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REVISED ROD BOW PENALTIES FOR ARKANSAS NUCLEAR ONE UNIT 2

DECEMBER, 1984

POWER
SYSTEMS
COMBUSTION ENGINEERING, INC

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REVISED ROD BOW
PENALTIES FOR ARKANSAS
NUCLEAR ONE
UNIT 2

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1.0 INTRODUCTION

Reference 1 contains NRC approved penalties due to fuel rod and poison rod bowing to account for the following three effects:

1. Linear heat generation augmentation due to fuel rod bowing.
2. Linear heat generation augmentation due to poison rod bowing.
3. Penalty on design minimum DNBR limit due to fuel rod bowing.

These penalties were generated on a generic basis for C-E 14x14 and 16x16 fuel designs. For the 16x16 fuel design, these penalties were calculated based on extrapolation from a channel closure model for the 14x14 fuel design. This extrapolation was obtained by using an L/I dependence, where:

L = span length between two adjacent grids
I = moment of inertia of fuel and poison rod cladding

The L/I dependence resulted in an extrapolation factor equal to 1.27 based on the ANO-2 16x16 fuel design. This factor is included in the generic channel closure model for the 16x16 fuel design as noted in Supplement-3 of Reference 1.

Since the issuance of Reference 1, C-E has accumulated irradiated fuel data specific to ANO-2 that support the use of a channel closure model for ANO-2 based on an L^2/I extrapolation rather than L/I extrapolation from the C-E 14x14 fuel design.

The purpose of this report is to revise the subject penalties contained in Reference 1 applicable to ANO-2 based on L^2/I extrapolation.

Section 2 of this report contains the data base which supports the use of a channel closure model based on L^2/I extrapolation for ANO-2 rather than L/I extrapolation from the C-E 14x14 fuel design.

Section 3 contains revised fuel and poison rod augmentation factors. These factors are provided in Figures 2 and 3 which supersede Figures 4.2-13 and 4.2-25 of Reference 1.

Section 4 contains revised rod bow penalties on minimum DNBR. These penalties are provided in Figure 4 which supersede the penalties given by Curve 2 in Figure G-2 of Reference 1.

Finally note that the revised subject penalties provided in this report are applicable only to the ANO-2 16x16 fuel design.

2.0 UPDATED CHANNEL CLOSURE MODEL FOR ANO-2 16x16 FUEL DESIGN

2.1 Observational Data

As part of the C-E EPRI 16x16 Fuel Performance Characterization Program, the fuel assemblies AKBT01 (2-cycles) and AKC107 (3-cycles) were measured for channel closure caused by fuel rod bow (or channel width) at the EOC-3 at ANO-2. Both of these assemblies and assembly AKA050 had been previously measured for fuel rod bow at the EOC-1, and the results were reported in Reference 2. In addition, pre-irradiation channel width measurements had been made on Spans 2, 6, and 10 of these two assemblies (AKBT01 and AKC107), and the data were summarized in Reference 3.

2.2 Measurement Technique

Channel widths were obtained by means of a strain gage measurement probe (Sulo probe). The probe consists of a blade with two leaf springs mounted near the forward end. Strain gages are bonded to the inner surface of the two leaves. The probe was mounted on a platform, which in turn was placed on the CFIS (Comprehensive Fuel Inspection Stand).X-Y translation of the probe was provided by the platform. As the probe was inserted into each flow channel, the leaf springs were deflected as they contacted fuel rods on either side. The strain gage converted the deflections to electrical signals that were transmitted to an amplifier and in turn to a strip chart recorder. A calibration gage block with three dimensional standards was mounted on the probe stand, and the strain gage was periodically passed through the gage block as a calibration check.

The channel width measurements were corrected for a small bias that resulted from the lateral deflection of the fuel rods by the probe. This correction was determined by measuring precharacterized channel spacings on a simulated 16x16 fuel assembly with artificially created channel closures, over the range 0.100 inches to 0.170 inches. The probe used to measure these simulated channel spacings had leaf springs that were 0.007 inches thick. Channel width measurements made at the ANO-2 examination also utilized leaf springs of similar thickness. The bias correction data are

Channel Dimension (inches)	Avg. Bias (inches)
0.100	0.0056
0.170	0.0014

After correction, the data are precise within ±0.001 inches and are estimated to be accurate within ±0.002 inches.

2.3 Results

The results of the channel width measurements from AKBT01 and AKC107 are summarized by span in Table 1. Span 1 was not measured because of the reduced span length, which has been shown to support the rods and therefore reduces the extent of rod bowing (Reference 4). The minimum channel width measured was [ ] mils for AKBT01 and [ ] mils for AKC107, both located in Span [ ] of the two assemblies. These data represent [ ] percent nominal channel closure, respectively, based on the nominal channel spacing at fabrication (0.124 inches).

A summary of the results of the ANO-2 EOC-1 channel width measurements is included in Table 2. The extent of fuel rod bowing, as identified by the standard deviation (σ) increases with additional irradiation. The maximum σ for AKC107 increased from a value of [ ] mils to a value of [ ] mils during Cycles 2 and 3. However, the maximum σ for AKBT01 only increased from a value of [ ] mils to a value of [ ] mils during Cycle 2. Additional irradiation also eliminates the preference observed at the EOC-1 for fuel rod bowing to be [ ] The extent of channel closure after three cycles is the same [ ] Additionally, the smallest channel observed in both assemblies at the EOC-3 was located in [ ] whereas the smallest channel at the EOC-1 was located in either [ ] The elimination of the span-to-span variation is attributable to the [ ]

The average channel width has increased from 0.124 inches prior to irradiation, to [ ] The increased channel width is attributable to: creep down of the cladding [ ], growth of the cold worked Zircaloy grids, relaxation of the grid tabs, and changes in the mechanical properties of the fuel rod due to irradiation. This increase in average channel width is not reflected in the percent channel closure calculation since the current model is based only on net changes from the nominal channel. A fractional channel closure based upon the post-irradiation average channel dimension would result in a [ ]

The channel closure data from the EOC-1 and EOC-3 poolside inspections at ANO-2 are plotted in Figure 1. This plot shows the fraction channel closure of the worst span at the 1σ level as a function of burnup. The worst span is defined as the span having the largest standard deviation of channel widths.

In Figure 1, the generic channel closure for C-E 16x16 designs from Reference 1 is shown as the upper curve. The 1.27 factor in the generic equation was obtained by L/I extrapolation between the C-E 14x14 design and the ANO-2 16x16 design. C-E believes that L^2/I extrapolation is more appropriate and would result in an extrapolation factor for ANO-2 of 1.00 (see Table 3) rather than 1.27. The channel closure curve for ANO-2 based on L^2/I extrapolation from the 14x14 design is shown as the lower curve in Figure 1. Both curves include a [ ] factor to account for batch-to-batch variations. Based on the results of Figure 1, it is proposed that the lower curve, based on L^2/I extrapolation, be used in the determination of fuel rod bowing penalties at ANO-2. The channel closure model presented in Supplement 3 of Reference 1 is revised accordingly for ANO-2:

$$S_{16} = (a_{16} + b\ (Bu)^n)\ 1.2 \times [\quad] \times 1.0 \text{ inches}$$

where:

S_{16} = 68th percentile or one-standard deviation significance level of channel closure for the ANO-2 16x16 design at burnup Bu and at "hot" conditions.

a_{16} = sample standard deviation of the as-fabricated channel width measurement [ ] for the 16x16 design.

b = burnup coefficient [ ] in/(MWD/MTU)^n.

n = exponent on burnup and is equal to 0.5.

1.2 = cold to hot factor.

[ ] = Batch-to-batch variation correction factor.

1.0 = Extrapolation factor from the 14x14 design to the ANO-2 16x16 design, based on L^2/I dependence (rather than L/I).

3.0 REVISED FUEL AND POISON ROD AUGMENTATION FACTORS

The purpose of this section is to revise 16x16 fuel and poison rod bowing augmentation factors for ANO-2 contained in Reference 1. These factors have been recalculated by using an L^2/I extrapolation factor (rather than L/I) for projection of the 16x16 channel closure, based on the 14x14 fuel design data. This L^2/I extrapolation factor has been calculated in Table 3 for ANO-2 and is equal to unity. Incorporation of this L^2/I dependence in the channel closure model results in lower fuel and poison rod bowing augmentation factors for ANO-2.

3.1 Fuel Rod Bowing

The fuel rod bowing augmentation factor (the allowance for an increase in power due to fuel rod bowing for which there is a 95% probability that 95% of the fuel will not exceed) is given by:

$$t_{95/95} = \left[\qquad \right] BS_c \qquad \text{(4.2-52 Reference 1)}$$

where

$$B = a + b\,\varepsilon + c(Bu) + d(Bu)^2 \qquad \text{(4.2-53 Reference 1)}$$

and

ε = fuel enrichment (w/o U-235)
Bu = fuel exposure (MWD/MTU)

Values of the constants, a, b, c and d are given below and have been taken from Table 4.2-2, Reference 1.

$$\left.\begin{array}{l} a = \\ b = \\ c = \end{array}\right. \left[\qquad\qquad \right]$$

$$d = \left[\qquad \qquad \right]$$

S_c, the standard deviation of worst span channel closure is specified on page G-7, Reference 1 (Supplement - 3). However, as discussed earlier, this parameter has been modified where an L/I dependence factor of 1.27 has been replaced with an L^2/I dependence factor equal to unity. The modified relationship is:

$$S_c = S_{16} = (a_{16} + b\,(Bu)^n)\ 1.2 \times \left[\quad \right] \times 1.0 \text{ inches}$$

where

$$\begin{array}{lll} a_{16} & = & \multirow{2}{*}{$\left[\qquad \qquad \right]$} \\ b & = & \\ n & = & 0.5 \end{array}$$

Use of the above equations results in the fuel rod bowing augmentation factors shown in Figure 2, which supersedes Figure 4.2-13 of Reference 1.

3.2 Poison Rod Bowing

Poison rod bowing augmentation factors for Type 3 shims (Type 3 shims are those presently in use; since Type 1 and 2 shims are no longer in use, they will not be addressed) are given by:

$$t^*_{95/95} = B^*\ \delta_{95/95} \qquad \text{(4.2-55 Reference 1)}$$

where

$$\delta_{95/95} = \left[\qquad \right](1.645)\ S_c \quad \text{(4.2-54 Reference 1)}$$

and S_c is defined as in Section 3.1 above and B* is given by Figure 4.2-24 of Reference 1.

Use of the above equations results in the poison rod bowing augmentation factors shown in Figure 3, which supersedes Figure 4.2-25 of Reference 1.

4.0 REVISED ROD BOW PENALTIES ON MINIMUM DNBR

The purpose of this section is to revise the rod bow penalties on minimum DNBR contained in Supplement-3 of Reference 1 for Arkansas Nuclear One Unit 2. The revised penalties are applicable only to ANO-2. The subject penalties have been recalculated in order to incorporate the revised channel closure model and are based on updated input from that which was originally used to calculate these penalties in Supplement-3 of Reference 1. The original input is presented in Tables G-1, G-2 and G-3 in Supplement-3 of Reference 1. Only the following changes to the original input have been made when calculating these revised penalties applicable to ANO-2.

1. In the channel closure model, the L/I dependence factor of 1.27 has been replaced with L^2/I dependence factor equal to unity. A calculation of the L^2/I dependence factor is provided in Table 3. Justification for this change has already been discussed in Section 2 of this report.

2. The original value for the hot rod average heat flux (Q_{AV}) which corresponds to reactor overpower trip and design rod radial peak has been changed from 0.387×10^6 to 0.374×10^6 Btu/hr-ft^2. The new value is appropriate for ANO-2 and this value is expected to bound the future cycles.

3. The original value for the reactor pressure which corresponds to reactor over pressure trip has been changed from 2475 to 2422 psia. The new value is appropriate for ANO-2 and this value is expected to bound the future cycles.

With the input changes noted above, the rod bow penalties on minimum DNBR have been recalculated for ANO-2. These penalties have been calculated using exactly the same methodology as outlined in Supplement-3 of Reference 1. The revised penalties are provided in Figure 4 as a function of burnup and supersede the penalties given by Curve 2 in Figure G-2 of Reference 1.

5.0 REFERENCES

1. Fuel and Poison Rod Bowing; CENPD-225-P-A, June, 1983.

2. R. G. Weber, et al., "C-E/EPRI Fuel Performance Evaluation Program, RP 586-1 Task B, Examination of Arkansas Nuclear Unit 2 Characterized Fuel Assemblies After Cycle 1", Report CE-NPSD-174, July, 1982.

3. D. E. Bessette, et al., "C-E/EPRI Fuel Performance Evaluation Program, RP 586-1 Task B, Fabrication and Characterization of Arkansas Nuclear One Unit II 16x16 Fuel Assemblies", October, 1978.

4. D. E. Bessette, et al., "C-E/EPRI Fuel Performance Evaluation Programs, RP 586-1 Task A, Examination of Calvert Cliffs I Test Fuel Assemblies at End of Cycles 1 and 2", September, 1978.

Table 1

SUMMARY OF CHANNEL CLOSURE MEASUREMENTS

AT ANO-2 EOC-3

SPAN	AKBT01[1]				AKC107[2]			
	N	Min	X	σ	N	Min	X	σ
11								
10								
9								
8								
7								
6								
5								
4								
3								
2								
1								
Assembly								

1) 2 cycle assembly, 24.8 GWd/MTU burnup

2) 3 cycle assembly, 32.8 GWd/MTU burnup

Note: all dimensions are in mils.

Table 2

SUMMARY OF CHANNEL WIDTH MEASUREMENTS

AT ANO-2 EOC-1

SPAN	AKA050[1]				AKBT01[2]				AKC107[3]		
	N	Min	X	σ	N	Min	X	σ	N	Min	X	σ
11												
10												
9												
8												
7												
6												
5												
4												
3												
2												
1												
Assembly												

1) 13.1 GWd/MTU burnup
2) 14.8 GWd/MTU burnup
3) 13.2 GWd/MTU burnup

Note: all dimensions are in mils.

Table 3

Dimensions Used to Calculate Correction Factor, Based on L^2/I Dependence for Projection of 16x16 Design (ANO-2) Channel Closure Based on 14x14 Data.

Dimension	14x14 Fuel Design	16x16 Fuel Design for Arkansas Unit 2
Span length, L (in)	18.86	14.81
Cladding outside diameter, OD (in)	0.440	0.382
Cladding inside diameter, ID (in)	0.388	0.332

Calculation of L^2/I Correction Factor

Moment of Inertia, $I = \frac{\pi(OD^4-ID^4)}{64}$

$$\left(\frac{L^2}{I}\right)_{14x14} = \frac{(18.86)^2\ (64)}{(\pi)\ (.44^4\ -.388^4\ )} = 489035 \quad (in^{-2})$$

$$\left(\frac{L^2}{I}\right)_{16x16} = \frac{(14.81)^2\ (64)}{(\pi)\ (.382^4-.332^4)} = 488631 \quad (in^{-2})$$

$$\text{Correction Factor} = \frac{\left(\frac{L^2}{I}\right)_{16x16}}{\left(\frac{L^2}{I}\right)_{14x14}} = \frac{488631}{489035} \approx 1.0$$

FIGURE 1
FRACTIONAL 1σ CHANNEL CLOSURE AS A
FUNCTION OF BURNUP

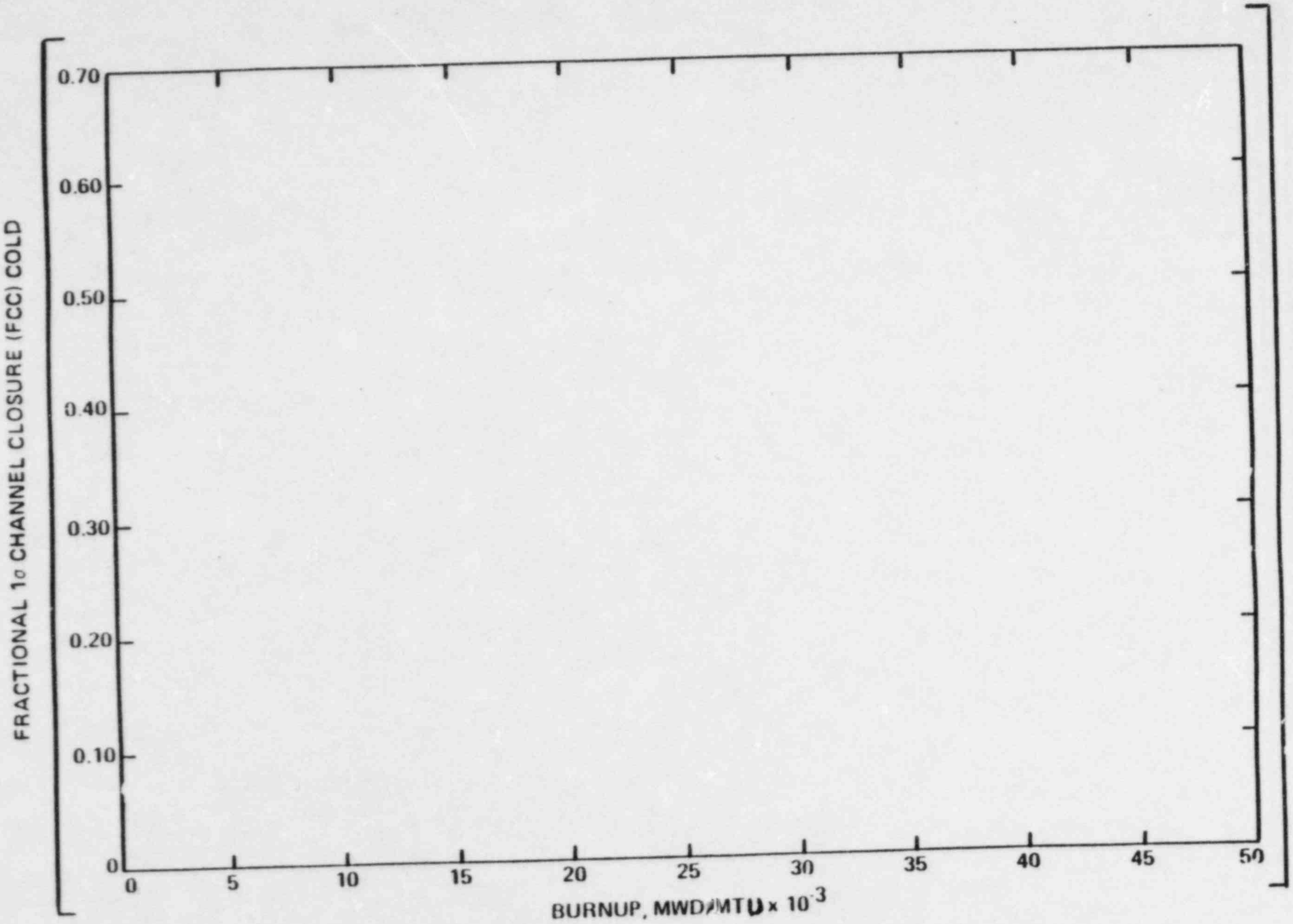


FIGURE 2
LINEAR HEAT GENERATION AUGMENTATION DUE TO FUEL ROD BOWING

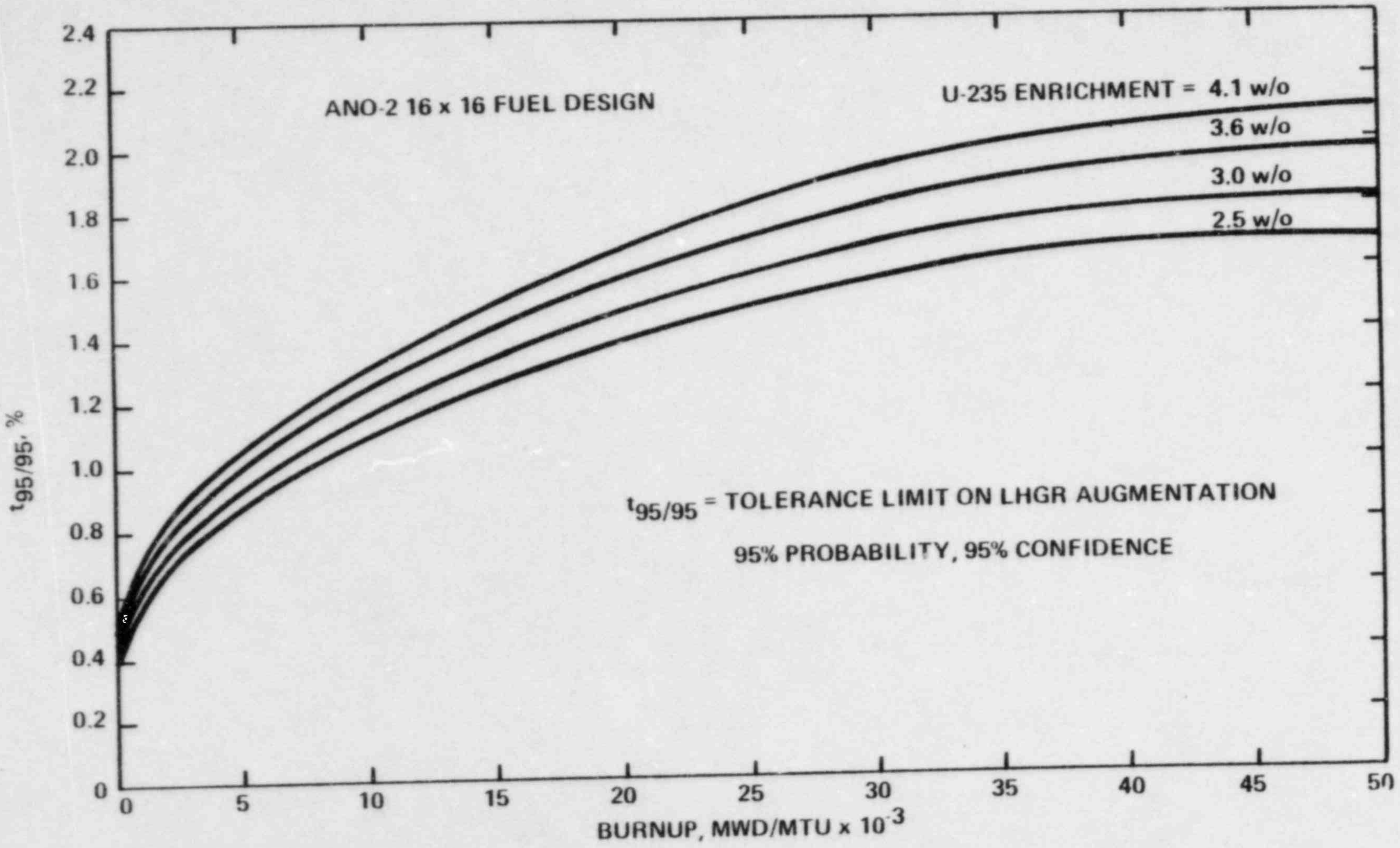


FIGURE 3
LINEAR HEAT RATE AUGMENTATION DUE TO POISON ROD BOWING

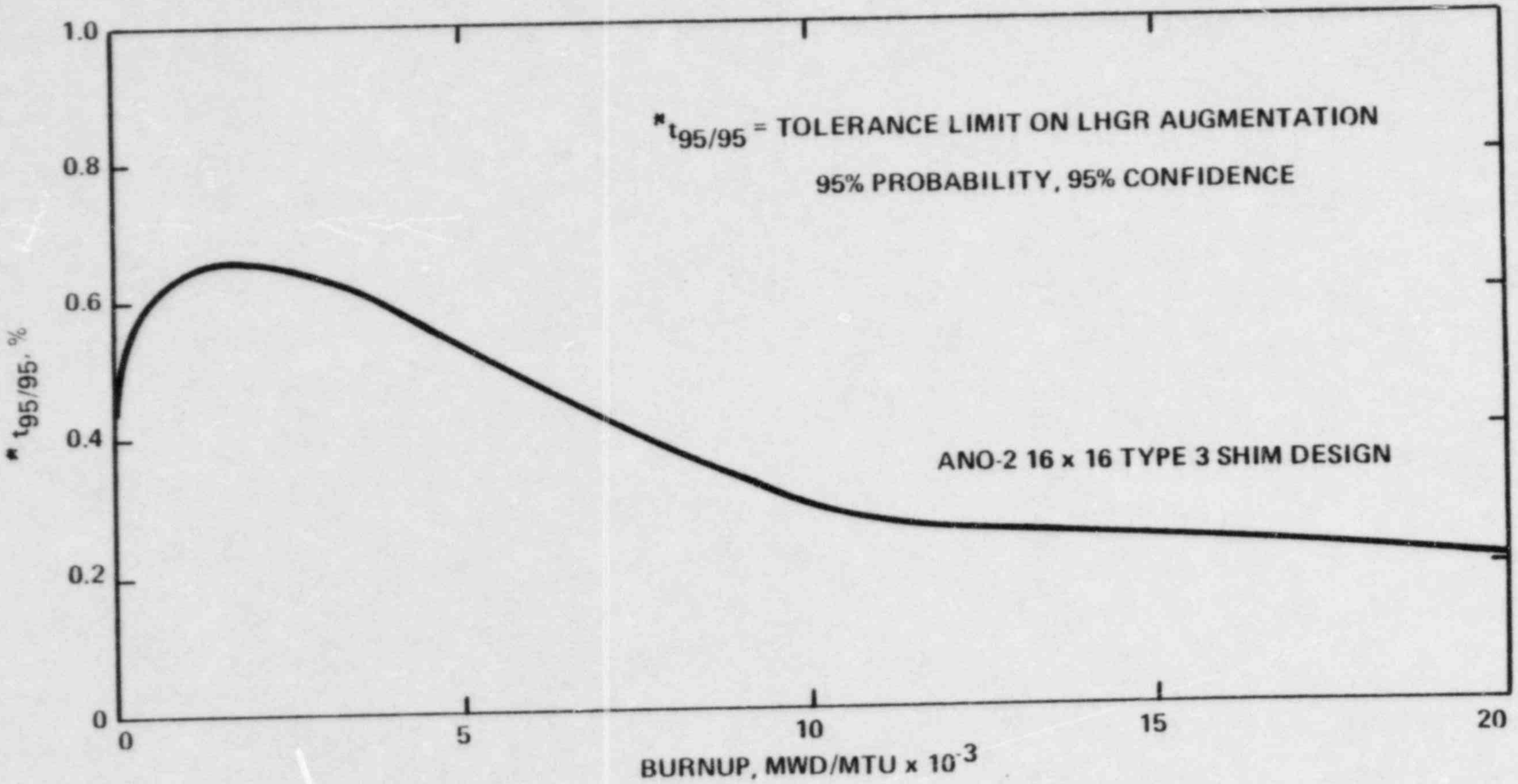
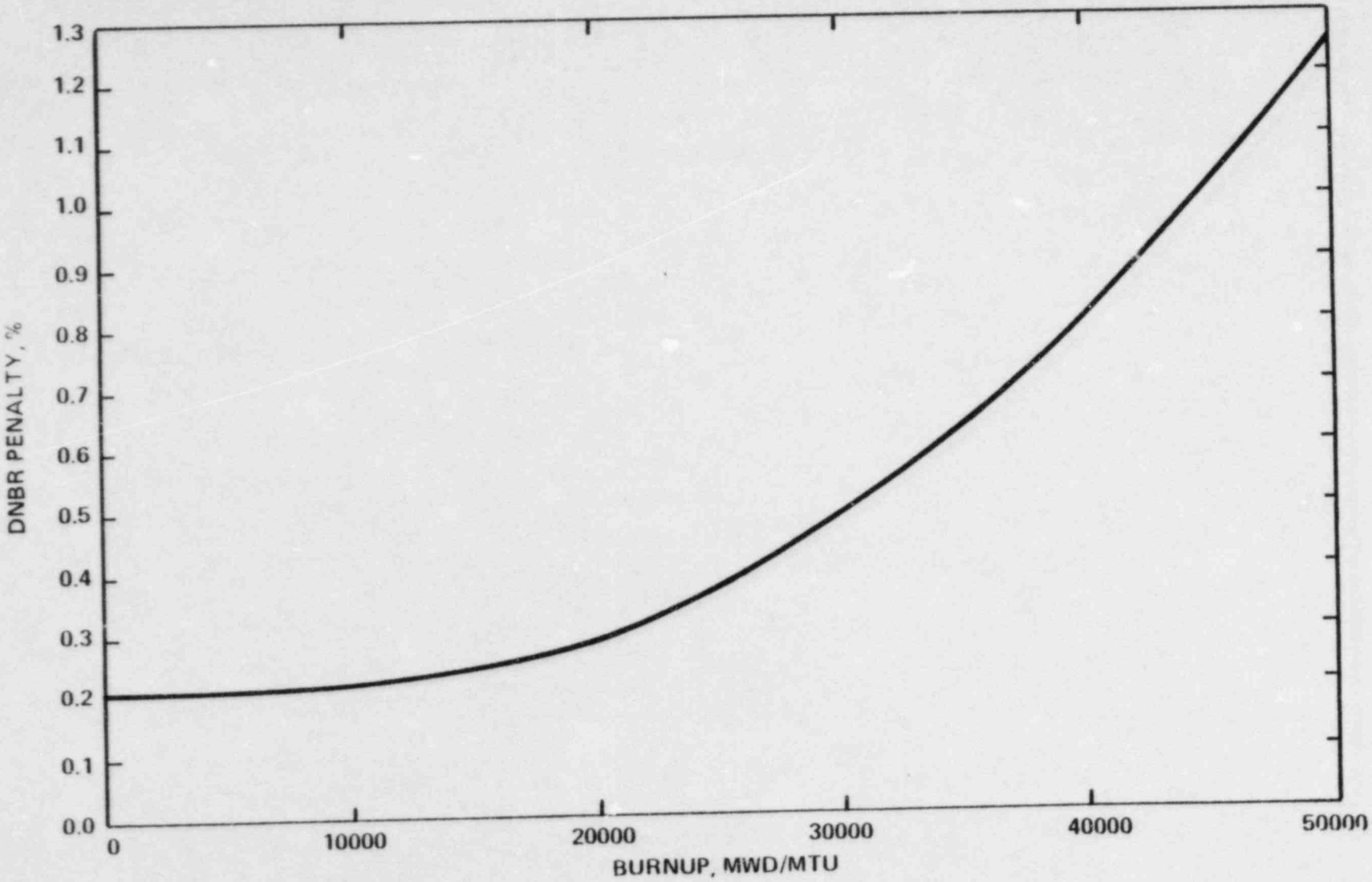


FIGURE 4
REVISED PENALTY ON MINIMUM DNBR DUE TO FUEL ROD BOWING AS A FUNCTION OF BURNUP USING CE-1 CHF CORRELATION FOR ARKANSAS NUCLEAR ONE UNIT 2



COMBUSTION ENGINEERING, INC.

AFFIDAVIT PURSUANT TO 10 CFR 2.790

Combustion Engineering, Inc.)
State of Connecticut)
County of Hartford) SS.:

I, P. L. McGill, depose and say that I am the Vice President, Commercial, of Combustion Engineering, Inc., duly authorized to make this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conformance with the provisions of 10 CFR 2.790 of the Commission's regulations and in conjunction with the application of Arkansas Power & Light Company for withholding this information.

The information for which proprietary treatment is sought is contained in the following document: CEN-289(A)-P, "Revised Rod Bow Penalties for Arkansas Nuclear One Unit 2," December 1984.
This document has been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by Combustion Engineering in designating information as a trade secret, privileged or as confidential commercial or financial information.

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, included in the above referenced document, should be withheld.

1. The information sought to be withheld from public disclosure is channel closure measurement data and correlation of this data with fuel burnup, which is owned and has been held in confidence by Combustion Engineering.

2. The information consists of test data or other similar data concerning a process, method or component, the application of which results in a substantial competitive advantage to Combustion Engineering.

3. The information is of a type customarily held in confidence by Combustion Engineering and not customarily disclosed to the public. Combustion Engineering 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 details of the aforementioned system were provided to the Nuclear Regulatory Commission via letter DP-537 from F. M. Stern to Frank Schroeder dated December 2, 1974. This system was applied in determining that the subject document herein is proprietary.

4. The information is being transmitted to the Commission in confidence under the provisions of 10 CFR 2.790 with the understanding that it is to be received in confidence by the Commission.

5. The information, to the best of my knowledge and belief, is not available in public sources, and any disclosure to third parties has been made pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.

6. Public disclosure of the information is likely to cause substantial harm to the competitive position of Combustion Engineering because:

a. A similar product is manufactured and sold by major nuclear fuel fabrication competitors of Combustion Engineering.

b. Development of this information by C-E required thousands of man-hours and hundreds of thousands of dollars. To the best of my knowledge and belief a competitor would have to undergo similar expense in generating equivalent information.

c. In order to acquire such information, a competitor would also require considerable time and inconvenience to obtain channel closure measurement data and correlate this data with fuel burnup.

d. The information required significant effort and expense to obtain the licensing approvals necessary for application of the information. Avoidance of this expense would decrease a competitor's cost in applying the information and marketing the product to which the information is applicable.

e. The information consists of channel closure measurement data and correlation of this data with fuel burnup, the application of which provides a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with Combustion Engineering, take marketing or other actions to improve their product's position or impair the position of Combustion Engineering's product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

f. In pricing Combustion Engineering's products and services, significant research, development, engineering, analytical, manufacturing, licensing, quality assurance and other costs and expenses must be included. The ability of Combustion Engineering's competitors to utilize such information without similar expenditure of resources may enable them to sell at prices reflecting significantly lower costs.

g. Use of the information by competitors in the international marketplace would increase their ability to market nuclear fuel assemblies by reducing the costs associated with their technology development. In addition, disclosure would have an adverse economic impact on Combustion Engineering's potential for obtaining or maintaining foreign licensees.

Further the deponent sayeth not.

P L McGill

P. L. McGill

Vice President

Commercial

Sworn to before me

this 14 day of Dec. 1984

Roger Olsen

~~Notary Public~~ J.P.

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