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ELIMINATION OF TOA CORROSION LIMITS

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IRRADIATION PROCESSING DEPARTMENT

ELIMINATION OF TOA CORROSION LIMITS

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ELIMINATION OF TOA CORROSION LIMITS

In 1958, planned large scale use of the new I & E slug geometry at more severe operating conditions than had been generally experienced suggested a possible compromise in reactor life and safety if a reasonable degree of rupture control with the new type of element was not maintained. The formalized slug corrosion limit (Top-of-Annulus limit) was issued as a Process Standard at the time of the full-scale loading of I & E geometry fuel elements to provide this limit for reactor operation.

The loading of I & E slugs at all reactors has been accomplished and initial power level increases have been made. To date, 67 I & E ruptures have been sustained including both "hole" and "annulus" failures. The type and behavior of ruptures to be expected with I & E geometry are now characterized. Recent studies have indicated that the I & E failure experience is consistent with the general mathematical rupture model formulated from analysis of solid slug experience. Increased confidence in the use of this model in combination with Optimization Studies⁽⁷⁾ permits greater emphasis to be placed on the rupture model as a guide for reactor operation. It is the purpose of this report to present the basis for substituting the rupture model for the TOA corrosion limits for rupture control purposes.

SUMMARY

Substitution of the rupture model for TOA corrosion limits as a basis for rupture control is recommended. The rupture model is believed to characterize more accurately the operational environmental factors contributing to current slug failure experience than does the TOA corrosion model.

The TOA corrosion limit model is conceptually conservative. This model characterizes the general corrosion that occurs on any slug subjected to "in pile" irradiation and presumes uniformity in slug quality and operational climate. Current "hot spot" and side failures may be assumed to be caused by non-uniformity in metal quality and operating environment. Failures will generally occur at less severe power-temperature conditions than failures predicted by the uniform corrosion model. Continued reliance upon the corrosion model as a means of rupture control may unnecessarily restrict reactor power levels.

This proposed change in limit philosophy can be made without compromising reactor safety or life. The effect of operating above existing TOA corrosion limits will be simply that of increasing rupture frequency at rates approximated by the rupture model. The threshold for failure rates predicted by the corrosion model will be at power levels approximately 30 per cent above normal operating levels. Further, it is proposed that rupture potential control be improved through the use of a broad Operational Severity Index (OSI) restriction in the Process Standards.

In addition, too great an emphasis on corrosion limit consideration may be misleading when concepts for improved fuel element performance are considered.

DISCUSSION

Revaluation of the TOA corrosion limit after six month's experience with I & E

fuel elements is desirable. To date, 67 I & E ruptures have been sustained including both "hole" and "annulus" failures and increased understanding of the relationship between I & E slug and solid slug experience has been obtained. With this increased understanding we may now critically review the purpose and basis of the TOA corrosion limits and consider the substitution of the rupture model as a more realistic guide to reactor production and safety objectives. The following discussion outlines the aspects of substituting the rupture model for TOA corrosion limits for rupture control purposes.

Character of TOA Corrosion Limits

TOA corrosion limits are based on empirical data characterizing slug corrosion rate as a function of slug power or heat flux, and slug surface temperature. These data were obtained from "in pile" production tests of both M-388 and 1245 jacketing material. Slug weight loss values were plotted against surface temperature and heat flux calculated from routinely collected tube operating data. The general character of these relationships permit the formulation of a model⁽¹⁾ describing the corrosion behavior of slug jacketing material within the region of normal operating conditions. Recent studies⁽²⁾ have indicated that a significant difference in corrosion behavior of 1245 and M-388 (X-8001) aluminum jacketing material exists at corrosion rates above 4 mils/month. Under more severe conditions of temperature and power the 1245 aluminum shows decidedly greater corrosion losses than does the M-388 material. The present corrosion limits were established primarily through the use of a "cut off" corrosion rate of 6.5 mils/month. (A "cut off" rate of 9.0 mils/month has been suggested for M-388 material.) Above these "cut off" rates, extrapolation into regions of uncertainty would no longer be prohibited by Process Standards if TOA corrosion limits are rescinded. Evaluation of the associated potential risk requires perspective of the general character of corrosion limits.

The TOA corrosion limits are designed to prevent or control "uniform corrosion" failures. "Uniform corrosion" is another name for the general corrosion mechanism to which all slugs are subjected during irradiation rather than being a unique mechanism. Implicit in the limit calculations are these principal assumptions:

1. Uniform metal quality, i.e., no quality differences between slugs,
2. Consistent geometric positioning and alignment of slugs within a process tube,
3. No other or unknown factors effecting slug failure potential unequally.

The above assumptions are obviously unrealistic. Higher powers and temperatures would be required for failures predicted by this idealistic model than for ruptures actually sustained because of non-uniform metal quality and non-uniform irradiation climate. Re-stated, hot spot and side failures occur because of discrete differences in alignment, metal quality, and/or other conditions. Problems associated with these differences would have to be solved and powers and temperatures raised considerably before "uniform corrosion" ruptures would be encountered. Thus, the apparent risk of allowing operation in regions of uncertain corrosion rates is essentially offset by the necessity of restricting power levels and temperatures from hot spot rupture considerations.

A comparison between the rupture control point) for controlling hot spot failures) and the present TOA corrosion limit for any given reactor and fuel element is not meaningful unless the present conservatism in TOA limits is also considered. Conservatism has been introduced into the TOA corrosion limit calculations through

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several different factors; the most important of these are briefly discussed below:

1. The AlSi braze layer contribution to the effective can wall thickness has been neglected. Observance of visible AlSi during post irradiation inspection of non-ruptured slugs would indicate a significant contribution of the AlSi to failure prevention.
2. Conservative "R" values were used for calculation of slug surface temperature thus resulting in conservative limits.
3. Implicit in the corrosion limit is the assumption that a slug column will be subjected to maximum power-temperature conditions during the entire "in pile" residence time, i.e., that the tube will operate continuously at limits. This, of course, is not characteristic of even a most limiting tube in the reactor. Periodic operation at less severe conditions of power and temperature will result in markedly reduced corrosion rates with an accompanying reduction in failure probability.

An order of magnitude estimate of the total combined conservatism in the TOA corrosion limit in terms of tube power is from 75 to 150 kw. Corrosion limits calculated without conservatism will be considerably higher than the rupture control point (RCP). The present TOA corrosion limits, (calculated with the above discussed conservatism), in some instances may coincidentally indicate tube power and outlet temperature limits similar to the RCP. It is, however, both more objective and realistic to use the rupture model as an operational guide rather than the TOA corrosion concept.

Character of the Rupture Model

The rupture model has been discussed in considerable detail in other documents⁽²⁾. Only a very brief description of the model is included here. It is not a magic or "cure all" formula; but it does represent the best understanding of rupture behavior that is currently available.

The rupture model is a mathematical correlation of slug failure rates for side and hot spot failures as a function of average power, average outlet water temperature, and exposure. This correlation is generally based on solid slug failure experience subsequent to the Spring of 1956 at C Reactor and the old reactors.

The model may be stated as:

$$RR = A E^5 P^{0.3} T^{8.7}$$

Where:

RR = Rupture rate (failures per unit of throughput)

A = Proportionality constant differing for C, K, and old reactors

E = Exposure (MWD/T)

P = Tube power (kw)

T = Outlet temperature °C

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or simply, that rupture rate will vary exponentially with power, temperature, and exposure.

The above model has been used as the basis for Rupture Control Point recommendations at all reactors subsequent to the Spring of 1958. Recent studies have indicated that the I & E failure experience is not inconsistent with the general rupture model noted above. It appears that when analysis is made using parameters of surface temperature, power, and time on the basis of estimated slug conditions, that side failure rates for I & E material are consistent with past solid slug behavior. There is also additional evidence that "hole" failure experience with I & E elements can be predicted from the same theoretical failure rate model.

To facilitate the use of this model as a guide to reactor operations, it is proposed that an Operational Severity Index (OSI) be established; defined as follows:

$$OSI = \frac{(P)^{3.3}}{(1000)} \frac{(T)^{8.7}}{(100)}$$

where: P is the average of the ten highest powered tubes and T the average of the corresponding outlet temperatures.

The OSI thus becomes a measure of rupture producing reactor climate to which slugs are subjected during irradiation. Although in the simple form above only tube power and outlet temperature variations are considered, it is quite possible that in the future it will be feasible to also factor in flux peaking, tube R values, etc. The OSI can be considered together with "in pile" residence time and metal quality variations to characterize slug performance.

Reactor operation at a constant OSI with constant exposure would be identical in principle with operation at a constant rupture potential. It can provide a fairly workable method of measuring the severity of the rupture producing operational factors and could serve as a substitute basis for Process Standards rate of tube power increase restrictions and as a basis for recommendations relating to rupture control points.

Graphical Comparison of the Rupture and Corrosion Models

A graphical comparison can best illustrate the inherent differences in the rupture and corrosion models. In Figure 1, rupture probability for a single tube is plotted as a function of power for the rupture model and for the M-388 and 1245 corrosion models. Rupture probabilities were determined⁽³⁾ from the corrosion model using calculated corrosion rates, can wall thickness distribution data⁽⁴⁾ and an assumed residence time of 60 days. Rupture model failure probabilities⁽³⁾ were determined using slug surface temperatures, heat flux, and the same residence time. For these calculations, flow, inlet temperature, R values, and residence time were held constant while tube power and, correspondingly, outlet temperature were varied. Both hole and annulus conditions were considered in all calculations. K-III-N slugs were used for this particular comparison but it can be shown that the general relationships illustrated in the accompanying figures will be the same for all present slug geometries.

A study of Figure 1 gives rise to some interesting conclusions. If a hot spot rupture probability of 0.02 is predicted for a high powered central zone tube

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the probability is virtually zero of having a "uniform corrosion failure." Or re-stated, if a tube hot spot rupture probability of 0.02 is predicted, a power increase of 25 to 30 per cent would be required before a significant probability of "uniform corrosion" failures with 1245 material would be encountered. An even greater power increase would be necessary for the occurrence of an M-388 "uniform corrosion" failure. It is difficult to visualize power increase of this magnitude being taken without the occurrence of an inordinate number of "hot spot" failures unless very dramatic improvements in metal quality, slug alignment, and operating climate are made. The dotted lines in Figure 1 indicate estimated rupture rates for 1245 and in M-388 jacketed slugs on a non-conservative basis. With conservatism eliminated, the corrosion model can be thought of as an upper limit to tube power increases with a given slug and jacketing material.

Figures 2 and 3 are similar except that tube power has been held constant and outlet temperature and residence time respectively, are the chosen variables. It can be seen that the relationship between the two models is generally consistent irrespective of the variable being studied.

The steep slope of the corrosion model rupture probability curve for 1245 material seemingly may be cause for concern. However, a comparison between Figure 1 and 4 would indicate that while the rupture probability of a single maximum powered tube may rapidly approach 1.0 with increasingly higher powers, the pile rupture rate would still be in the order of 6×10^{-4} . A further increase of maximum tube power in the order of 50-75 kw would be required to increase the pile rupture rate to 3×10^{-3} which is a nominal value for current failure rates. This may serve to illustrate that even if the probability of a uniform corrosion failure is high for a few maximum powered tubes in a reactor, the over-all pile failure rate will still be low and corrective action can be taken before inordinate pile rupture rates are sustained.

Effect of Rescinding the TOA Corrosion Limit

If TOA corrosion limits are rescinded it is anticipated that some reactors will be operated at tube powers higher than presently allowed by the existing limits. It is to be expected that some ruptures will occur; however, this should not be interpreted to imply that TOA corrosion limits were improperly removed. Some ruptures may occur, perhaps at lower tube powers, some coincidentally with TOA corrosion limits, and some at powers exceeding present limits.

Initial I & E experience at the K Reactors resulted in a rupture outbreak in the Spring of 1958. Calculations, using TOA corrosion concepts, dictated the power reduction which was subsequently made. It is important to note, however, that the failure experience was not inconsistent with the rupture model when parameters of surface temperature, heat flux, and time were used. It was concluded (5) (6) from the rupture examination that these failures were typical hot spot failures and not uniform corrosion failures.

In most instances, slug design concepts, mixing slug usage, etc. would indicate a similar direction of approach to improve either rupture potential or TOA corrosion limits. However, occasional conflicts do occur. An example of this is demonstrated in the consideration of 1245 or M-388 jacketing material. The use of M-388

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material would permit a substantial increase in corrosion limits. However, conversely M-388 jacketed slugs to date have experienced a hot spot rupture rate of about two to three times that of the 1245 clad fuel elements. Whether this failure ratio will continue to be sustained is unknown; however, this example may illustrate that too great an emphasis on corrosion considerations alone may be misleading when concepts for the improvement of fuel element performances are considered. The recommendation to remove TOA corrosion limits is not meant to imply elimination of TOA corrosion concepts from considerations. These concepts have been, and should continue to be used, as a useful tool for slug and tube design considerations.

As improvements are made in metal quality and problems of slug alignment and tube variations are minimized, the use of slug corrosion considerations as a basis for operating limits may again be desirable. It could be postulated that the initial loading of self-supported fuel elements in zirconium tubes might exemplify such a condition.

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- (1) HW-59737, "A Correlation of 1245 and X-8001 Aluminum Alloy Fuel Jacket Corrosion Rates," N. R. Miller, publication pending
- (2) HW-55377, "Analysis and Correlations of HAPO Rupture Experience with Natural Uranium Material," R. R. Bloomstrand/W. I. Neef, April 23, 1958.
- (3) Personal Communications from J. L. Jaech
- (4) Personal Communications from K. E. Carpenter
- (5) HW-56894, "Preliminary Evaluation of I & E Natural Failures, 105-KE Reactor," R. E. Hall, July 23, 1958
- (6) HW-56006, "I & E Enriched Slug Failures," E. C. Wood, et al, May 13, 1958
- (7) HW-58996, "Methods of Optimizing Net Return, C & K Reactors," R. L. Turner/R. R. Bloomstrand, February 2, 1959.

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FIGURE 1
SINGLE TUBE RUPTURE PROBABILITY
VS TUBE POWER

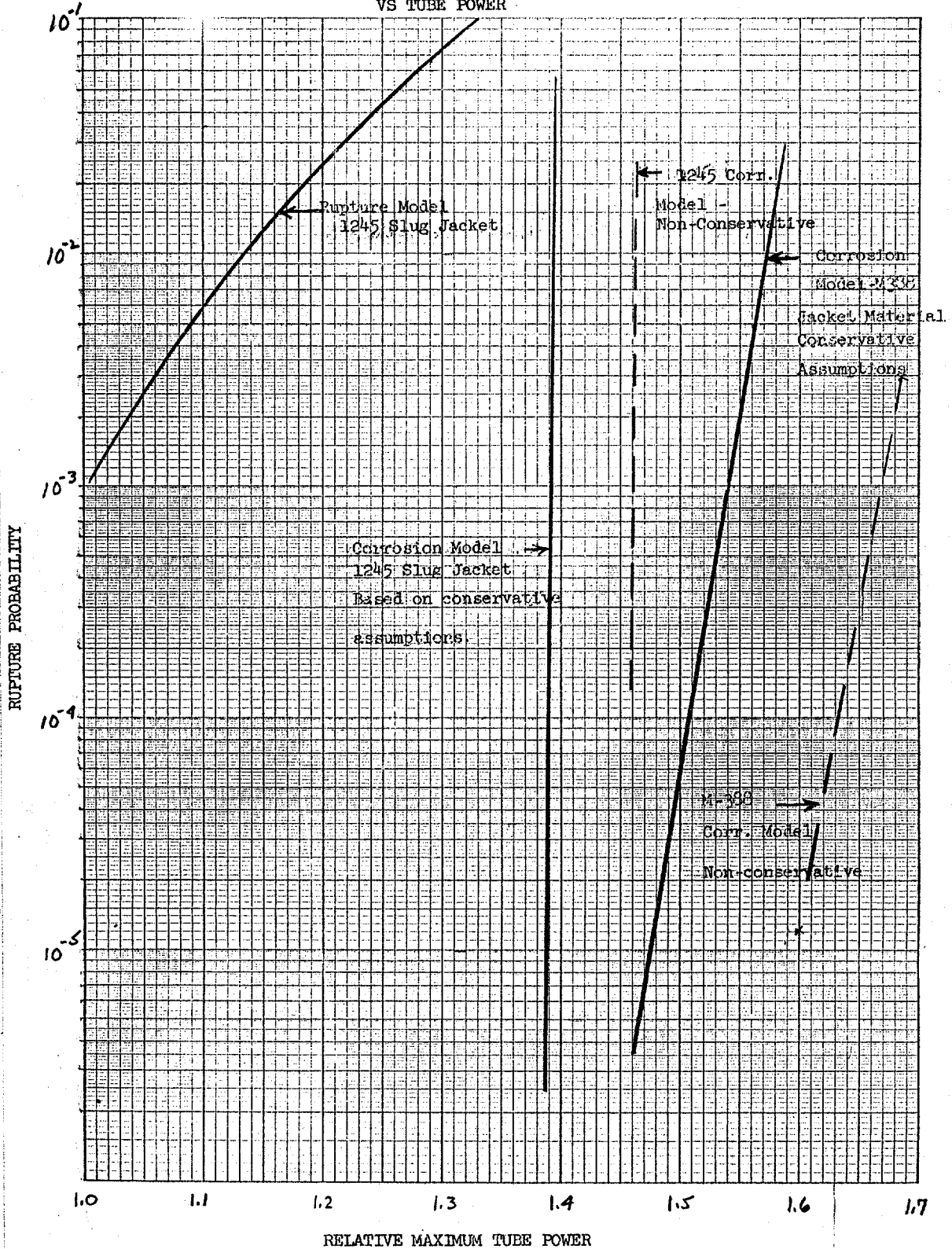


FIGURE 2
SINGLE TUBE RUPTURE PROBABILITY
VS TUBE OUTLET TEMPERATURE

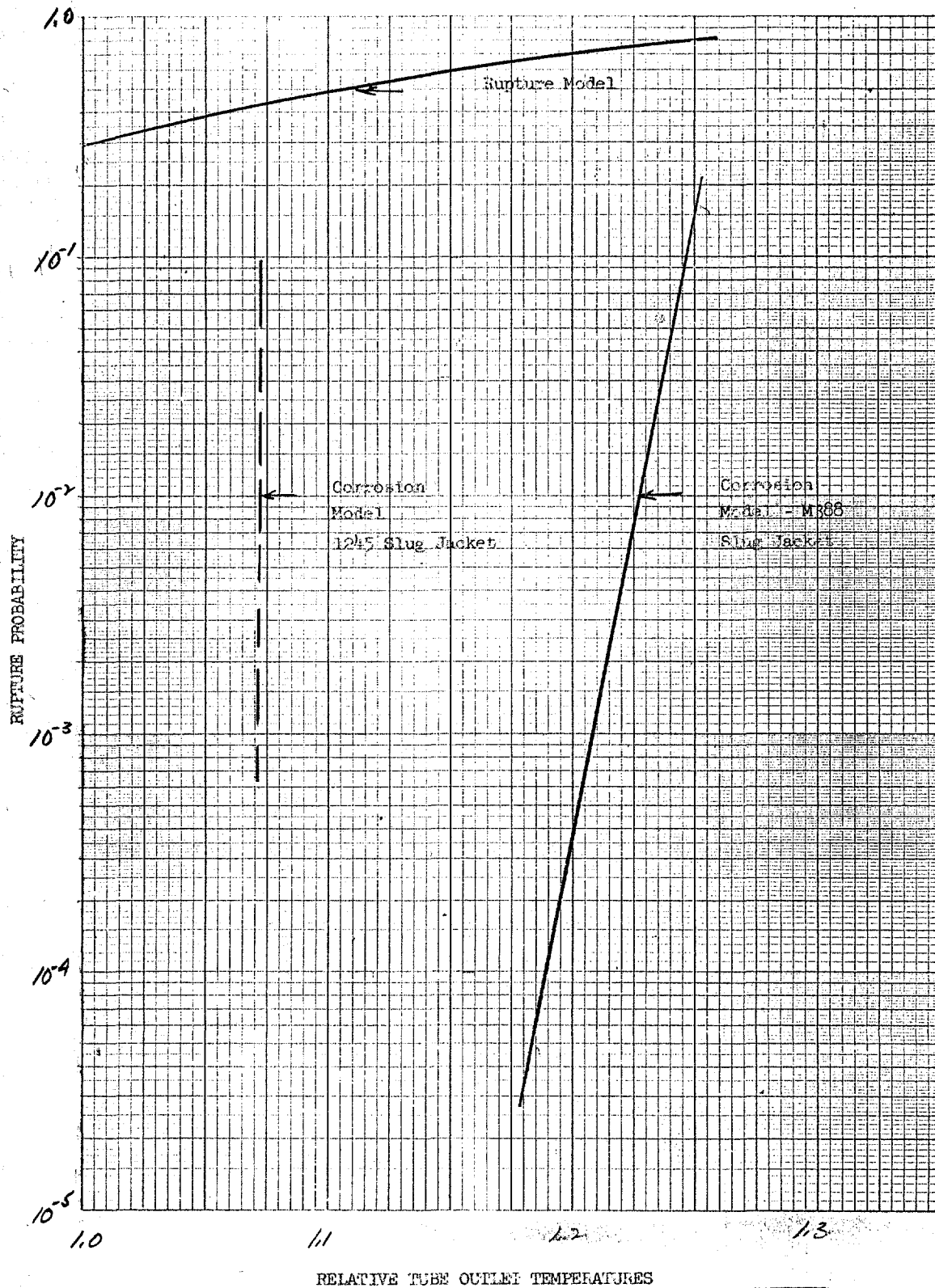
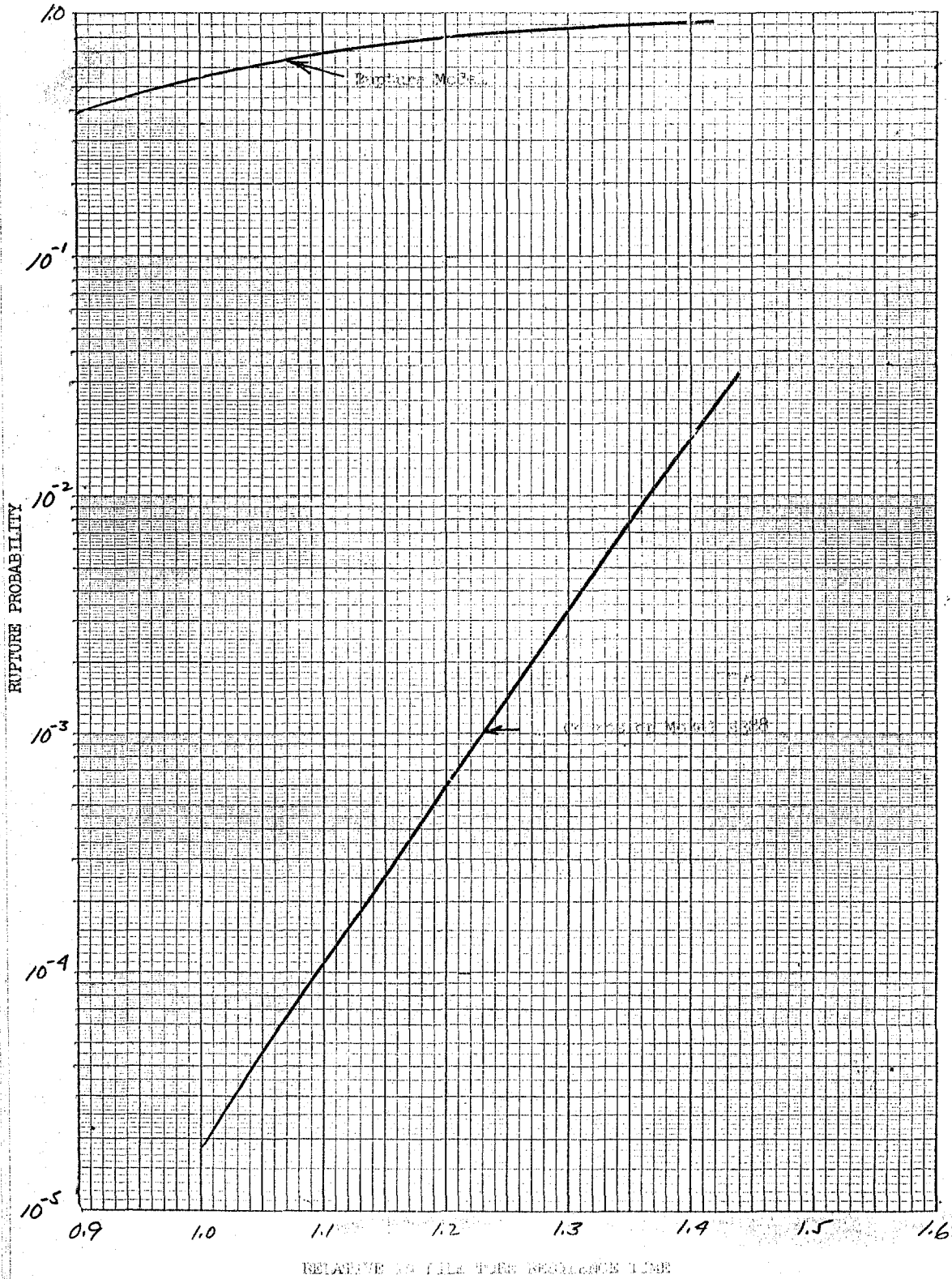
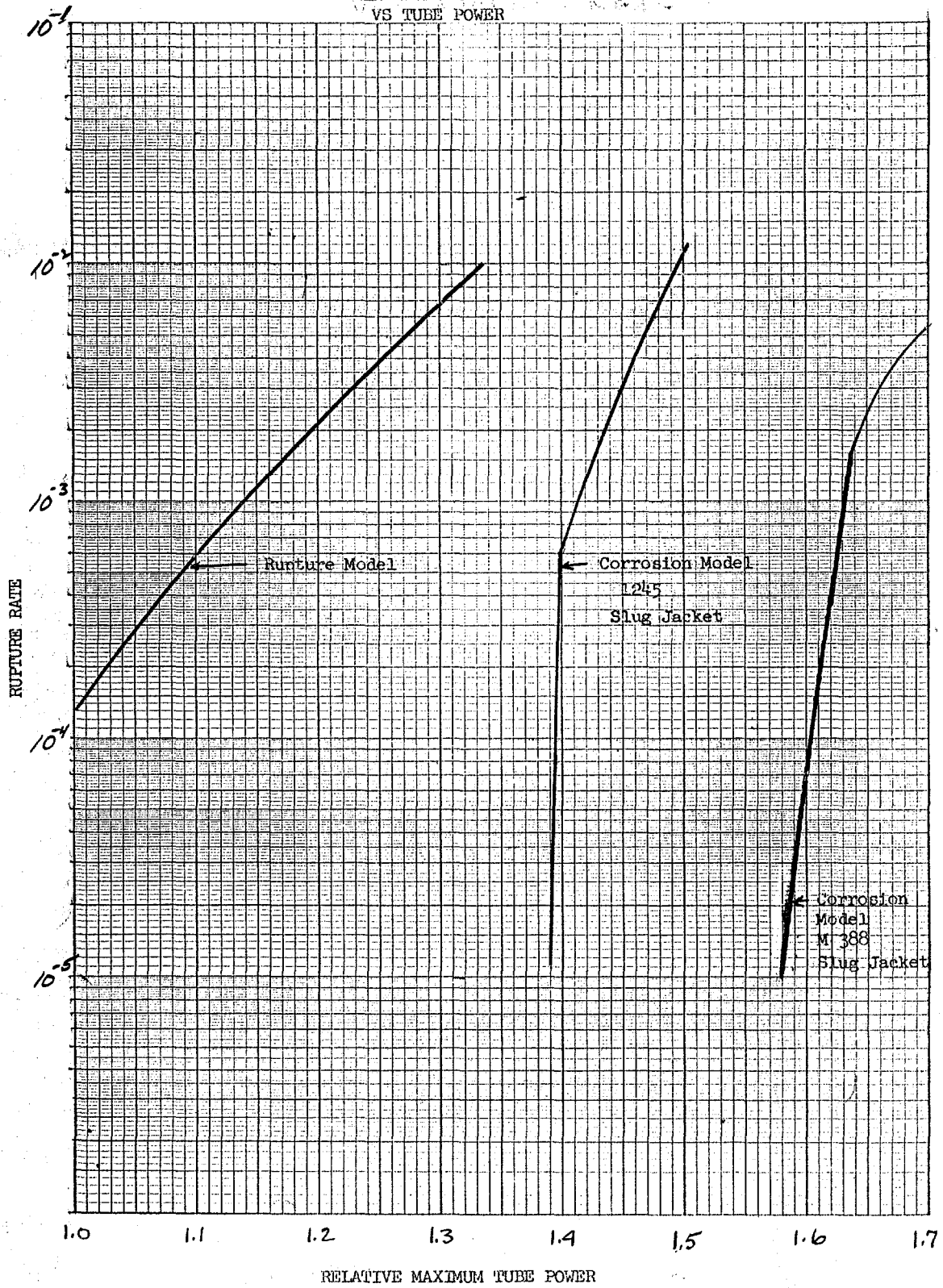


FIGURE 3
SINGLE TUBE RUPTURE RATE
VS RESIDENCE TIME



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FIGURE 4
PILE RUPTURE RATE
VS TUBE POWER



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