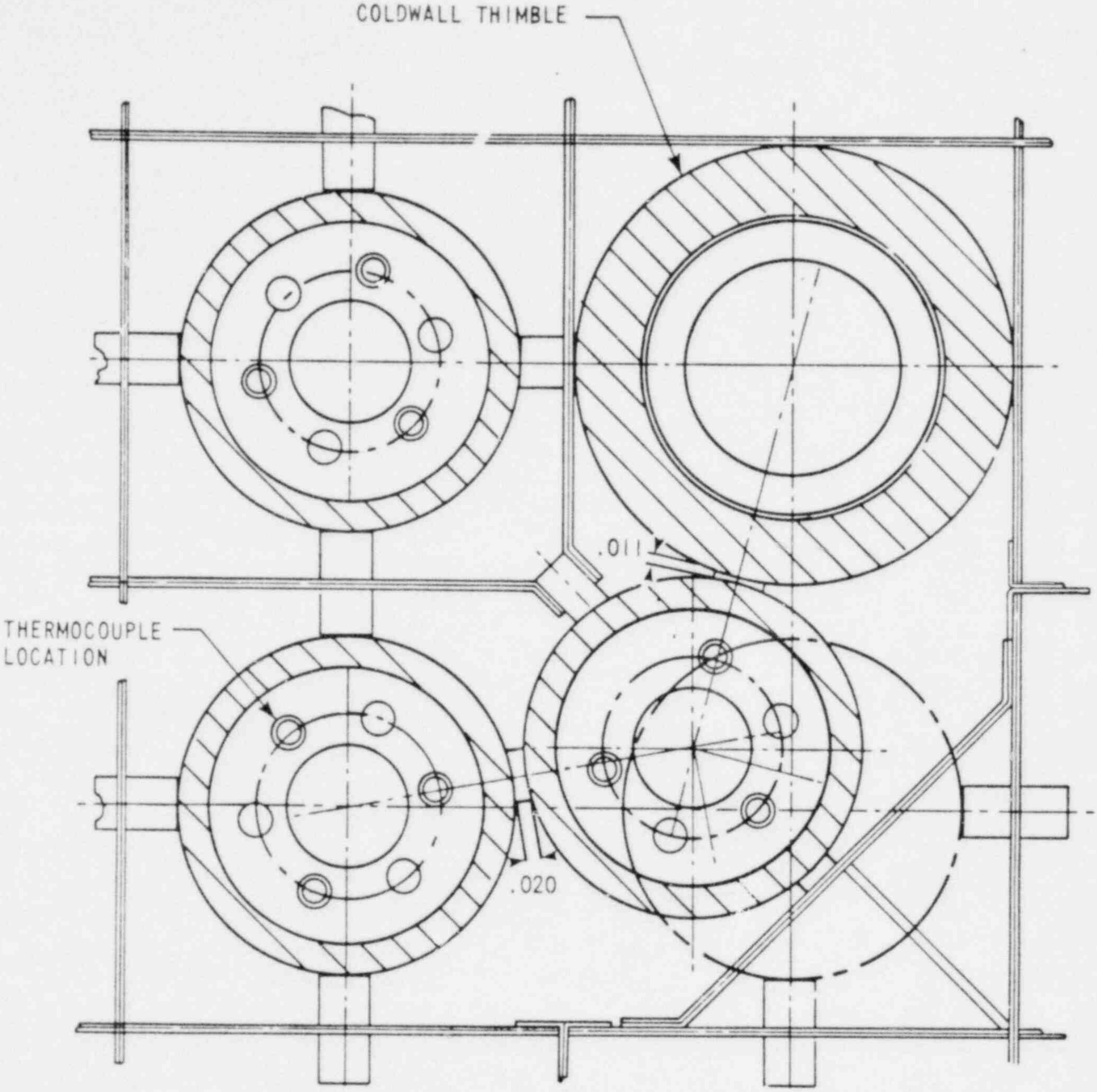

Figure 2 Special Support Grid, 85 Percent Closure

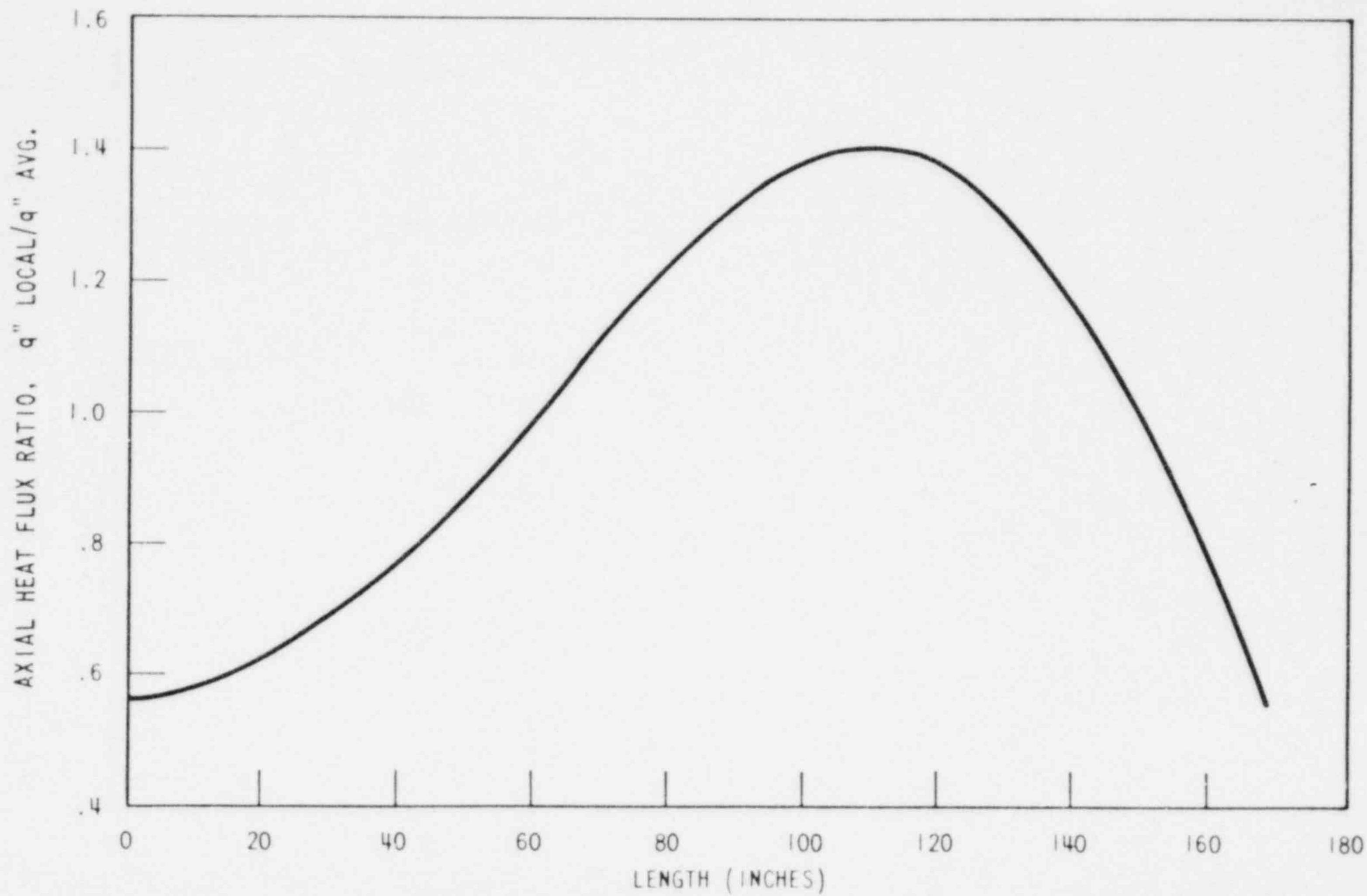

Figure 3 Axial Heat Flux Distribution of 14-Foot Heater Rods

FIGURE 4

ROD BOW DNBR PENALITY VERSUS
FRACTIONAL CLOSURE