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NOTE ON EFFECT OF EXPOSURE ON
I & E FUEL ELEMENT RUPTURE RATE

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NOTE ON EFFECT OF EXPOSURE ON
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INTRODUCTION

The rupture model presently being used by IPD Research and Engineering is the Weibull cumulative distribution function written:

$$F(X) = 1 - \exp(a_0 P^{a_1} T^{a_2} M^{a_3})$$

Where: $F(X)$ = failure rate in number of ruptures per total number of tubes,

P = average tube power

T = average tube outlet temperature

M = exposure

a_0, a_1, a_2, a_3 = parameters determined from rupture experience.

In the region of interest, say below rupture rates of about 0.10, the model can be expressed approximately as:

$$F(X) = a_0 P^{a_1} T^{a_2} M^{a_3}$$

The parameters $a_1 = 3.3$, $a_2 = 8.7$, and $a_3 = 5$ were estimated⁽¹⁾ from experience with solid slug side-other and side-hot spot failures occurring from the spring of 1956 to the end of 1957, and were found to hold quite well for experience through 1958 as well. The model using the aforementioned estimates of the a_1 , a_2 , and a_3 parameters is being used in numerous ways, including fuel performance measurement (estimating values of a_0 , in essence), reactor optimization, project justification, production scheduling and forecasting, and fuel element test design.

From time to time, doubt has been expressed about the appropriateness of applying these estimates of the a_1 , a_2 , and a_3 parameters, to failures in I & E fuel elements. Recently concern has centered specifically on the parameter a_3 , currently assumed to be five (5). This note concerns itself principally with the validity of this parameter.

DISCUSSION

The concern about the validity of currently used parameter estimates is certainly understandable. There would be an economic benefit from being able to show that the rupture rate is considerably less sensitive to exposure, i.e., a_3 less than 5. Increase (decrease) in plant performance parameters of interest, e.g., unit costs, production, residual income, could be achieved by adjusting operating conditions accordingly. But comparable losses will occur if adjustments are made based on an unwarranted conclusion that the estimate is incorrect.

Of the parameters in the model, the exposure effect is by far the easiest to study and probably the most precisely defined. The effect of exposure on I & E rupture rates has been examined a large number of times, because checking the

(1) HW-55377, "Analyses and Correlations of HAPO Rupture Experience With Natural Uranium Material," Bloomstrand, RR, and WI Neef, 4/23/58, (Secret).

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exposure dependence of the rupture rate model was an integral part of the determination of the current level of metal performance* until a switch several months ago to an improved "Rupture Index" method of determination. The checks mentioned above and other studies that have been made of I & E rupture experience show no reason to revise the exposure parameter estimate. These studies cover most of the experience up to the fall of 1959. Few failures occurred in the remainder of 1959. A shift in the performance level of C-II-N and O-II-N material near the end of the year would require that data on these types since then be studied separately.

Data obtained on C and K natural and enriched I & E slugs prior to 1959, although scanty, were analyzed(2) with the conclusion quoted: "Side rupture rates experienced to date for I & E fuel elements give rupture rate curves which do not differ significantly from those predicted on the basis of solid fuel elements experience."

Results of the checks on exposure dependence with 1959 data are shown on Figures 1, 2, and 3. On each figure, M^4 , M^5 , and M^6 exposure dependence curves have been drawn through the approximate centroid of the data. The reader may judge for himself which is the best fit, on the average. No sizeable deviations from an M^5 relationship are evident on these charts.

The experience with the depleted uranium load at C reactor is shown by Figure 4. The rupture rate in this material appeared to have a more sensitive dependence on exposure. Worthy of note is the fact that the irradiation of this material was continued until the rupture rate was about a factor of 40 higher than on any of the other figures. The lack of "leveling-off" of the rupture rate curve at failure rates beyond these tolerable for a full pile load, say .003, is contrary to any hope that a leveling-off would occur with the normal I & E loads, were irradiations to be extended to higher exposures.

There are sound reasons why one would expect the estimates of the a_1 , a_2 , and a_3 parameters from solid slugs to hold for I & E slugs. The reasons will not be discussed herein, however, they are substantiated by the fact that failures observed in I & E slugs are similar in appearance to those that occurred in solid slugs. Nonetheless, the rupture experience for I & E slugs has been and will continue to be analyzed at appropriate times, with the intention of revising the parameter estimates when warranted. This does not mean that the current parameter estimates would be substantially revised at the first "hint." Matters of pure chance supply these apparent "hints" or "indications" virtually continually, making it difficult to detect significant deviations from the values currently in use.

Large numbers of failures are needed to evaluate the parameters in the model with good precision. It is primarily the influence of chance variations that makes this so, although the uncertainty in reactor data has some effect. There is nothing that can be done to eliminate the uncertainty due to pure chance. An additional factor in the problem is that power and outlet temperature change together, for the most part, and tube flow rates are nearly the same for each design of I & E slug. This means that there is very little spread in the power and temperature data, i.e., differences in average power between tube charges operated at the same average temperature, and vice versa, are small. This small spread in data requires that a very large number of failures be used to determine the separate effects of power and temperature.

* This determining of the metal performance level is equivalent to determining the value of a_0 in the model. The metal performance level is examined frequently to see if it has changed; changes usually require adjustment in reactor conditions.

(2) Jaech, JL, "Comparing Observed Rupture Rates of I & E Fuel Elements With Predicted Rates," HW-58416 RD, 12/5/58, (Secret).

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Figure 1

K-II-N RUPTURE RATE VS. EXPOSURE

January Through June 1959

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Figure 2

O-II-N RUPTURE RATE VS. EXPOSURE

January Through July 1959

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Figure 3

O-II-N RUPTURE RATE VS. EXPOSURE

March Through October 1959

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Figure 4

C-REACTOR I & E DEPLETED RUPTURE RATE VS. EXPOSURE

STATUS AT DISCHARGE OF ORIGINAL LOAD

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To date, the pattern of failures in I & E slugs does not indicate a need to revise the model, nor is the quantity of data sufficient, at this time, to justify undertaking a large scale detailed analysis of power, temperature and exposure relationships. The assignment of priority to performing such analyses is a balance between manpower utilization, probable results, and economic effects of these factors. So far, the overriding factor has been that the probable results would not warrant revision to current parameter estimates.

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