Westinghouse Electric Corporation

Water Reactor Divisions

Nuclear Technology Division

Box 355
Pittsburgh Pennsylvania 15230

March 16, 1982

AW-82-12

Mr. James R. Miller, Chief
Special Projects Branch
Division of Project Management
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

APPLICATION FOR WITHHOLDING PROPRIETARY

INFORMATION FROM PUBLIC DISCLOSURE

SUBJECT: "Fuel Rod Bow Evaluation", WCAP-8691, Revision 1 (Proprietary)

REF: Westinghouse Letter No. NS-EPR-2572, Rahe to Miller dated March 16, 1982

Dear Mr. Miller:

This application for withholding is submitted by Westinghouse Electric Corporation pursuant to the provisions of paragraph (b)(1) of 10CFR 2.790 of the Commission's regulations. It applies to the proprietary material transmitted by the referenced letter which responds to NRC questions on the subject topical report.

The affidavit previously provided to justify withholding the proprietary information in the subject topical report, AW-76-35, a copy of which is attached, is equally applicable to this material. The referenced affidavit was submitted by Westinghouse letter No. NS-CE-1161, Eicheldinger to Stello, dated August 13, 1976.

Accordingly, it is requested that the subject Westinghouse proprietary material be withheld from public disclosure in accordance with the provisions of 10CFR 2.790 of the Commission's regulations.

Correspondence with respect to the proprietary aspects of this application for withholding or the accompanying affidavit should reference AW-82-12 and should be addressed to the undersigned.

Very truly yours,

Robert A. Wiesemann

Robert A. Wiesemann, Manager
Regulatory & Legislative Affairs

/kk
Attachment

cc: E. C. Shomaker, Esq.
Office of the Executive Legal Director, NRC

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared Robert A. Wiesemann, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Corporation ("Westinghouse") and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

Robert A. Wiesemann, Manager
Licensing Programs

Sworn to and subscribed before me this 3 day of August 1976.

Notary Public

[illegible] EXPIRES [illegible] 15, 1978

(1) I am Manager, Licensing Programs, in the Pressurized Water Reactor Systems Division, of Westinghouse Electric Corporation and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing or rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Water Reactor Divisions.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse Nuclear Energy Systems in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned by Westinghouse and by other parties and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(g) It is not the property of Westinghouse, but must be treated as proprietary by Westinghouse according to agreements with the owner.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition in those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information is not available in public sources to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in the attachment to Westinghouse letter number NS-CE-1161, Eicheldinger to Stello, dated August 13, 1976, concerning information relating to NRC notification, under 10 CFR 50.59(a) and 10 CFR 50.55(e), of generic problems on increased temperature in the upper head and DNB penalty associated with rod bow. The letter and attachment are being submitted in response to the NRC request at the August 9, 1976 NRC/Westinghouse meeting.

This information enables Westinghouse to:

(a) Justify the Westinghouse design correlations.

(b) Assist its customers to obtain licenses.

(c) Meet warranties.

(d) Provide greater flexibility to customers assuring them of safe and reliable operation.

(e) Optimize performance while maintaining high level of fuel integrity.

Further, the information gained from the rod bow program is of significant commercial value as follows:

(a) Westinghouse uses the information to perform and justify analyses which are sold to customers.

(b) Westinghouse sells testing services based upon the experience gained and the test equipment and methods developed.

Public disclosure of this information concerning DNB penalty associated with rod bow is likely to cause substantial harm to the competitive position of Westinghouse because competitors could utilize this information to assess and justify their own designs without commensurate expense.

The tests performed and their evaluation represent a considerable amount of highly qualified development effort. This work was contingent upon a DNB development and testing program which has been underway during the past four years. Altogether, a substantial amount of money and effort has been expended by Westinghouse which could only be duplicated by a competitor if he were to invest similar sums of money and provided he had the appropriate talent available.

Further the deponent sayeth not.

QUESTION 8

In the det- -ation of a DNBR penalty, only single rod displacement configurations are employed. What is the effect of multiple rod displacements and gap closures on the DNBR penalty function and how is this effect accounted for?

RESPONSE

To obtain the DNR penalty, the lesser of the residual gaps between the hot rod and its neighbors in the hot channel is used (see also response to Question 33). The increase in the magnitude of the penalty from 85% closure to contact and the absence of any penalty for moderate (50%) closures imply: 1) the effects of the absence of any penalty for moderate (50%) closures imply: 1) the effects of gap reduction are dominant, and 2) the effects of subchannel flow area reduction are negligible. Localized enthalpy increases or mass velocity changes would not result in the magnitude of penalties observed in the DNB tests.

The results of the three configurations of contact testing described in the response to Question 55 imply no superimposition of CHF effects of multiple closures on the same rod. As there is no effect on CHF for an unheated rod in contact with a heated rod, a superimposition effect would have resulted in Bow Test 1 showing a larger CHF effect than Bow Test 2. As the results of these two tests are essentially the same, such an effect is ruled out.

Question 9. Several conservatisms have been identified in the bowing analysis including (1) selection of the maximum span bowing and (2) neglect of rod power reduction on DNBR, etc. List known conservatisms in the bowing analysis of power peaking and DNBR and give estimates of their magnitudes.

Response:

Note: All quantitative estimates given in items 2 through 6 are absolute reductions in the DNBR penalty, not percent reductions in the magnitudes.

1) The use of Equation (5-1) rather than the relationships given in Appendix B results in a 0 - 15% closure conservatism.

2) Coolant pressure and hot rod average heat flux are set at their maximum values to calculate the rod bow DNBR penalty at contact. The penalty calculations for .422 inch rods were repeated using the contact penalty at nominal conditions. The results indicate a 1.65% decrease in the rod bow DNBR penalty at a burnup of 33,000 MWD/MTU. Similar results would be expected for .374 inch rods.

3) The use of more realistic local mass velocities would reduce the low flow and full flow DNBR penalties at 33,000 MWD/MTU by about 0.25%.

4) The use of best estimate $\sigma_{closure}$ correlations would reduce the DNBR penalties at 33,000 MWD/MTU by 2.4 - 2.6% for .422 inch rods and 1.7 - 2.3% for .374 inch rods.

5) The worst span bow for each assembly is used to obtain the $\sigma_{closure}$ correlations. In many cases the worst span is in the lower regions of the assembly, where the minimum DNBR is not likely to occur. The conservatism inherent in this approach may be estimated by comparing the worst span results with those obtained from spans where DNB is more likely to occur. With this in mind, an upper 95/95 limit on $\sigma_{closure}$ for span 6 was obtained for .374 inch rods. The results indicate a rod bow DNBR penalty of less than 0.15% at 33,000 MWD/MTU for the WRB-1 and R-grid correlations at full and low flow conditions.

6) An upper 95/95 limit is used for the K factor in Equation (5-8) to determine the limit DNBR including the effect of rod bow. The use of a best estimate 95 percent tolerance limit would reduce the full flow and low flow rod bow DNBR penalties at 33000 MWD/MTU by 0.7% for the WRB-1 correlation, 2.4% for the R-grid correlation and 3.0% for the L-grid correlation.

7) Rod bowing conservatisms used in the power peaking portion of WCAP-8691, Rev. 1, are the burnup assumed, the boron concentration used, and the scattering cross section set assumed (P_0 vs. P_1). Estimates of their magnitude are listed in the table attached to the reply to Question #27.

   The best estimate burnup would reduce the reference rod power increase (2.83%) by .15%. Best estimate boron concentrations would reduce this reference increase by .20%. The use of P_1 vs. P_0 would reduce this increase by another .83%. These are, however, offset by small non-conservatisms of spectrum and enrichment (see #27). The reference lattice (15x15) has a single event power peak of [ ]^{a,c} compared to the reference value of 2.83% for 3.4 w/o fuel.

QUESTION 10

In the determination of the effects of rod bowing on local rod powers, the effect of poison rod bowing has been neglected. Describe in detail the effects of poison rod bowing and incorporate this effect into the F_Q^B and DNBR penalties?

ANSWER

Westinghouse feels that for burnable poison rodlets (BPs), the effect of poison rod bowing is negligible in respect to the effect of rod bowing.

Westinghouse places its BPs inside of the zirc-guide thimbles. If the burnable poison rodlet did bow within this thimble the bowing would be restrained to the guide thimble inner diameter. This area surrounding the BP is already an area of lower power and any corresponding change in power would tend to be annealed by burnup. As the BP depletes during cycle burnup, the effects of BPs with fuel rod bowing would be similar to the effects of a thimble cell rod already discussed in WCAP-8691, Revision 1.

These effects apply to non-integral BPs which are inserted into thimbles occupying a single fuel rod pitch. Other types of burnable poisons have not yet been addressed.

In the determination of $\hat{\sigma}\ (\frac{m}{p})$ on p. 5-6 of WCAP-8691 (Rev. 1), the error introduced by the regression analysis of the experimental data as defined in Reference 1 has been neglected. Therefore, determine this additional uncertainity and include it in the DNBR penalty.

RESPONSE

The value of the unbiased estimate of the standard deviation of the DNB data distribution $\hat{\sigma}(m/p)$ is determined from the DNB data using the relationships given on p. 5-6 of WCAP-8691 (Rev. 1). This value includes the error introduced by the regression analysis of the experimental unbowed rod DNB data; the p in the term m/p being the DNB heat flux value predicted from the appropriate DNB correlation.

A letter from T. M. Anderson to J. F. Stolz dated March 16, 1979, is included as the second part of Appendix H of WCAP-8691 (Rev. 1). On page 6 of that letter, the result of a statistical test using the Student's t distribution is summarized. This result verified that the m/p distributions for unbowed rod DNB data and for partially bowed rod DNB data (corrected using the partial rod bow correlation) can be considered as being obtained from the same DNB population. Consequently, no additional regression analysis error need be considered in the procedure shown on pp. 5-6ff. To obtain the limit DNBR value including the effect of rod bow, as this effect has been included in carrying out the original regression analysis leading to the DNB correlation used.

QUESTION 27

Are the calculated power peaking sensitivities to rod-bow conservative with respect to all fuel designs? If not, identify the non-conservative designs and explain in detail how this non-conservatism is properly accounted for in the proposed analysis.

ANSWER

WCAP-8691, Revision 1, is applicable to 14x14, 15x15, 16x16, and 17x17 fuel design as stated in Appendix F. The power peaks for the 17x17 were lower than those referenced in Figures F-1, F-2 and F-3 but the higher values were used in the bowing power change calculations.

The ISER had already evaluated the applicability of Westinghouse methods and concluded that:

> "The net results of these studies is that the base 15x15 calculation results serve as a suitably conservative representation of the peaking factor changes for the full range of reactor conditions of interest."

The following table shows the effect of various parameters and their approximate sensitivities to power peaking for all present Westinghouse fuel designs including Westinghouse designs of Combustion Engineering (CE) 14x14 and 16x16 fuel types. This table relates the reference single event peak increase of 2.83%, the 3.04 w/o enrichment, the 22000 MWD/MTU burnup, 0 ppm boron concentration to the fuel types and an assumed 3.4 w/o enrichment.

This table shows that for all fuel types there is conservatism encompassed by using the reference rod power increase in the single power event calculations as input to the DRAW code. The combination of the burnup, boron, and P_0 vs P_1, sensitivities provide margin for perturbed spectrum, higher enrichment and lattice changes. Thus, the calculated power peaking sensitivities to rod bow are applicable to all Westinghouse fuel designs.

Also, in CE-type fuel lattices, the guide tube water holes in an assembly each displace four fuel rods. As with Westinghouse type thimble cell rods (see Section F.5, WCAP-8691, Rev. 1), the single event power change on a rod near this guide tube due to the bow of surrounding rods, is slightly greater than on a rod completely surrounded by fuel rods. However, the power change on a rod near this guide tube due to its bow is likewise more negative than a rod completely surrounded by fuel rods. Also, near guide tubes there are 4 less rods near the center rod that can contribute to the total power change. As a result, the net power increase on rods near guide tubes are less than on rods completely surrounded by fuel rods.

Also, see answer to Question #9.

QUESTION 26

Describe in detail the application of the proposed rod bow analysis to a typical plant, including the input parameters and their basis (either explicitly or by reference) and the equations and figures (appropriately referenced) used to determine both the DNBR and F_Q^B penalties. Indicate what parameters are plant and cycle dependent.

RESPONSE

As noted in the response to Question 26, in most cases a plant specific calculation would not be required if a penalty for the fuel type used were available and if the maximum hot rod average heat flux, pressure and minimum mass velocity were within the ranges covered. The effect of different fuel assembly designs on F_Q^B is not plant or cycle dependent beyond the effect of different fuel assembly designs addressed in the response to question 27.

For the sample case of a RESAR-3S type plant (i.e. 17x17 standard fuel, R-grid DNB correlation), the DNBR penalties indicated in Figure 2 of the response to Question 33 would apply. A RESAR-3S type DNB analysis would contain conservatisms which would result in "generic" margins previously identified (see discussion in Reference 3 of WCAP-8691, Rev. 1) due to pitch reduction, corservative DNB correlation coefficients (e.g. TDC), and limit DNBR. The total margin for RESAR-3S type analysis has been quantified at 9.1% DNBR. Since this value exceeds the penalties calculated over the burnup ranges of concern, no additional margin would be required. If the generic margins were insufficient to cover the penalties, plant/cycle specific reductions in allowable $F_{\Delta H}$ could be required if no other source of plant/cycle margin were available (e.g. excess flow, low operating temperature, other plant specific analytical conservatisms). Excess DNBR penalty has been historically converted to $F_{\Delta H}$, penalty by the relation:

1.8% DNBR penalty = 1% $F_{\Delta H}$, penalty

For the sample case of the type of plant analysis described in WCAP-9500 (Reference Core Report - 17x17 Optimized Fuel Assembly) several features are different. The amount of rod bow for the OFA is expected to be less in that of standard 17x17 fuel (see Section 4.2.3.1-7 of WCAP-9500). Using the same tolerance limit .374-inch rod bow correlation, the DNBR Penalties from Figure 1 of (WRB-1/.374-inch rod) the response to Question 33 would apply. The source of DNBR margin would be the difference between the design DNBR value and the value used in safety analysis as part of the Improved Thermal Design Procedure (See Section 4.4.11 of WCAP-9500). If this difference were insufficient to cover the penalties, the same scenario identified above for the RESAR-3S sample case to account for excess penalty would apply.

The Figures for total power peaking factor uncertainty (Figure 6-1 of WCAP-8691, Rev. 1 and Figure 3 of the response to Question 33) represent the minimum acceptable values to account for nuclear power distribution uncertainty, engineering heat flux hot channel factor, and rod bow power peaking effects. In practice the product of the first two of these has been used in the evaluation and measurement of total power peaking factor, F_Q. See for example the discussion of F_Q uncertainties contained in NUREG-0452, Rev. 2 (Standard Technical Specifications for Westinghouse Pressurized Water Reactors), Surveillance Requirement 4.2.2.3 (p. 3/4 #2-6). This product (1.05 x 1.03 = 1.0815) exceeds all values shown in the figures noted above.

For a competitor reload design, the rod bow effects on DNBR and F_Q would be addressed on a plant specific basis via the Basic Safety Report. For the sample case of the Westinghouse Model C reload for Millstone Unit 2, the new methodology would be employed as follows:

1) Use L^2/I scaling of the (hot) tolerance limit closure correlation for .422 inch rods and apply the methods of Section 5.2 to obtain the rod bow DNBR penalty.

2) Use the scaled closure correlation in the conjunction with Figure F-8 of WCAP-8691 Rev. 1 to obtain F_Q^B as a function of burnup; statistically combine F_Q^B with F_Q^E and F_N^U as described in Section 6-2.

These calculations have been performed for the Model C fuel as 33,000 MWD/MTU, the maximum burnup of concern. Applying the L^2/I scaling factor of 0.4366 to the (hot) .422 inch tolerance limit correlation in Table 6-1 of WCAP-8691 Rev. 1 gives a channel closure standard deviation of [ ]$^{+a,c}$ at this burnup. The corresponding rod bow DNBR penalty can be found by determining the burnup at which the .422 inch rods attain this value. Since the channel closure standard deviation for .422 inch rods exceeds this value at all burnups and Figure 6-4 indicates no penalty at zero burnup, the Model C reload fuel would not require a rod bow DNBR penalty.

The synthesis of the total peaking factor (F_Q^T) for the Model C fuel is described in WCAP-9660 (Basic Safety Report - Millstone Nuclear Power Station Unit 2). The resulting equation is given as:

$$F_Q^T - \max\ [F_{xy}^N(z) \times P(z) \times S(z)] \times U$$

where,

$F_{xy}^N(z)$ = ratio of peak power density to average power density in the horizontal plane at elevation z.

$P(z)$ = ratio of the power per unit core height in the horizontal plane at elevation z to the average value of power per unit core height.

$S(z)$ = the allowance made for densification effects at height z in the core.

U = The uncertainty factor, defined in WCAP-9660 as

$$= F_U^N \times F_Q^E$$

where

F_U^N = the measurement-prediction uncertainty associated with the TURTLE model and INCA power distribution measurements.

F_Q^E = the engineering heat flux hot channel factor which accounts for manufacturing variations.

The minimum acceptable value for the total power peaking factor uncertainty would be:

$$U = 1 + \sqrt{(F_U^N - 1)^2 + (F_Q^E - 1)^2 + (F_Q^B - 1)^2}$$

Figure F-8 indicates tha the calculated channel closure standard deviation at 33,000 MWD/MTU would result in a rod bow peaking factor uncertainty of [ ]$^{+a,c}$. Convoluting this value with the measurement-prediction uncertainty of 7% (see WCAP-9660, Addendum 1) and the engineering heat flux hot channel factor of 3% (see WCAP-9660) gives a total power peaking factor uncertainty of [ ]$^{+a,c}$. This value is less than the total uncertainty as currently defined.

The above sample discussions are intended as respresentataive examples and not generic doctrine. Alternative sources and applications of margins may occur on a plant/cycle specific basis, although to date use of generic margins to offset bow penalties has been the established trend. An example of such a variation may be to demonstrate that sufficient DNBR exists in those DNBR analyses at reduced flow (loss-of-flow transient or one loop out of service operation) to offset the incremental low flow DNBR penalty over that shown for high flow.

QUESTION 30

Describe the surveillance procedures and other measures that will be used to confirm and update when necessary the rod bowing data base and analysis.

RESPONSE

The extensive rod bowing data base as reported in WCAP-8691, Rev. 1 is considered to be sufficient to confirm the validity of the results and conclusions contained therein.

There is a fuel surveillance inspections program for several 17x17 plants to verify satisfactory fuel performance. There is also a high burnup program on-going to assess general fuel performance at higher burnups. Data from these programs will be used to confirm the validity of the proposed gap closure correlation.

QUESTION 31

Since Reference 1 required and L/I rod bow scaling, unless the proposed scaling was supported with data, either (1) justify the use of the L^2/I scaling with measured data, (2) demonstrate that it is conservative, or (3) account for the error introduced by this assumption in the rod bowing penalties.

RESPONSE

At the time Reference 1 was issued, there was no available data on 17x17 fuel designs supporting the proposed L^2/I scaling factor. Channel closure data obtained later from the 17x17 demonstration assemblies (7 grids) and from 17x17 standard assemblies (8 grids) enabled Westinghouse to validate span length dependence. As discussed in Appendix D of WCAP-8691, Rev. 1, the comparison of these data supported a second power span length dependence. Thus, analytical mehtods and actual rod bow data support the L^2/I scaling factor.

Fuel Design Parameters			Reference Rod Power Increase (%)	Adjustments for Parameter Sensitivity[1] to Obtain Best Estimate Power Increase (%)						Net Rod Power Increase for 3.4 w/o Fuel (%)
Fuel Type	Fuel Rod OD (in)	Fuel Rod Pitch (in)		Lattice Adjustment	Burnup	Boron	P_0 vs P_1	Spectrum	Enrichment	
							+(a,c)			+(a,c)
14x14	.422	.556	2.83				- .83	+ .17	+ .07	
14x14 OFA	.400	.556	2.83				- .83	+ .17	+ .07	
16x16	.374	.485	2.83				- .83	+ .17	+ .07	
15x15	.422	.563	2.83				- .83	+ .17	+ .07	
17x17	.374	.496	2.83				- .83	+ .17	+ .07	
17x17 OFA	.360	.496	2.83				- .83	+ .17	+ .07	
E[2] 14x14 Millstone 2)	.440	.580	2.83				+ .83	+ .17	+ .07	
16x16	.382	.506	2.83				- .83	+ .17	+ .07	

1) Lattice Adjustment - changes to account for pitch and H/U
Burnup - Peak rods would generally occur at 11,000 MWD/MTU.
Boron - Peak rod Power for the cycle would usually occur at BOL, 1000 ppm.
Po vs P_1 - P_1 is more detailed analysis.
Spectrum - Bowed configuration spectrum raises peaking.
Enrichment - Higher enrichment raises peaking.

2) Westinghouse design of CE fuel type.

QUESTION 33

In the determination of the fuel rod DNBR penalty, the bowing of the eight surrounding rods and associated gap closures determine the reduction in DNBR margin. The penalty for each gap is determined by summing over the contributions from each possible closure. The closure contribution is given by the product of the probability of occurrence for that closure and the associated closure penalty. (In Reference 1 this method was used to determine the penalty arising from the bowing of two rods on opposite sides of the rod of interest.) Therefore, update the bowing analysis to include the contribution to the DNBR penalty from all eight surrounding rods.

RESPONSE

Westinghouse has updated the .374 rod bow correlations presented in WCAP-8691, Rev. 1 to include additional data obtained since submittal of the topical. Based on the evaluation described in Attachment I, the following relations were obtained:

A. Best Estimate

$$S_{be} = [\qquad]^{+} + [\qquad]^{+} \times BU \qquad (a,c)$$

B. Tolerance Limit

$$S_{w} = [\qquad]^{+} + [\qquad]^{+} \times BU \qquad (a,c)$$

where, S_{be} = best estimate standard deviation of percent channel closure for the worst span of each assembly

S_w = upper 95 percent tolerance limit for the standard deviation of percent channel closure for the worst span.

BU = assembly average burnup (10^3 MWD/MTU)

After application of a cold-to-hot multiplier of 1.2, the tolerance limit curve was used to calculate rod bow DNBR penalties as described in Section 5.2. The resulting penalties for the WRB-1 and R-grid correlations are shown in Figures 1 and 2, which supersede Figures 6-2 and 6-3 of WCAP-8691, Revision 1.

The total power peaking factor uncertainty resulting from the use of the new correlation is shown in Figure 3, along with the curve it replaces from Figure 6-1.

Section 5.2 of WCAP-8691 (Revision 1) describes the "worse-of-two gaps" approach used to calculate the rod bow DNBR penalties. This approach is consistent with the Westinghouse philosophy of designing to the highest power rod in the most limiting flow channel of the core.

The method suggested in Question 33 for calculating DNBR penalties is overly conservative and not consistent with experimental results. The nominal distance from the hot rod to its diagonal neighbors is 2 1/2 times greater than the distance to its closer neighbors. Hence, the probability of the gap to one of the diagonal neighbors being smaller than the minimum gap to the closer neighbors is negligible, and the effect of bowing of the diagonal neighbors may be ignored in the penalty calculations. Secondly, the results of the bowed-to-contact CHF tests indicate no superposition effects for multiple closures (see response to Question 8). Therefore, the correct approach is to assign the DNBR penalty associated with the largest gap closure between the hot rod and its closer neighbors.

Westinghouse has repeated the rod bow DNBR penalty calculations using the "worst-of-four gaps" approach to quantify the impact of including the effect of the two neighboring rods which are outside the hot channel. Figures 4 through 6 show the resulting penalties. These calculations are overly conservative in that they assume that all four flow channels surrounding the hot rod are equally limiting hot channels. It is Westinghouse's position that the magnitude of the conservatisms listed in the response to Question 9 are more than adequate to account for the actual effects of bowed rods outside of the hot channel and consequently, that Figures 1-3 based on the "worse-of-two" procedure can be used to quantify the DNBR penalties associated with rod bow.

FIGURE 1 ROD BOW DNBR REDUCTION AS A FUNCTION OF FUEL ASSEMBLY AVERAGE BURNUP, BASED ON GAP CLOSURES BETWEEN THE HOT ROD AND ITS CLOSEST NEIGHBORS IN THE HOT CHANNEL (0.374 ROD, HRB-1)

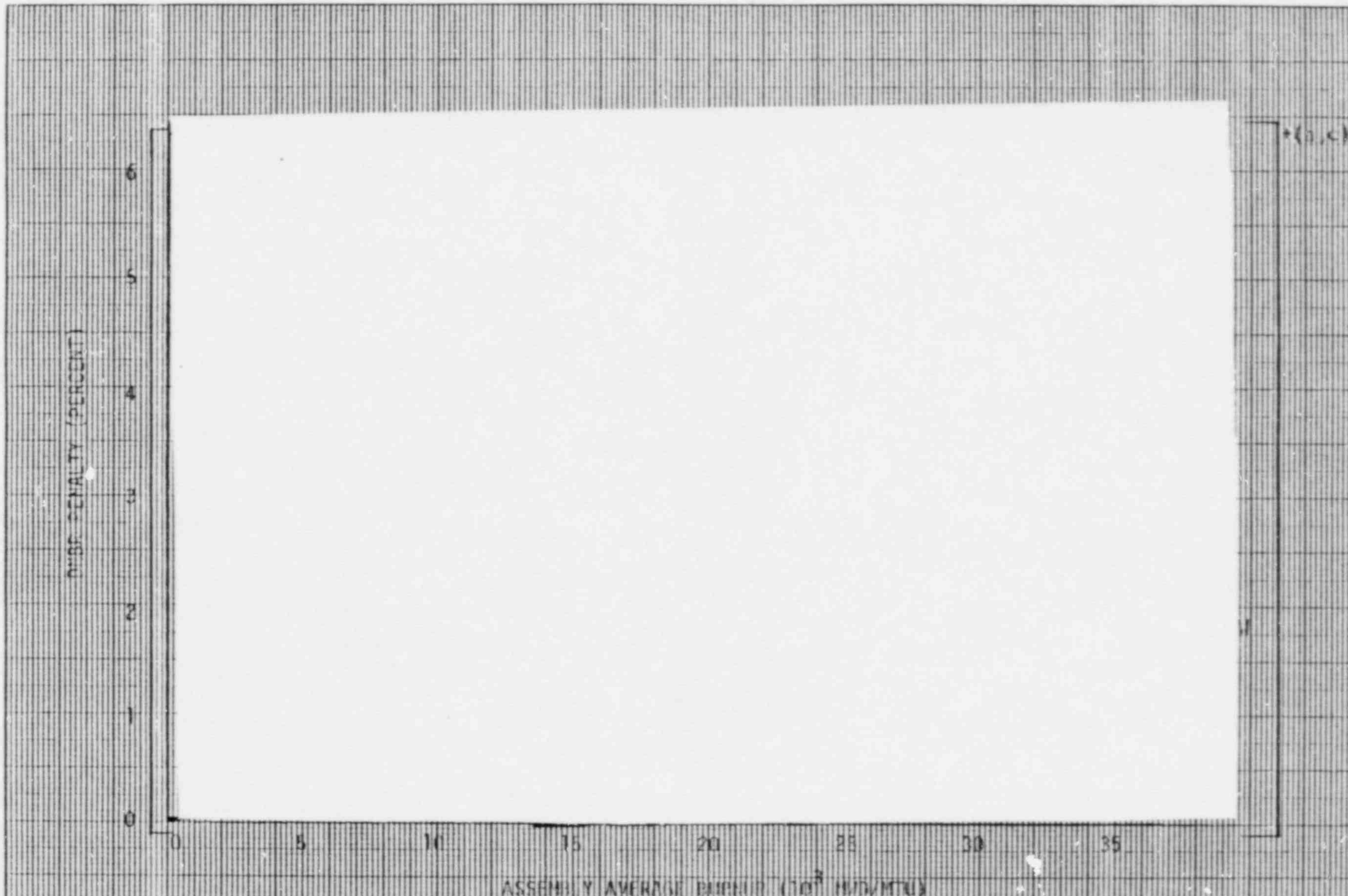

FIGURE 2 ROD BOW DNBR REDUCTION AS A FUNCTION OF FUEL ASSEMBLY AVERAGE BURNUP, BASED ON GAP CLOSURES BETWEEN THE HOT ROD AND ITS CLOSER NEIGHBORS IN THE HOT CHANNEL (0.374 ROD, R-GRID)

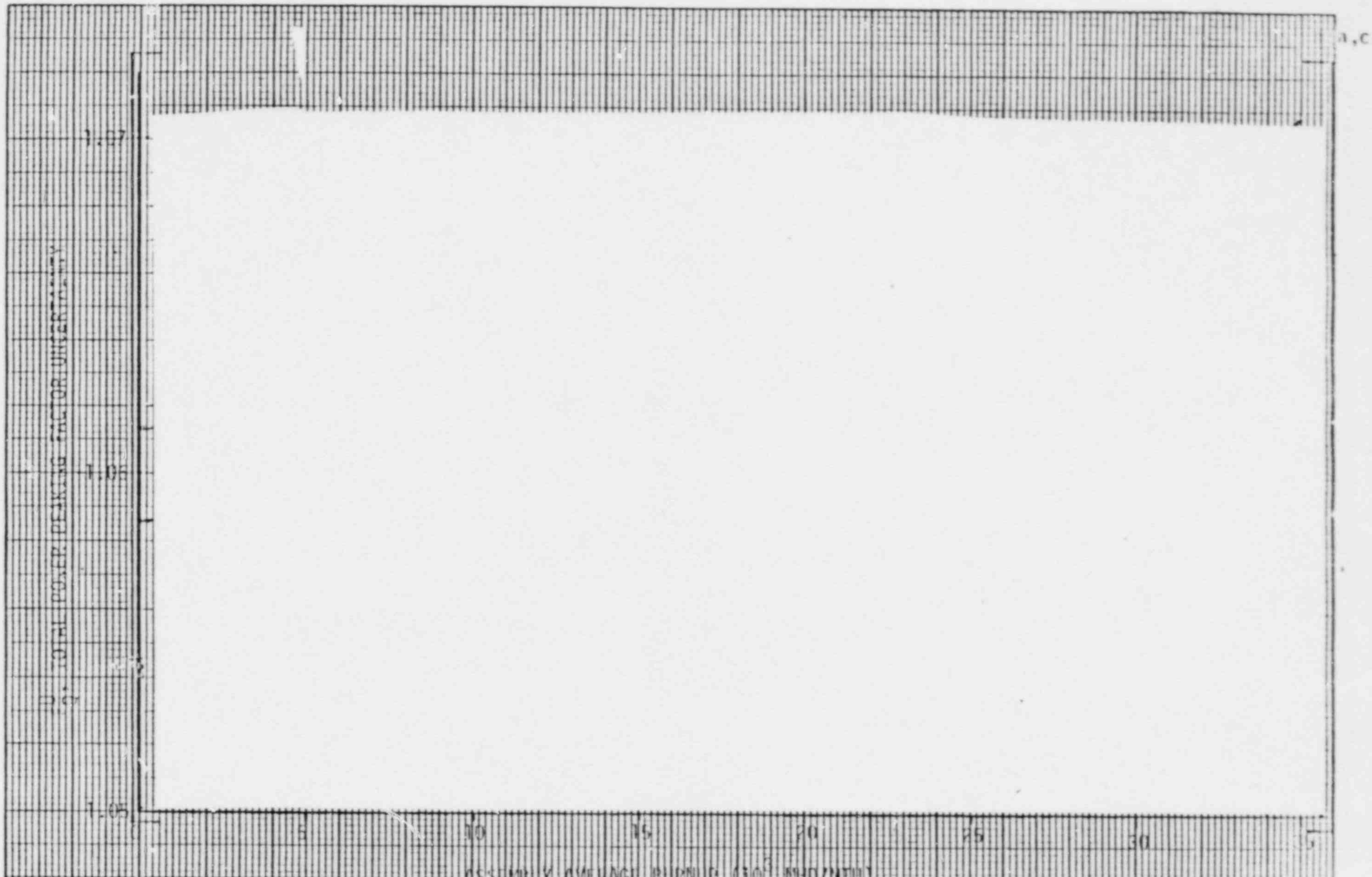

FIGURE 3. TOTAL POWER PEAKING FACTOR UNCERTAINTY (INCLUDING ROD BOW) VERSUS ASSEMBLY AVERAGE BURNUP FOR 0.374 INCH RODS

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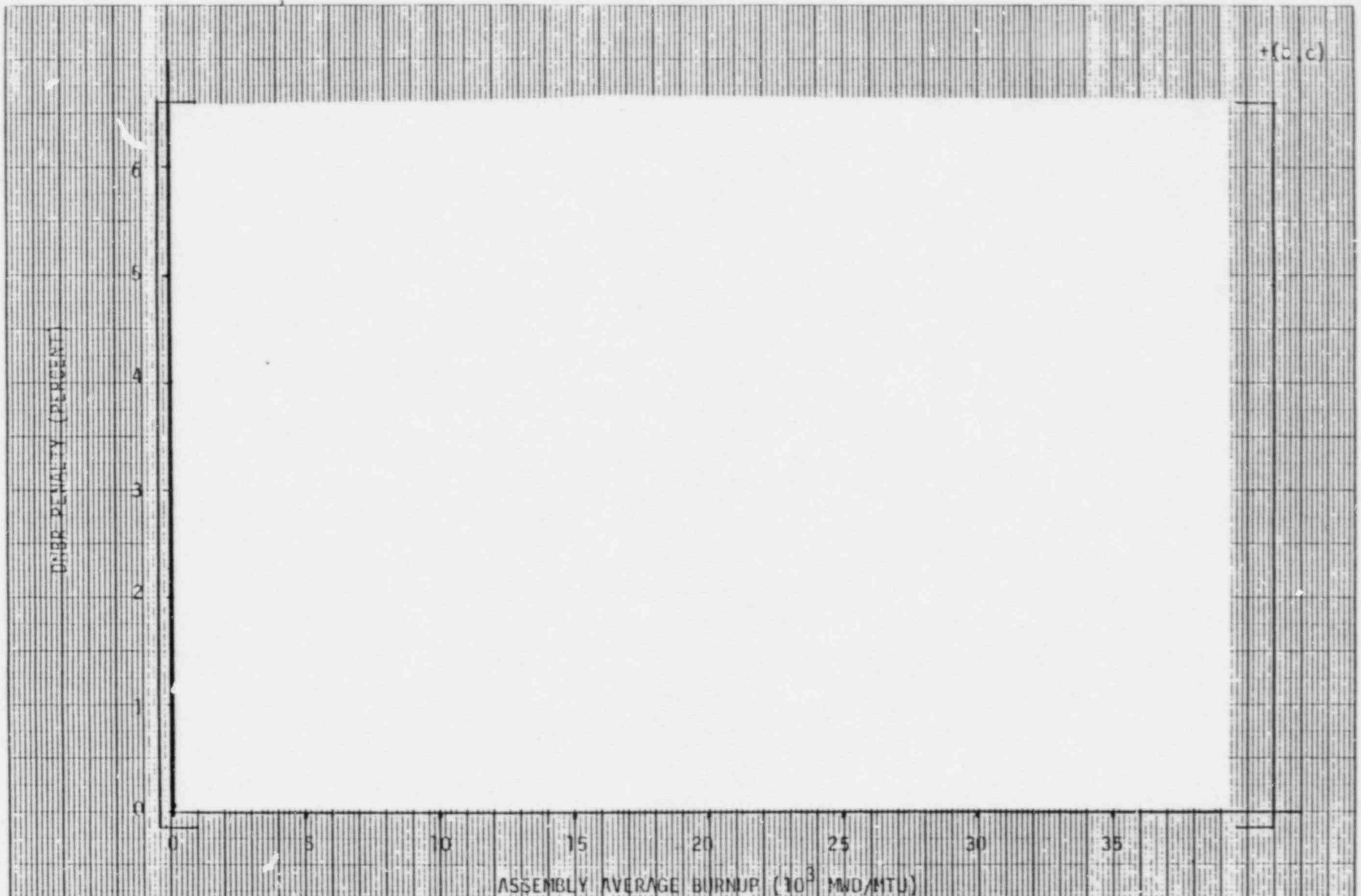

FIGURE 4 Rod Bow DNBR Reduction as a Function of Fuel Assembly Average Burnup, Including Gap Closures Between the Hot Rod and Neighboring Rods Outside the Hot Channel (0.374-inch Rod, WRB-1)

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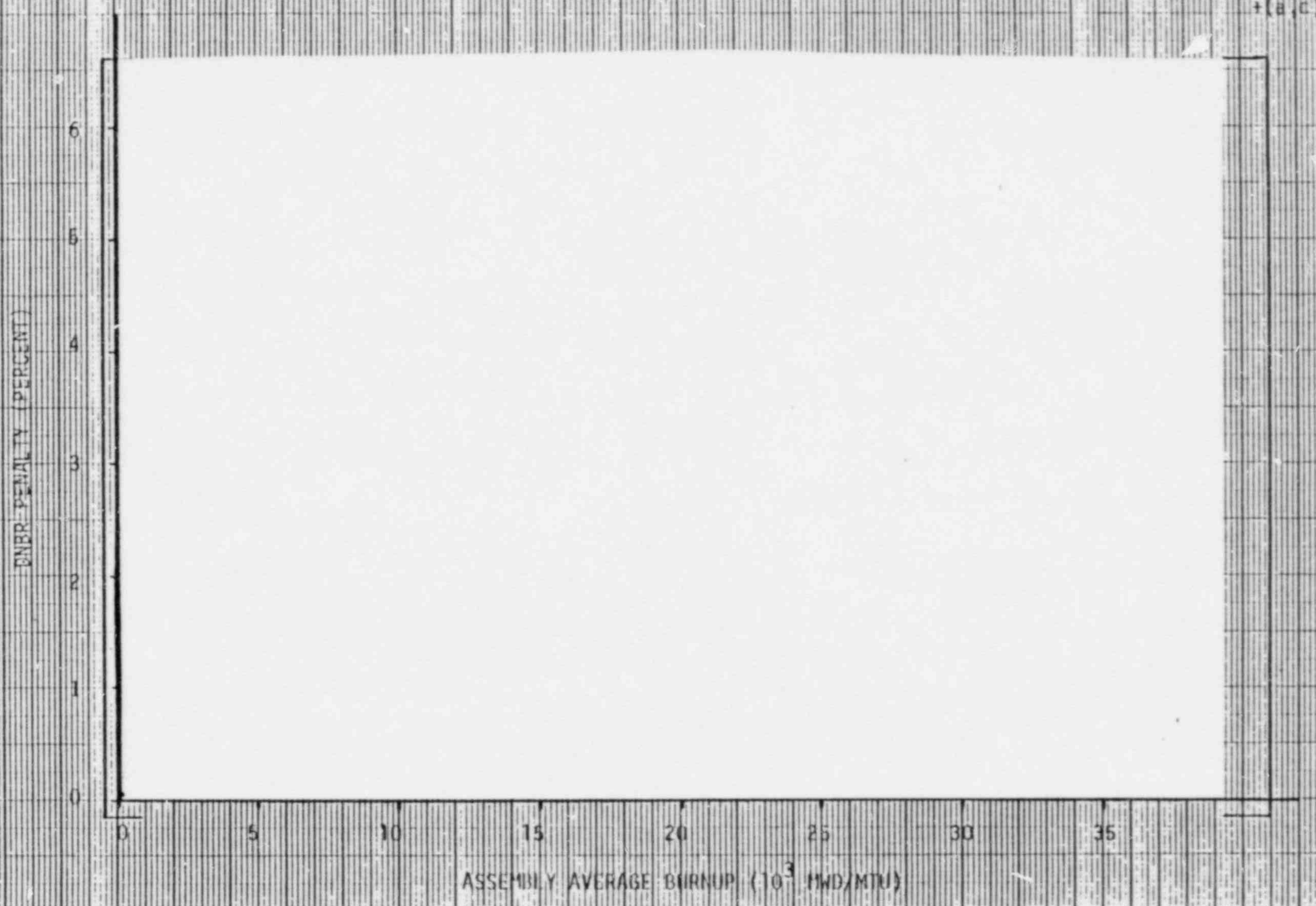

FIGURE 8 Rod Bow DNBR Reduction as a Function of Fuel Assembly Average Burnup Including Gap Closures Between the Hot Rod and Neighboring Rods Outside the Hot Channel (0.374-inch Rod, R-GRID)

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KEUFFEL & ESSER CO.

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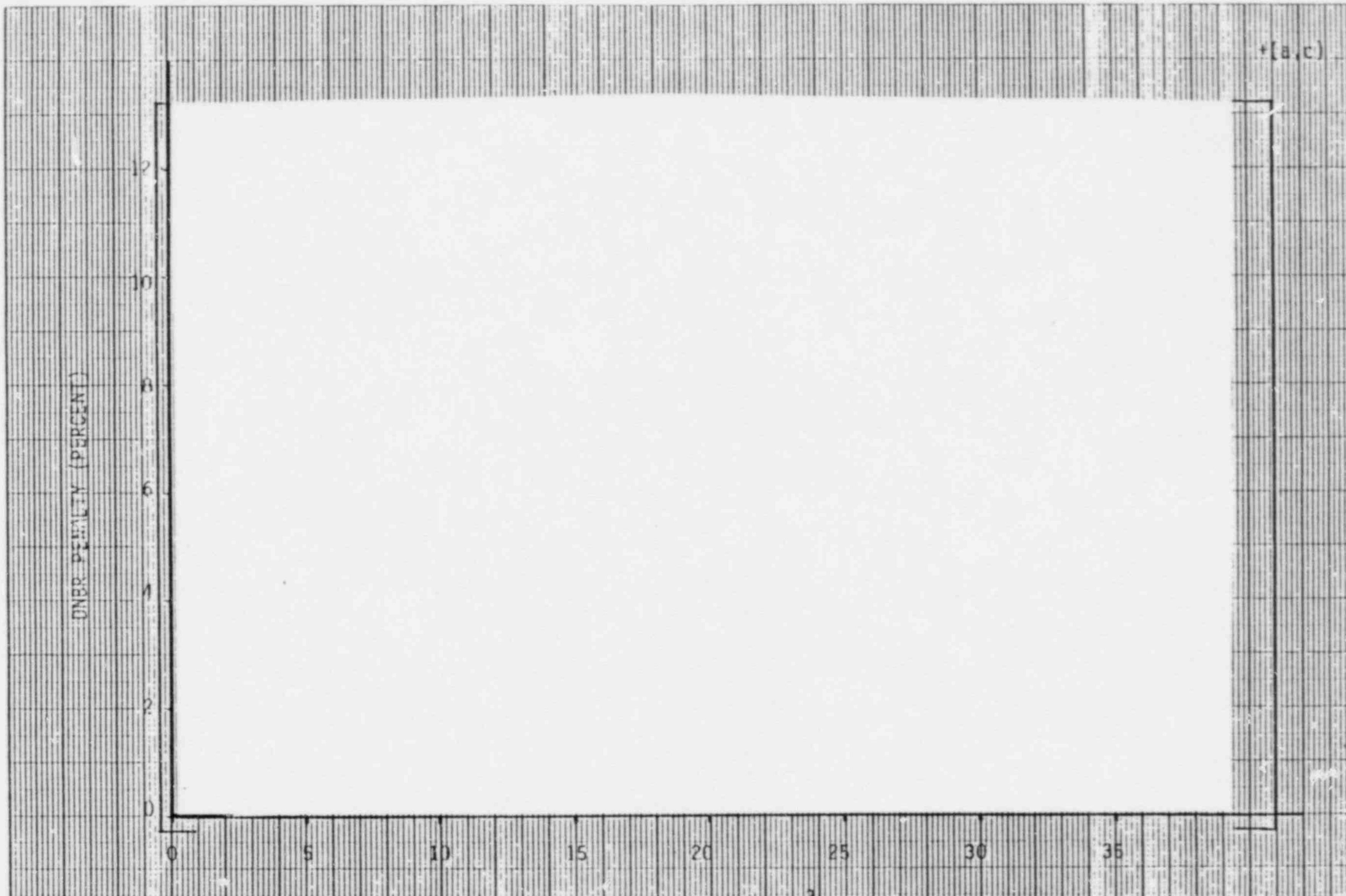


FIGURE 6 Rod Bow DNBR Reduction as a Function of Fuel Assembly Average Burnup, Including Gap Closures Between the Hot Rod and Neighboring Rods Outside the Hot Channel (0.422 inch Rod, L-grid)

QUESTION 36: Large assembly bow on the order of hundred of mils has recently been measured at several plants.[2),3),4)] This bow is of concern because (1) the bow magnitude is at least an order of magnitude larger than the reported rod bow measurements, (2) the resulting rod bow is apparently extremely correlated with all rods in an assembly face bowing together, and (3) the bow involves inter-assembly gap closure. All of these aspects are outside the scope of the proposed bowing analysis. Therefore, discuss in detail the effects of assembly bow on fuel rod gap closure and the assumptions and methods used to evaluate rod bowing.

RESPONSE: The inpile assembly displacement cannot be as great as observed out of pile due to the constraint imposed by the upper and lower core plate guide pins as well as the contact of the outer grid straps of adjacent assemblies and the baffle. Assembly bow may increase the time required for removal and refueling of fuel assemblies. Although assembly bow has been generally considered by utilities and refueling personnel as an inconvenience and annoyance, assembly bow has not been the controlling factor in critical path refueling schedules, nor a primary concern of the refueling operators. Further, no fuel performance or operational problems have been associated with assembly bow. Fuel shuffling and refueling difficulties have been satisfactorily resolved through use of different handling techniques during core loading which have minimized delays to acceptable levels.

Listed in Table 1 are nominal dimensions for several Westinghouse fuel designs. Also shown are the inter-assembly edge rod gaps for assemblies bowed to grid strap contact. For all designs, the edge rod gap would be reduced to slightly less than the nominal gap if assemblies bow to grid strap contact. The closure between rods in adjacent assemblies induced by assembly bow alone, being well below 50%, would not result in any DNB effect. This gap reduction would have the greatest effect on 14x14 fuel assemblies, since that design has the highest percentage of fuel rods on the periphery and the largest gap reduction from nominal if adjacent assemblies touch.

The rod bow DNBR penalty for 0.422 inch rods was recalculated with an initial closure of 16% imposed on inter-assembly edge rod gaps in order to simulate the effect of all assemblies bowed to grid strap contact in a core with 14x14 standard fuel assemblies. This situation could result in an additional rod bow DNBR penalty of 0.5% at a burnup of 33,000 MWD/MTU. This result is conservative for the following reasons:

1) It assumes all assemblies are bowed to grid strap contact at every span.
2) Rod bow penalties are based on thimble cell DNB test data; all peripheralcells include heated rods only and thus have no cold wall effect on DNB.

In addition to the above conservatism, other considerations allow this additional penalty to be disregarded:

1) The peak rod tends to be on the periphery of the assembly at low burnups only (< 15,000 MWD/MTU), when the magnitude of rod bow is small and the effect of the superimposed assembly bow is negligible.
2) Assembly bow to grid strap contact will decrease the peripheral rod powers ($\sim$ 1%) due to a decrease in moderation.

The effects of assembly bow on power peaking and F_Q are difficult to quantify for two reasons. First, out-of-core measurements of assembly bow are only indications of the in-pile assembly bow. The assemblies themselves and the baffle, combined with the top and bottom core restraints, restrict assembly bow effects. Second, assembly bow effects are like rod bow effects, i.e., local effects. A power increase of several percent for several rods of an assembly will perturb the overall assembly only slightly. Incore flux measurement changes from assembly bow would not be separable from other in-pile effects, e.g., measurement uncertainties.

For F_Q considerations, assembly bows which increase the nominal inter-assembly gap are of concern. For a typical fuel assembly, the peak rod is normally located near a water hole (thimble) with nominal assembly gaps. For very large gap increases, the peak rod location migrates from this water hole to the corner assembly rod (assuming no burnup gradients, etc.) For fuel assemblies with burnable poisons, however, the peak rod with nominal assembly gaps can be the corner rod initially. As the gap increases the corner rod will increase in power as in the typical fuel assemblies. But in this case the peak rod is in and remains in the corner location, thereby accentuating the effects of assembly bow for increased gaps.

Accordingly, two typical 17x17 4-loop first core arrangements of four fuel assemblies were modelled. This 2x2 mini-core modelling was done using TURTLE, the standard two-dimensional, two-group diffusion theory design code, in an atypical fashion to simulate asymmetric gap increases and decreases. The first 2x2 mini-core was comprised of four 3.1 w/o assemblies containing no burnable poisons. Figure 1 shows this arrangement with nominal gaps (~ 40 mils). The peak rod is near the water hole with a relative power of 1.042. The corner rod has a rod power of .960. Figure 2 shows this arrangement with the two adjacent gaps increased to 80 mils. (Assembly gaps of 80 mils represent at least one adjacent assembly bowing away to closure.) Note that the corner rod power has increased ~ 3%, the assembly power by ~ .5% but the peak rod by only .3%. Figure 3 shows the situation in which one gap has increased to 80 mils but another one has decreased to closure. Note that again the assembly power and peak rod power has changed only slightly.

The second 2x2 mini-core was comprised of one 3.1 w/o, 20 BP assembly, two 2.10 w/o, no BP assembly, and one 2.6 w/o, 16 BP assembly. This is a typical 4-loop, 17x17 first core enrichment, burnable poison loading mixture. The geometries depicted in Figure 4 through 6 are the same as those shown in Figures 1 through 3 respectively. In this arrangement, however, the peak rod was a corner rod in the 3.1 w/o assembly for the unperturbed configuration (Figure 4). When two gaps increased to 80 mils, the peak rod power increased 2.6% while the overall assembly power increased ~ 0.5% (Figure 5). For the other case, the peak rod increase was less than .6% and the assembly power increase was less than 0.2% (Figure 6).

Although calculated for particular fuel arrangements of 17x17 fuel assemblies, both mini-cores showed very similar rod power increases and decreases for the same rod positions. Thus, it is expected that these results should be representative for all fuel types and configurations in which inter-assembly gaps are off-nominal.

Assembly bow effects have not been incorporated into the F_Q peaking factor uncertainty factor because other peaking factors applied have been arrived at with conservatisms (including those detailed in answers to Questions #9 and #27).

This fact combined with the following considerations shows that an increase in the F_Q uncertainty applied would not be required.

(1) Increased assembly gaps have their greatest impact on the rows of rods near the periphery of the assemblies. For geometries and core arrangements in which peak power rods are inboard from the gaps, the resultant assembly bow effects on peaking are very small.

(2) Worst assembly bow peaking increases would occur in assemblies where corner rods are initially the peak rod with nominal gaps. This commonly occurs in assemblies with large number of BP's. The maximum assembly burnup of assemblies needing BP's is ~ 15000 MWD/MTU. At this burnup, actual rod bow effects are small even though the F_Q calculated penalty typically used for rod bow is at a higher burnup.

(3) Assembly bow at any given assembly junction can cause power peaking to increase or to decrease depending on the type and arrangement of the assemblies at the junction and the magnitude of the gaps.

Power peaking perturbations tend to "heal themselves". In an assembly with BP's, a peak power increase in a corner rod would quickly reduce in magnitude as burnup occurs and as the BP's deplete allowing the peak power location to move inboard to the thimbles. Also, for a corner rod at somewhat less than nominal power from a closed gap the location of peak power would shift inboard with depletion.

(4) Core loadings with a large number of BP'ed assemblies (first cores) have a higher probability of having increased gaps near a potential peak rod (more assemblies with BP's), but they also have zero burnup and best estimate power peaks substantially lower than the design limit. Large gap increases could be accommodated in such cores. Also, few reload cores if any with large numbers of BP's have best estimate power peaks near design limits.

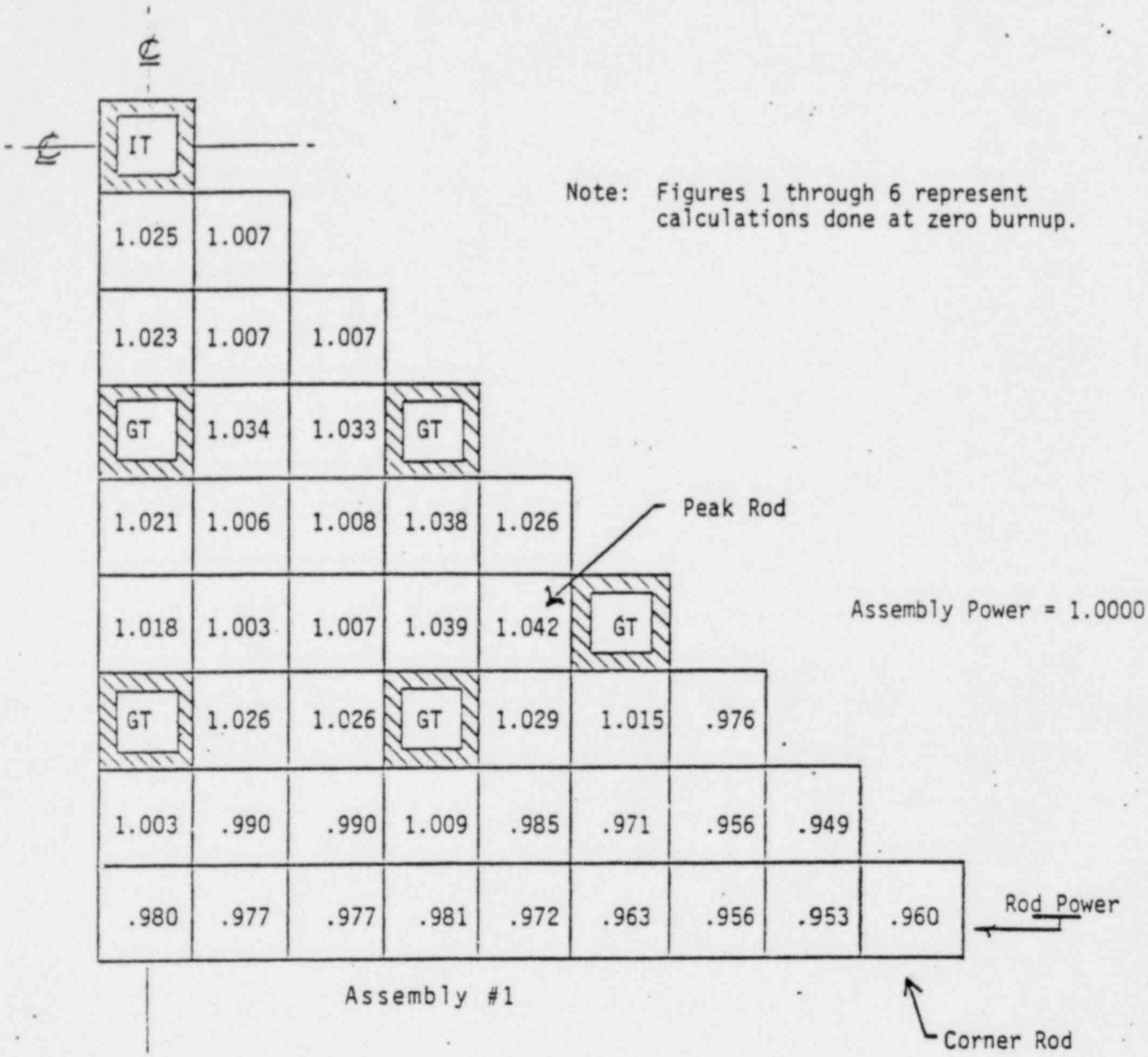
TABLE 1

REDUCED FUEL ASSEMBLY GAP DIMENSIONS

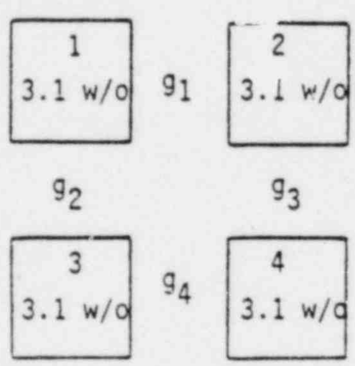
	14x14 Std.	14x14 OFA	Model C	15x15 Std.	15x15 OFA	17x17 Std.	17x17 OFA
Nominal Rod-Rod Gap (in.)	0.134	0.156	0.140	0.141	0.163	0.122	0.136
Inter-Assembly Edge Rod Gap with Grids Touching* (in.)	0.113	0.128	0.110	0.120	0.136	0.116	0.122
% Reduction from Nominal Gap with grids touching	16	18	21	15	17	5	10
% of Fuel Rods on Assembly Periphery	29	29	30	27	27	24	24

* Rod bow induced by assembly bow is neglected; this bow is <1.5 mils for the middle span if an assembly is bowed symmetrically about the midplane to grid strap contact.

Note: Figures 1 through 6 represent calculations done at zero burnup.



Mini-Core Geometry #1



Gap Sizes (mils)

g_1 = 40

g_2 = 40

g_3 = 40

g_4 = 40

FIGURE 1 NOMINAL ROD POWER DISTRIBUTION

℄

IT								
1.025 -----	1.007 -----							
1.023 -----	1.007 -----	1.008 +.1						
GT	1.035 +.1	1.034 +.1	GT					
1.023 +.2	1.007 +.1	1.010 +.2	1.040 +.2	1.028 +.2				
1.022 +.4	1.007 +.4	1.010 +.3	1.043 +.4	1.045 +.3	GT			
GT	1.032 +.6	1.030 +.5	GT	1.035 +.6	1.022 +.7	.986 +1.0		
1.014 +1.1	1.001 +1.1	1.001 +1.1	1.021 +1.2	.997 +1.2	.984 +1.3	.970 +1.5	.966 +1.8	
1.002 +2.2	.999 +2.3	.999 +2.3	1.002 +2.1	.994 +2.3	.986 +2.4	.979 +2.4	.979 +2.7	.990 +3.1

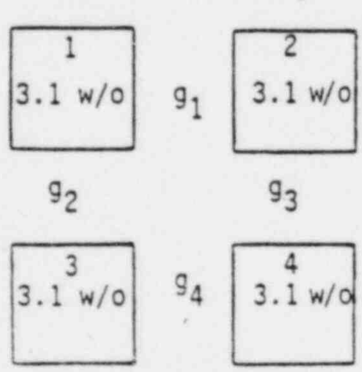
Assembly Power = 1.0047

Rod Power

% Difference

Assembly #1

Mini-Core Geometry #1



Gap Sizes (mils)

g_1 = 80

g_2 = 80

g_3 = 40

g_4 = 40

FIGURE 2 ROD POWER DISTRIBUTION WITH OFF-NOMINAL GAPS (CASE 1)

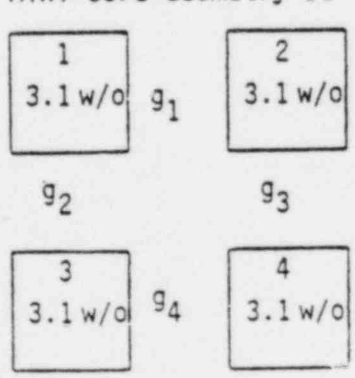
IT	1.025 -----	1.023 -----	GT	1.022 +.1	1.021 +.3	GT	1.014 +1.1	1.001 +2.1
1.025 -----	1.007 -----	1.007 -----	1.035 +.1	1.007 +.1	1.006 +.3	1.032 +.6	1.001 +1.1	.999 +2.3
1.023 -----	1.007 -----	1.008 +.1	1.034 +.1	1.010 +.2	1.010 +.3	1.030 +.5	1.001 +1.1	.999 +2.3
GT	1.034 -----	1.033 -----	GT	1.040 +.2	1.042 +.3	GT	1.020 +1.1	1.002 +2.1
1.021 -----	1.006 -----	1.009 +.1	1.039 +.1	1.027 +.1	1.044 +.2	1.034 +.5	.996 +1.1	.993 +2.2
1.019 +.1	1.004 +.1	1.007 -----	1.040 +.1	1.042 -----	GT	1.019 +.4	.981 +1.0	.983 +2.1
GT	1.026 -----	1.024 -.1	GT	1.030 +.1	1.016 +.1	.980 +.4	.965 +.9	.974 +1.9
1.003 -----	.989 -.1	.989 -.1	1.009 -----	.986 +.1	.972 +.1	.959 +.3	.955 +.6	.969 +1.7
.979 -.1	.977 -----	.977 -----	.980 -.1	.972 -----	.963 -----	.956 -----	.955 +.2	.968 +.8

Rod Power
% Difference

Assembly #1

Assembly Power = 1.0020

Mini-Core Geometry #1



Gap Sizes (mils)

g_1 = 80

g_2 = 40

g_3 = 40

g_4 = 0

FIGURE 3 ROD POWER DISTRIBUTION WITH OFF-NOMINAL GAPS (CASE 2)

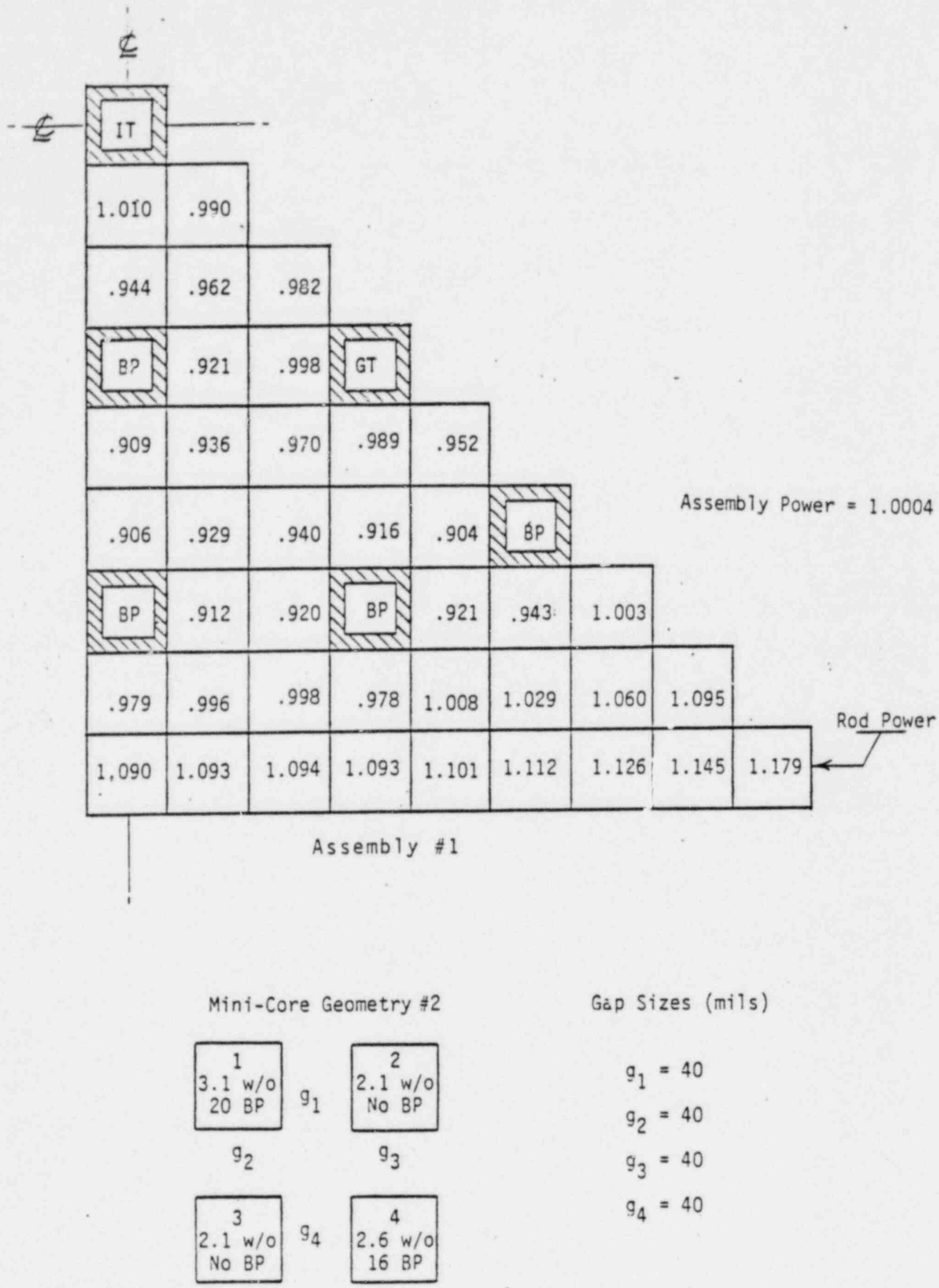
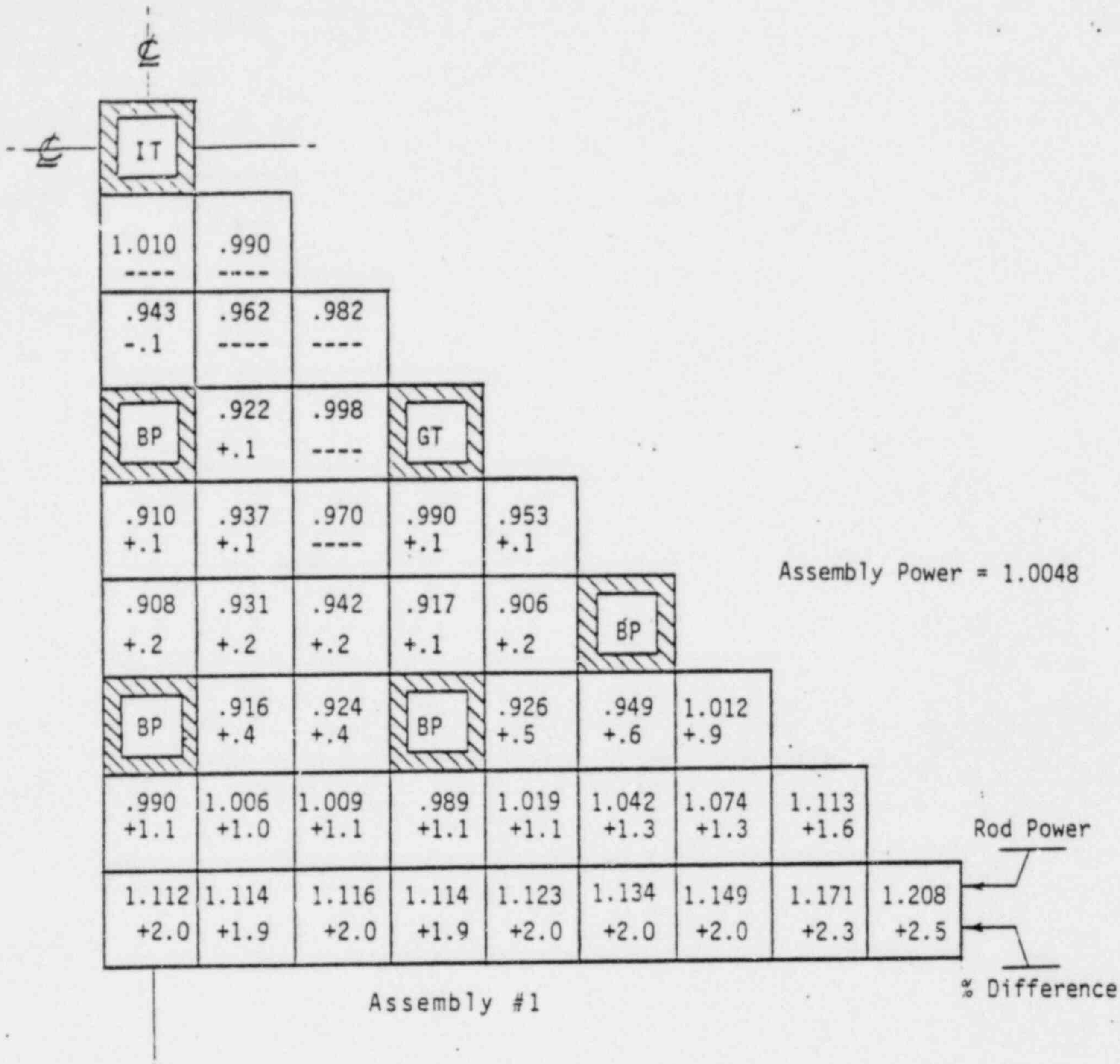
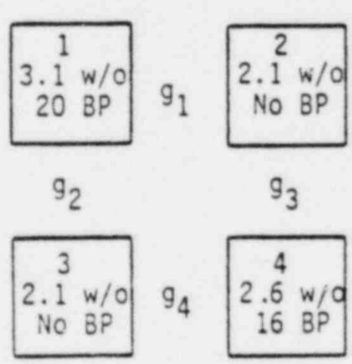


FIGURE 4 NOMINAL ROD POWER DISTRIBUTION



Mini-Core Geometry #2



Gap Sizes (mils)

g_1 = 80

g_2 = 80

g_3 = 40

g_4 = 40

FIGURE 5 ROD POWER DISTRIBUTION WITH OFF-NOMINAL GAPS (CASE 1)

℄

IT	1.010 ----	.943 -.1	BP	.910 +.1	.908 +.2	BP	.989 +1.0	1.111 +1.9
1.010 ----	.990 ----	.962 ----	.922 +.1	.937 +.1	.931 +.2	.916 +.4	1.006 +1.0	1.114 +1.9
.943 -.1	.962 ----	.982 ----	.998 ----	.970 ----	.942 +.2	.924 +.4	1.009 +1.1	1.115 +1.9
BP	.921 ----	.997 -.1	GT	.990 +.1	.917 +.1	BP	.983 +1.0	1.114 +1.9
.909 ----	.936 ----	.969 -.1	.989 ----	.952 ----	.905 +.1	.925 +.4	1.018 +1.0	1.122 +1.9
.906 ----	.929 ----	.940 ----	.915 -.1	.904 ----	BP	.947 +.4	1.039 +1.0	1.131 +1.7
BP	.911 -.1	.919 -.1	BP	.921 ----	.944 +.1	1.006 +.3	1.068 +.8	1.144 +1.6
.979 ----	.995 -.1	.998 ----	.978 ----	1.008 ----	1.030 +.1	1.062 +.2	1.101 +.5	1.160 +1.3
1.090 ----	1.093 ----	1.094 ----	1.092 -.1	1.101 ----	1.111 -.1	1.125 -.1	1.147 +.2	1.185 +.5

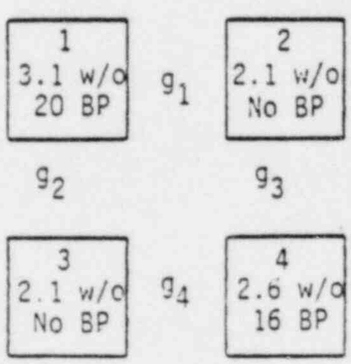
Rod Power

% Difference

Assembly #1

Assembly Power = 1.0020

Mini-Core Geometry #2



Gap Sizes (mils)

$g_1 = 80$

$g_2 = 40$

$g_3 = 40$

$g_4 = 0$

FIGURE 6 ROD POWER DISTRIBUTION WITH OFF-NOMINAL GAPS (CASE 2)

References

(2) "Interim Report Surry Unit 2 End-of-Cycle 2 Onsite Fuel Examination of 17x17 Demonstration Assemblies After One Cycle of Exposure", Westinghouse Report, WCAP-8873, January (1978).

(3) "Pool Side Examination of PWR Demonstration Fuel Assemblies and Creep Specimens - End-of-Cycle 1," Babcock and Wilcox Report, LRC 4733-3, May (1977).

(4) "Pool Side Examination of PWR Demonstration Fuel Assemblies and Creep Specimens - End-of-Cycle 2," Babcock and Wilcox Report, LRC 4733-S, August (1978).

ATTACHMENT 1

Table 1 contains the updated rod bow data base for .374-inch rods. Only those measurements obtained with high magnification TV tape (data quality 3) were used to develop the revised .374-inch rod bow correlations. This table updates the .374-inch rod bow data presented in Table 3-1 of WCAP-8691, Revision 1.

Figure A-1 shows the best estimate and tolerance limit curves for the new correlation. This figure replaces Figure 4-6.

TABLE 1 SUMMARY OF WESTINGHOUSE ROD BOW PERFORMANCE DATA ON 0.374" DIAMETER ROD

Plant/ Fuel Rod Diameter (inches)	Region	Cycle	Assembly AVG. BU (10^3 MWD/MTU)	Number of Assemblies	Data Quality

Plant/ Fuel Rod Diameter (inches)	Region	Cycle	Assembly AVG. BU (10^3 MWD/MTU)	Number of Assemblies	Data Quality

*These data previously listed in Table 3-1, WCAP-8691, Revision 1

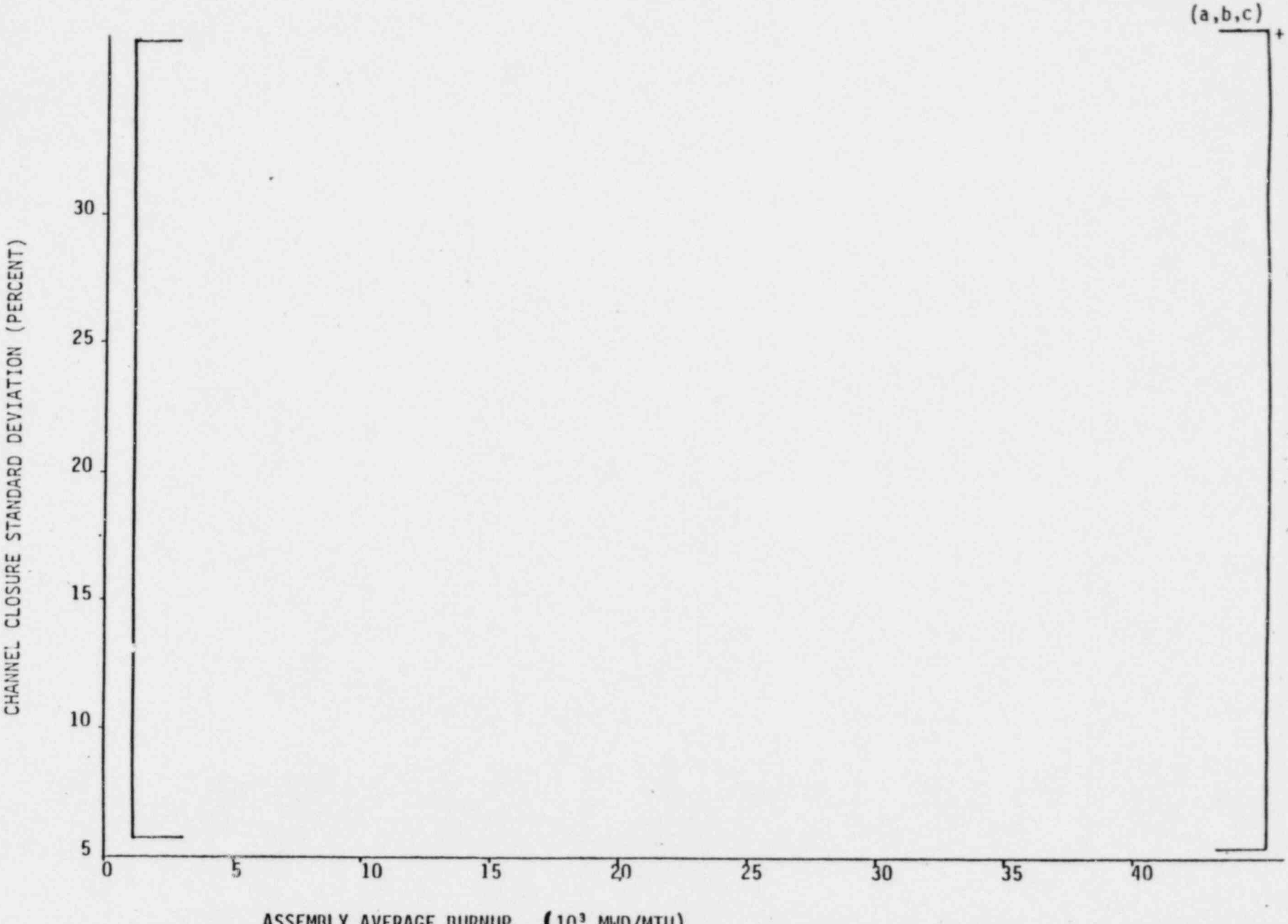


FIGURE A-1 CORRELATION OF WORST SPAN CHANNEL CLOSURE WITH ASSEMBLY BURNUP FOR 0.374 INCH RODS