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H. R. Spencer

March 3, 1961

D. L. Renberger
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IRRADIATION PROCESSING DEPARTMENT

RE-EVALUATION OF METAL PERFORMANCE LEVELS
OF C-II-N AND C-II-E MATERIAL

MASTER

Introduction

This report presents, for the record, an analysis of rupture experience at C reactor over the past two years. The purpose of the study was to provide a basis for revising, if necessary, the current metal performance level multipliers for C-II-N and C-II-E material.

Summary and Conclusions

Based on a detailed analysis of the rupture experience at C reactor for twenty-five months, beginning January, 1959, it is concluded that the metal performance level multiplier (q) for C-II-N material should be revised from 1.17×10^{-39} to 0.60×10^{-39} . A major part of this improvement was due to improvements in axial

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HW-68737

D. L. Renberger

-2-

March 3, 1961

flux shape. It is also concluded that the present q estimate for C-II-E material, namely 2.65×10^{-39} , should not be altered at this time. Appropriate revisions to the recommended variable goal exposure plan for C-II-N material will be made under separate cover.

Discussion

Revisions to estimates of the metal performance level are normally based on control charts of rupture experience using methods and procedures which are documented⁽¹⁾. An out-of-control point implies either an improvement or decline in the metal performance level, and the performance level estimates are revised according to a predetermined decision rule^(1,2). The selection of the current decision rule⁽²⁾ was based to a large extent on the premise that cycles or trends in the true metal performance level are not normally extreme, say only occasionally being as large as a factor of two. Overall, the experience of the past several years has been consistent with the premise. An exception arises, for example, when a reactor is known to be experiencing significant changes in axial flux distribution⁽³⁾, as has been the case at C reactor during the past year or two. In this situation, control charts will detect the fact that a change in the metal performance level has occurred, but flux distribution data should be used in estimating the magnitude of the change. Actually, if sufficient axial flux data were routinely available, changes to the metal performance level estimates could be made before they would be detected by the control charts.

Based on available flux data, the concerted effort of the past three quarters to improve the axial flux shape has significantly improved (reduced) the rupture producing climate of the reactor. Therefore, based on the total information now available, which includes underlying metal quality trends determined from total IPD rupture experience, as well as axial flux data, the metal performance levels of C-II-N and C-II-E material have been re-evaluated.

The metal performance level multiplier (q) is defined by the equation:

$$(1) \quad q_i = \frac{R_i}{\Delta RI_i}$$

Where R_i is the number of ruptures for the i th interval.

ΔRI_i is the change in rupture index for the i th interval.

- (1) HW-65550, Bloomstrand, RR, "Use of Control Charts for Analysis of Plant Rupture Experience," June 9, 1960, (Secret).
- (2) "Revision to Decision Rule for Adjusting (q) Values," Bloomstrand, RR, October 21, 1960, (Confidential-Undocumented).
- (3) The effects of various axial power distributions on rupture potential have been estimated and reported in HW-61496, "Rupture Potential and Axial Power Distribution," Neef, WI, August 11, 1959, (Secret).

DECLASSIFIED

HW-68737

D. L. Renberger

-3-

March 3, 1961

Shifts in q , i.e., shifts in the metal performance level, result from changes in intrinsic metal quality and/or changes in reactor parameters other than power, temperature, and exposure. The effects of power, temperature and exposure are reflected in ΔRI . The major reactor parameter not included in ΔRI , which is therefore included in q , is the rupture potential associated with axial flux distribution. When sufficient data are available, the axial flux contribution can be estimated and removed from q .

The procedure followed in this analysis was to estimate, from the available data, shifts in the reactor rupture producing climate resulting from changes in axial flux, over the time period being considered. Trends in underlying metal quality with time were estimated from total IPD irradiation experience. Both of these important factors were then quantified on a relative basis, with "current" flux and quality factors being taken as 1.0. Monthly rupture index data were then adjusted by the appropriate flux and quality factors to normalize to the current situation. Estimates of the "current" metal performance level multipliers (q) for both C-II-N and C-II-E material were determined by equation (1), from the sums of the adjusted rupture index data and the number of ruptures observed. The period from January, 1959, through January, 1961, was used in the analysis. The data and calculations are appended.

From the data of this report the metal performance level multiplier (q) for C-II-N material was estimated to be 0.48×10^{-39} ; the 95 per cent confidence limits on q are 0.30 to 0.72×10^{-39} . This is significantly lower than the currently used value of 1.17×10^{-39} . Clearly, revision to the q value for natural material is warranted, as is revision to the goal exposure plan for this material*. Some conservatism in adjusting q seems prudent, because the shift is substantial. We recommend that q for C-II-N material be revised to 0.60×10^{-39} , about a factor of two lower than the previous value.

For C-II-E material q was estimated to be 1.75×10^{-39} , with 95 per cent confidence limits of 0.74 and 3.50×10^{-39} . This estimate is lower, but not significantly, than the currently used value of 2.65 . No revision to q for C-II-E material is warranted, from these data.

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*A revised goal plan will be recommended under separate cover, in line with current procedure.

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HW-68737

-4-

March 3, 1961

APPENDIX I

Axial Flux Data

Axial flux distribution data used in this analysis were compiled from weasel data from numbered uranium columns. Most of the tubes weaseled were irradiated under various production tests (a large number under PT-IP-216-A) or they were numbered columns charged under C reactor's flux monitoring program. From these data, four regions in the central zone of the reactor were adequately characterized. These regions are roughly outlined on Figure 1. The tube data are summarized in Tables 1 and 2.

From the data it was concluded that in Regions III and IV (see Figure 1) the rupture potential related to axial flux shape was essentially constant over the past two years. This does not imply that the flux distribution was unchanged; only that the combined effects of changes in peaking and skewing had no appreciable effect on the rupture potential, in these regions. In regions I and II, which were combined because their flux factors were not significantly different, substantial changes in rupture potential were observed over the past two years. No attempt is made, herein, to thoroughly analyze the cause(s) of the shifts in axial flux shape. The data from these areas of the reactor are plotted on Figure 2; the time periods defining shifts in rupture potential were arbitrarily selected, but seem reasonable. It would appear from the data that a shift in flux shape occurred some time in March - April, 1959, as evidenced from tubes discharged about June - July, 1959. In November, 1959, a residue of 3X balls could not be removed from some hoppers in the front part of the reactor, and the data from tubes discharged beginning about January, 1960, indicate that the residual balls apparently aggravated an already poor situation. Beginning in late July, 1960, mixed enriched-natural columns were charged into the reactor as part of a flux improvement program. By September-October about 85 per cent of the current inventory of this type of column had been charged, and the flux data from tubes discharged since about September, 1960, reflect a definite improvement.

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HW-68737

March 3, 1961

FIGURE 1

Axial Flux Data Regions

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HW-68737

-6-

March 3, 1961

TABLE 1

RUPTURE POTENTIAL RELATED
TO AXIAL FLUX DISTRIBUTION

<u>Region I</u>			<u>Region II</u>		
<u>Tube Number</u>	<u>Discharge Date</u>	<u>Rupture* Potential</u>	<u>Tube Number</u>	<u>Discharge Date</u>	<u>Rupture* Potential</u>
2563	3/29/59	1.9	2572	3/29/59	1.6
2463	3/29/59	1.5	2081	4/27/59	1.5
2262	3/29/59	1.8	2281	4/30/59	4.6
2263	3/29/59	1.8	2477	5/12/59	1.9
2666	3/29/59	0.8	2474	5/25/59	1.9
2260	3/29/59	1.4	2775	6/30/59	6.0
2760	3/29/59	1.4	2477	7/20/59	4.7
2763	4/27/59	0.7	2775	11/7/59	1.7
2663	4/27/59	0.9	2484	12/9/59	5.0
2766	4/27/59	1.1	2171	1/14/60	11.0
2564	5/12/59	1.7	2576	1/21/60	5.4
2464	5/12/59	5.4	2875	2/5/60	7.0
2267	8/31/59	3.1	2276	2/5/60	5.0
2564	9/10/59	3.3	2276	3/1/60	5.0
2464	9/10/59	4.2	2771	3/29/60	4.4
2564	12/10/59	2.4	2774	3/29/60	12.0
2464	12/10/59	2.7	2077	7/24/60	6.4
2362	12/27/59	5.0	2671	7/24/60	5.3
2168	1/3/60	4.2	2774	9/4/60	4.0
2567	3/29/60	5.0	2081	10/17/60	3.7
2168	4/19/60	6.5	2683	10/17/60	1.7
2064	6/30/60	1.5	2683	1/17/61	4.8
2264	6/18/60	3.6	2081	1/17/61	2.2
2357	6/3/60	6.8	2074	1/17/61	2.3
1868	7/24/60	13.0	20774	2/4/61	3.5
2264	10/18/60	1.4			
2167	11/7/60	1.8			
2059	12/4/60	1.6			
2158	12/4/60	1.9			
2167	1/17/60	5.2			

*Rupture potential of chopped cosine flux shape taken as 1.0.

DECLASSIFIED

HW-68737

-7-

March 3, 1961

TABLE 2

RUPTURE POTENTIAL RELATED
TO AXIAL FLUX DISTRIBUTION

<u>Region III</u>			<u>Region IV</u>		
<u>Tube Number</u>	<u>Discharge Date</u>	<u>Rupture* Potential</u>	<u>Tube Number</u>	<u>Discharge Date</u>	<u>Rupture* Potential</u>
3475	4/27/59	2.5	1678	3/4/59	2.3
3472	4/27/59	1.5	1675	4/22/59	1.6
3478	4/27/59	0.3	0775	4/26/59	1.8
3974	9/24/59	0.9	1468	4/28/59	1.8
3979	9/24/59	0.9	1074	7/20/59	2.0
3982	9/24/59	0.7	0973	8/4/59	1.8
3773	12/28/59	1.2	1074	11/7/59	1.1
3774	12/28/59	1.3	0973	12/10/59	1.5
3373	2/10/60	1.3	1069	6/18/60	2.0
3677	5/3/60	0.8	1568	9/24/60	2.7
3668	5/3/60	0.7	1069	10/9/60	0.5
3375	6/3/60	1.0	1076	10/9/60	1.5
3568	6/3/60	2.7	0970	12/4/60	1.4
3576	6/3/60	2.9	1673	12/4/60	2.8
3874	6/3/60	0.7	1580	1/17/61	2.1
3975	6/4/60	1.8	1568	2/4/61	2.1
3873	6/18/60	1.4			
3569	7/24/60	1.0			
3573	7/24/60	1.0			
3574	7/24/60	1.2			
3671	7/24/60	0.6			
3672	7/24/60	1.3			
3673	7/24/60	0.7			
3674	7/24/60	0.7			
3873	10/9/60	0.6			
3874	10/9/60	1.0			
3280	11/7/60	0.3			
3966	12/4/60	1.3			
3280	2/4/61	2.2			

*Rupture potential of chopped cosine flux shape taken as 1.0.

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HM-68737
March 3, 1961
-8-
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FIGURE 2

March 3, 1961

APPENDIX IIMetal Quality Trends

Underlying trends in intrinsic metal (fuel) quality over the past two years were estimated from the total IPD irradiation experience. The following paragraphs are a capsule summary of the work that has been done on this problem. The major trend over the past two years, which has been exhibited by all production fuel types from the rupture control charts*, has been a steady improvement. A temporary decline in performance was observed during the first quarter of CY-1960, which appears to have been largely confined to material fabricated in the last quarter of CY-1959. This decline was apparently suffered in all fuel types, regardless of geometry or cladding alloy.

Figure 3, P 10, shows curves of the overall plant metal performance level (relative) versus time for CY-64 and X-8001 clad materials, as developed from normalized rupture index data. The negative slope indicates improvement. The curves, as drawn in, are the "best-fits" of the plotted data. In preparing these data, the aforementioned decline was assumed to be atypical, was assessed as being a factor of two, and the bias was removed. Note that the rate of improvement for X-8001 material was greater than for C-64 material. Similar differences in performance between C-64 and X-8001 clad materials have been observed in the FPD autoclaves.

APPENDIX IIIEstimation of q Values(1) Flux Factors

The overall flux factor (ϕ') for a particular time period was estimated from the following relationship:

$$\phi' = (.33)(\phi_{I,II})_i + (.33)(\phi_{III})_i + (.33)(\phi_{IV})_i$$

This is simply a statement to the effect that, on the average, one third of the total rupture index calculated for natural material, for example, would be in tubes whose flux-related rupture potential was described by the changes noted in Regions I and II, and so on. The same equation was used for the enriched material calculations, although it is possibly non-conservative because the proportion of the enriched rupture index that would come from tubes irradiated in Regions I and II is probably closer to 1/5 than to 1/3. The flux corrections for the enriched material are uncertain, regardless, because there are no flux data available from within the enrichment ring itself.

*The rupture control charts are routinely published in the monthly "Rupture and Water Leak Memorandum."

DECLASSIFIED

HW-68737

-10-

March 3, 1961

FIGURE 3

March 3, 1961

Flux factors in the various regions for the selected time periods are summarized in Table 3 below.

TABLE 3

<u>Time Period</u>	<u>$\phi_{I,II}$</u>	<u>ϕ_{III}</u>	<u>ϕ_{IV}</u>	<u>ϕ'</u>	<u>Relative* ϕ'</u>
(1) Jan. thru May 1959	1.68	1.20	1.60	1.49	0.82
(2) June thru Dec. 1959	3.56	1.20	1.60	2.12	1.17
(3) Jan. thru Aug. 1960	5.02	1.20	1.60	2.60	1.44
(4) Sept. 1960 thru Feb. 1961	2.62	1.20	1.60	1.81	1.00

(2) Quality Factors

The quality factors (ϕ) for C-64 and X-8001 clad materials were based on the metal performance level curves of Figure 3 (Appendix II). The overall quality factor (ϕ') for the reactor at a given time was estimated by roughly proportioning the amounts of C-64 and X-8001 being irradiated. For the first three quarters of CY-1959 the quality of C-64 material was assumed to be controlling; for the fourth quarter of CY-1959 and the first quarter of CY-1960, a 50-50 contribution for each alloy was assumed; by the third and fourth quarters the quality of both types of materials were essentially identical, so correct apportionment was no longer of concern. The quality factors for both C-64 and X-8001 material were adjusted upward by a factor of two from the estimates of Figure 3, for first quarter CY-1960 irradiation experience. The quality factor for C-64 material for the second quarter CY-1960 irradiations was adjusted upward by 50 per cent from the Figure 1 value, on the basis that most of this material was of the same vintage as that irradiated during the first quarter CY-1960.

The quality factors used in this analysis are shown in Table 4 below.

*Relative to period (4).

March 3, 1961

TABLE 4

Time Period	$\bar{e}$		$\bar{e}'$	Relative* $\bar{e}'$
	C-64	X-8001		
First Quarter 1959	3.2	---	3.2	2.13
Second Quarter 1959	2.5	---	2.5	1.67
Third Quarter 1959	2.2	---	2.2	1.47
Fourth Quarter 1959	2.0	2.5	2.2	1.47
First Quarter 1960	3.6	4.0	3.8	2.53
Second Quarter 1960	2.5	1.7	2.0	1.33
Third Quarter 1960	1.6	1.5	1.6	1.07
Fourth Quarter 1960	1.5	1.5	1.5	1.00

(3) Adjusted Δ RI

The monthly rupture index (Δ RI) data from January, 1959, through January, 1961, were normalized to the "current" flux and quality conditions by multiplying by the appropriate flux and quality factors developed in the preceeding sections of this Appendix. The adjusted rupture index (Δ RI) data were then summed over the entire time period. The observed number of ruptures** for the same time period were then summed. The metal performance level multiplier (q), as defined in the body of this report, was then estimated. These calculated q 's, then, are estimates of the "current" values.

The rupture index data are summarized in Table 5 below.

*Relative to fourth quarter 1960.

**Excludes second failures in multiple failure lots. One rupture incurred in early February, 1961, was also included.

DECLASSIFIED

HW-68737

-13-

March 3, 1961

TABLE 5

<u>Month</u>	<u>Relative Flux Factor (ϕ')</u>	<u>Relative Quality Factor (ρ')</u>	<u>Rupture Index*</u> <u>(ΔRI)</u>		<u>Adjusted Rupture*</u> <u>Index ($\Delta RI'$)</u>	
			<u>C-II-N</u>	<u>C-II-E</u>	<u>C-II-N</u>	<u>C-II-E</u>
Jan. 1959	0.82	2.13	0.24	.021	0.41	.037
Feb.	0.82	2.13	0.49	.036	0.86	.063
Mar.	0.82	2.13	1.20	.077	2.09	.134
Apr.	0.82	1.67	2.05	.058	2.81	.079
May	0.82	1.67	2.09	.085	2.85	.116
June	1.17	1.67	1.02	.086	2.00	.168
July	1.17	1.47	1.14	.121	1.95	.208
Aug.	1.17	1.47	0.96	.068	1.65	.117
Sept.	1.17	1.47	0.59	.060	1.01	.103
Oct.	1.17	1.47	1.35	.201	2.32	.346
Nov.	1.17	1.47	1.26	.173	2.17	.298
Dec.	1.17	1.47	0.95	.100	1.63	.172
Jan. 1960	1.44	2.53	0.46	.081	1.67	.295
Feb.	1.44	2.53	0.58	.173	2.11	.630
Mar.	1.44	2.53	0.45	.090	1.64	.328
Apr.	1.44	1.33	0.40	.053	0.77	.172
May	1.44	1.33	1.26	.094	2.41	.180
June	1.44	1.33	0.89	.085	1.70	.163
July	1.44	1.07	0.84	.116	1.29	.179
Aug.	1.00	1.07	1.58	.107	1.69	.115
Sept.	1.00	1.07	0.89	.045	0.95	.048
Oct.	1.00	1.00	2.07	.083	2.07	.083
Nov.	1.00	1.00	2.99	.145	2.99	.145
Dec.	1.00	1.00	0.97	.189	0.97	.189
Jan. 1961	1.00	1.00	2.12	.211	2.12	.211

*The numbers tabulated are the true numbers multiplied by 10^{-39} .

DECLASSIFIED

HW-68737

-14-

March 3, 1961

Rupture history over the subject time period is summarized in Table 6.

TABLE 6

<u>Month</u>	<u>Number of Ruptures*</u>	
	<u>Natural</u>	<u>Enriched</u>
January 1959	0	0
February	0	0
March	0	0
April	1	0
May	2	0
June	2	0
July	1	0
August	0	0
September	0	0
October	1	0
November	0	0
December	1	0
January 1960	4	0
February	3	0
March	1	1
April	1	1
May	0	1
June	1	1
July	0	1
August	0	0
September	1	0
October	0	1
November	1	0
December	0	2
January 1961	1**	0

*Excludes second failures in multiple failure lots.

**Rupture was actually incurred on February 2, 1961, but was included in this analysis.

DECLASSIFIED

HW-68737

-15-

March 3, 1961

From the data of Tables 5 and 6, above, the "current" metal performance level multipliers (q) for C-II-N and C-II-E material are estimated as follows:

For C-II-N Material

$$\begin{aligned} q_{C-II-N} &= \frac{\sum R}{\sum \Delta RI'} \\ &= \frac{21}{(44.13)(10^{39})} \\ &= 0.48 \times 10^{-39} \end{aligned}$$

(With 95% confidence, q lies between 0.30 and 0.72 x 10⁻³⁹)

For C-II-E Material

$$\begin{aligned} q_{C-II-E} &= \frac{\sum R}{\sum \Delta RI'} \\ &= \frac{8}{(4.58)(10^{39})} \\ &= 1.75 \times 10^{-39} \end{aligned}$$

(With 95% confidence, q lies between 0.92 and 3.50 x 10⁻³⁹)

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