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A STUDY OF EXPECTED REACTOR POWERS AFTER PRO-
CG-558 AS DETERMINED BY SLUG RUPTURE
CONSIDERATIONS

AUTHOR

J. K. Anderson

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A STUDY OF EXPECTED REACTOR POWERS AFTER PROJECT CG-558
AS DETERMINED BY SLUG RUPTURE CONSIDERATIONS

INTRODUCTION:

Studies were conducted to estimate at what powers the B, D, DR, F, and H Reactors will be limited by slug rupture frequencies after completion of project CG-558. Various approaches were used in the calculations. Methods of raising the reactors to the optimum power levels in a manner so as to protect against the possibility of an excessive number of slug ruptures were studied. This report discusses these studies and presents the conclusions drawn.

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SUMMARY AND CONCLUSIONS:

Predictions were made of tube powers to which the B, D, DR, F, and H Reactors be limited by slug rupture considerations at goal exposure of 500 MWD/T after project CG-558. The predictions were based on the assumptions that:

1. Experience during the latter part of 1955 and the early part of 1956 was representative of the performance of present quality slugs.
2. Failure rates double for an increase of 100 KW in maximum tube powers..
3. Failure rates increase by a factor of 2.5 for an exposure increase of 100 MWD/T.
4. Optimum failure frequencies after completion of CG-558 will be on the order of two to three failures per month.

For some of the reactors, predictions were made using various bases. Results of the calculations were as follows:

1. The B, D, DR, and F Reactors will probably be limited to maximum tube powers on the order of 950 KW. (a)
 - a. These Reactors could be limited to maximum tube powers as low as 850 KW.
 - b. These Reactors may be limited at maximum tube power as high as 1050 KW.
2. The H Reactor will probably be limited to maximum tube powers on the order of 850 KW. The limit should not be much lower than this power, but may be as high as 1050 KW.

Because there are indications that slug rupture considerations could limit the B, D, DR, and F Reactors to maximum tube powers as low as 850 KW, and, because the relationships used in the calculations are not exact, the raising of maximum tube powers to about 950 KW (believed to be the most probable limit) immediately after startup from the project outage would involve some risk of a severe rupture situation. To guard against such an eventuality it is desirable that some exploration of slug performance be conducted before all piles are raised to higher powers. Various plans for raising powers have been considered and are presented below.

- (a) The term "maximum tube power," as used in this report is a representative maximum, and limits might best be expressed as the average of the ten highest powered tubes so that one or two tubes which might be running at abnormally high powers will not limit the reactor power level.

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- I. The plan which appears most attractive from a production standpoint is outlined as follows:
 - A. When operation is resumed at the B Reactor, the first at which Project CG-558 will be completed, maximum tube powers will be raised to 950 KW. This reactor will be used as a pilot for 950 KW tube power operation. If its experience shows that a limiting slug failure rate does not exist at this power, the B Reactor will be used to explore slug rupture performance at higher powers.
 - B. After the completion of the Project CG-558 outage at each of the D, DR, and F Reactors, these Reactors will be operated with tube powers limited to the highest level previously demonstrated to be safe at B. Reactors starting up prior to the time that maximum tube powers of 950 KW have been shown to be feasible will be limited initially to 850 KW maximum tube powers.
 - C. Since the analyses indicated that optimum tube powers at the H Reactor are somewhat lower than at the B, D, DR, and F Reactors, initial tube power limits at H may be somewhat below powers demonstrated to be safe at B. Further analyses of the slug performance at the various Reactors should be conducted before selecting initial power limits at the H Reactor.
- II. The above plan has production advantages over other plans which might be used, if the optimum maximum tube power is on the order of 950 KW or higher, but also involves some risk of economic or production losses if the optimum maximum tube power is lower. An alternative and more conservative plan which might be used is outlined as follows:
 - A. When each Reactor resumes operation at the completion of Project CG-558 tube powers will be raised to 850 KW.
 - B. The B Reactor, the first at which the project will be completed, be used to pilot power increases at the other reactors.
 1. Tube powers at this reactor will be limited to 850 KW until a sufficient number of charges have been irradiated to the goal exposure to show that the reactor is not operating near an optimum rupture rate. The time required will be at least four months.
 2. If feasible, maximum tube powers at B will then be raised to 950 KW, and held at this level until sufficient information has been obtained to indicate that further raises are practical.
 3. The above procedure will be continued, with B Reactor tube powers being raised in increments of 100 KW until the rupture experience indicates that a limiting slug failure rate has been reached or is being approached.
 - C. As soon as experience at the B Reactor has demonstrated that operation at a given tube power is feasible, the D, DR, and F Reactors will be raised to this level. The timing under this program is such that each of these reactors will spend sufficient time at a given level to provide, from its own experience, an indication of its performance at a somewhat higher level as well as having the assurance provided by the experience at B Reactor at the higher level.

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- D. The planned startup date for the H Reactor is such that should it follow the same plan as outlined for the D, DR, and F Reactors, it would be operated with maximum tube powers of 850 KW for less than one month and then be raised to a higher level. This period is insufficient to demonstrate the H Reactor performance at the 850 KW limit. Since the calculations indicate that a limiting failure rate may occur at this reactor at lower tube powers than at the B, D, DR and F Reactors, it is suggested that H be held at the 850 KW maximum tube power level for a sufficient time to show its slug rupture performance relative to that at the other reactors, or to show that at this level the failure rate is not near to being limiting. Thus, the level at this reactor would be raised in a step-wise manner with each level being held a minimum of three to four months.

III. A comparison of the advantages and disadvantages of the two plans outlined above showed that:

- A. If maximum tube powers on the order of 950 KW are optimum, as is probably the case, the plan outlined in Item I, above, will produce a total of about 43,000 MWD, more than will the more conservative plan outlined in Item II if the startup schedule is as shown in Figures I and II. If the startup dates for the DR, D, and F Reactors are delayed for one month the gains from using the plan in Item I will be about 34,000 MWD and if the startups of these reactors are delayed two months the gains will be approximately 25,000 MWD.
- B. If a slug rupture limit exists at maximum tube powers of 850 KW, the use of the less conservative plan could result in either:
1. A cost of about \$90,000 for discharging about 83 tons of uranium short of goal exposure, with little or no production loss, or;
 2. No special discharging, with a loss of up to 5,000 MWD to additional slug failures, if the assumed slug rupture-power relationships are approximately correct, or;
 3. An undeterminable but probably serious production loss to ruptures if no metal is available for special discharging and if the assumed slug rupture-power relationships are greatly in error. The probability of this third event, however, is believed to be slight.

In view of the above considerations the less conservative plan appears to be best.

Plans with even less conservatism might be used, but in general these add substantially to the risk and show little probability of major production or economic gains.

DISCUSSION:

After completion of project CG-558 and the raising of the bulk outlet temperature limit to 100° C, power levels between 1500 and 1750 MW will be possible at the B, D, DR, F and H Reactors. Experience during the past year has shown that the present fuel elements, even if irradiated to a goal exposure of 500 MWD/T, would probably produce a prohibitive failure rate at such powers.

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In an effort to predict at what powers slug rupture performances might be satisfactory after the completion of CG-558, analyses of rupture rates at the various piles during the last one to two years were conducted. Using the best exposure and power relationships presently available, assuming the failure rate to double for every 100 KW increase in maximum tube power and to increase by a factor of 2.5 for a 100 MWD/T increase in exposure, these rates were extrapolated to post CG-558 conditions. In most cases no exposure extrapolation was necessary, present rates at 500 MWD/T being read directly taken from plots of failure rate vs. exposure.

In these calculations the contribution of failures by uniform corrosion and by corrosion in the region between the process tube ribs was assumed to be negligible after project CG-558. Although higher powers and water temperatures would result in higher slug corrosion rates, this should be counterbalanced to a large extent by the recent decrease in the pH of the coolant. Further, because of the decrease in goal exposure to 500 MWD/T and the fact that the higher powers will decrease the time required for the irradiation of metal to a given exposure, the irradiation period will be approximately one-half that required at present. Thus, at least at powers and temperatures at which other types of failures are expected to be limiting, total slug corrosion at time of discharge should be considerably less after CG-558 than in the past. The large-scale tube replacement during the past year should even further reduce the possibility of failures resulting from corrosion in the region between the process tube ribs.

In general, reactors were studied individually, with the recent performance at a specific reactor being used to predict its future performance. Predictions of performances at the B, D, DR, and F Reactors were also made on the basis of rupture experience at H and C. Results of these studies were rather conservative as compared with those obtained when experience at B, D, and F, was used as a basis. Because past experience has shown that the translation of rupture experience at one reactor to another reactor operating under comparable conditions is rarely valid, and because of differences (flattening, enrichment, etc.) between the B, D, DR, and F Reactors and the H and C Reactors, these conservative results were considered only to have established a point at which caution should be used in making further power increases. The level calculated from experience at the specific reactor was assumed to be most probably correct.

One further study, based on C Pile experience, indicated that if failures of the "hot-spot" type should be reduced to insignificance, higher powers will be practical. Such a reduction is possible if certain remedial actions being investigated are successful.

Results of these studies indicate that after project CG-558, with present quality slugs, limiting slug failure rates will be reached at the powers shown in Table I.

The levels shown in Table I were calculated to produce three to five ruptures per reactor per month with a fixed goal exposure of 500 MWD/T for all tubes. The variable goal exposure scheme to be used should decrease this frequency to two to three ruptures per month.

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TABLE I

PREDICTED ATTAINABLE POWERS AFTER CG-558---SLUG RUPTURE CONSIDERATIONS

Pile	Basis	Max. Tube Power	Approximate Reactor Power Level (c)	Outlet Temp. of Max. Powered Tube--Annual Average (d)
B, D, F (a)	1955 Experience at D & F	950 KW	1330 MW	101° C
DR (a)	1955-56 Experience at DR	950 KW	1330 MW	101° C
B, D, DR, F	1955-56 Experience at H	850 KW	1190 MW	92° C
B, D, DR, F (b)	1955 Experience at C	850 KW	1190 MW	92° C
B, D, DR, F (b)	1955 Experience at C - Non-"Hot Spot" Failures	1050 KW	1470 MW	111° C
H (a)	1955-56 Experience at H	850 KW	1275 MW	92° C
H	1955 Experience at D & F	900 KW	1350 MW	96° C

- (a) These cases are probably the most realistic.
(b) Assuming "hot spot" failures are reduced to insignificance.
(c) Assuming 1400 ECT for B, D, DR, and F and 1500 ECT for H.
(d) This temperature is the average for one complete year assuming an average annual river temperature 12° C and a central zone tube flow of 40.5 g.p.m.

The results expressed in Table I show that should the powers be raised to the predicted most probable limits there is some possibility that an excessive number of slug failures would result. In order to minimize this possibility it is desirable that some exploration of slug performance under various power conditions be conducted before gross quantities of slugs are subjected to such conditions. Various plans for raising powers have been considered and are presented below.

I. The plan which appears most attractive from a production point of view is outlined as follows:

A. Initially after start-up from the CG-558 outage, tube powers at the various reactors would be limited as outlined below:

1. At the B Reactor, maximum tube powers will be raised to 950 KW. Powers at B will be maintained at this level for approximately three and one-half months, a sufficient length of time to demonstrate that slug failure rates are not excessive at this power limit, unless rupture experience during this period shows that the optimum maximum tube power is not this high.
2. After start-up from the CG-558 outage, tube powers at the D and DR Reactors will be limited to 850 KW until the experience at B has demonstrated that an excessive slug failure rate does not exist with maximum tube powers of 950 KW, at which time powers at D and DR would be raised.
3. The planned post CG-558 start-up date for the F Reactor is after the period required for piloting 950 KW maximum tube powers at the B Reactor. Tube power limits to be used for F immediately after the CG-558 outage will be determined by the experience at B.

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4. The maximum tube powers to be used for the H Reactor will be determined by the slug rupture experience at the other reactors. The analyses showed that for the same maximum tube power, failure rates at H are higher than at the B, D, DR, and F Reactors. Therefore, should experience show that the failure rate at the other reactors is at or near optimum when maximum tube powers are 950 KW, it might be desirable to make the initial tube power limits at H somewhat lower.
- B. After the initial exploration period, tube power limits will be adjusted in a manner depending on the experience at the B Reactor.
1. Should this experience indicate that the slug failure rate is excessive with maximum tube powers of 950 KW tube powers at the five reactors under consideration will be limited to 850 KW.
 2. Should the experience at B indicate that the optimum maximum tube power is about 950 KW this power will be used as a limit for the B, D, DR, and F Reactors, and possibly for H.
 3. Should the experience at B indicate that maximum tube powers well above 950 KW may be achieved before a limiting slug failure rate is reached, the B Reactor will be used to explore slug performance at higher powers. The amount maximum tube powers will be raised at this reactor may be determined from the analysis of experience with maximum powers of 950 KW, but for each step maximum powers should not be raised more than 100 KW. Plots of maximum tube powers at the various reactors after Project CG-558 if the above plan is used are presented in Figure I.
- II. The above plan has production advantages over other plans which might be , if the optimum maximum tube power is on the order of 950 KW, but also involve some risk of economic or production losses if the optimum maximum tube power is lower. An alternative plan which might be used is outlined as follows:
- A. The B Reactor, the first at which project CG -558 is to be completed, will be raised initially to the point where maximum tube powers are about 850 KW. As soon as experience at this reactor is sufficient to demonstrate that the slug failure rate is well below the tolerable rate, the maximum tube powers will be raised to 950 KW.
 - B. Should no limiting failure rate be encountered with powers at 950 KW, another raise of 100 KW in maximum tube power will be made. A period of at least three to four months will be required to establish the failure rate at that level with sufficient certainty to allow the next raise.
 - C. The D, DR, and F Reactors will initially be operated with maximum tube powers of 850 KW. As soon as experience at the B Reactor has demonstrated a higher level to be feasible, these three reactors will be raised to that level.
 - D. Since the calculations indicate that slug failure rates will be limiting at lower powers at the H Reactor than at the others, there would be some risk in raising powers at H to a level piloted by B Reactor. It is suggested that levels at H be held for a sufficient time to show comparative performances of H and the other reactors at that level, or to indicate with some confidence that a raise in maximum tube powers would not produce an excessive failure rate at this reactor.

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Plots of maximum tube powers at the various reactors after Project CG-558 if this plan is used are presented in Figure II.

This program involves essentially no risk of a serious rupture problem at any reactor except B. At the B Reactor a serious rupture situation would be incurred only if a power threshold for some new failure type is encountered or if the increase of failure rate with power is much greater than expected. In view of the fact that some experience has been obtained in the C Reactor at the powers under consideration, the probability of either of these events is believed to be slight.

III. A comparison of the advantages and disadvantages of the two plans outlined above showed that:

- A. If maximum tube powers on the order of 950 KW are feasible the plan outlined in Item I will produce a total of about 43,000 MWD more than will the more conservative plan outlined in Item II if the startup schedule is as shown in Figure I and II. It has been calculated that this additional production would be
 - (1). If the startup dates at the DR, D, and F Reactors are delayed one month from the dates shown in the figures, the gain from using the plan outlined in Item I rather than the plan in Item II will be approximately 34,000 MWD, If the startup dates are delayed two months the gain will be about 25,000 MWD,
- B. If a slug rupture limit exists at maximum tube powers of 850 KW the more conservative plan would obviously be the better of the two. If the less conservative plan were adopted in this case, certain losses might result.
 1. If a large enough stockpile of slugs were available for special discharging, three or four additional slug ruptures and the discharging of about 83 tons of slugs short of goal, at a net cost of about \$90,000, (1) might result at the B Reactor. There should be little or no production loss because the additional production obtained by operating for a time above the optimum power might well equal or exceed the production loss resulting from extra downtime for slug ruptures and discharging. No losses would result at Reactors other than B.
 2. If metal were not available for special discharging, and if the assumed slug rupture-power relationships are near correct, an additional six to ten slug ruptures might result at the B Reactor. This might produce a net production loss as high as 5,000 MWD.
 3. If metal were not available for special discharging and if the assumed slug rupture-power relationships are drastically incorrect, then a large number of slug failures involving serious production losses might result. However, the probability of such an occurrence is believed to be slight.

In view of the possible gains to be made by using the less conservative plan, and the fact that the calculations in which most confidence can be placed indicate that maximum tube powers of 950 KW are not in excess of a slug rupture limit, this plan is the more

(1) Personal Communication, R.J. Shields to J.K. Anderson.

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attractive of the two, especially if some backlog of slugs is available for any required special discharging.

Two even less conservative plans were considered; however, neither appeared particularly attractive.

The first of these was the case in which maximum tube powers at each Reactor would be raised to 950 KW immediately after startup from the project outage. However, if the B Reactor is already piloting this level then the possible losses from raising powers at the other Reactors prematurely is equal to or greater than the possible gain.

The second case is that in which maximum tube powers at the B Reactor would be raised initially to about 1050 KW. If successful this plan would produce a considerable production gain. However, the chance that operation at such powers will be optimum is believed to be slight, and if such operation is not successful losses as great as fifteen to twenty additional failures, or \$150,000 to \$200,000 for discharging slugs short of the goal exposure may be incurred.

Whatever plan is adopted need not be applied rigidly. Continuing analysis of the slug rupture performance at the various reactors could lead to variations from the adopted plan to either increase production or the decrease risks.

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Process Analysis Operation
Research and Engineering Operation
IRRADIATION PROCESSING DEPARTMENT

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FIGURE 1

PREDICTED PAST - CG-558 TUBE POWERS - B PILE TUBE POWERS INITIALLY RAISED TO 950 KW

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FIGURE II

PREDICTED PAST-CG-558 TUBE POWERS - B PILE TUBE POWERS INITIALLY RAISED TO 850 KW

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