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D. S. Lewis, Manager
H Processing Sub-Section
H Reactor Section
IRRADIATION PROCESSING DEPARTMENT

H FILE AXIAL FLUX DISTRIBUTION

INTRODUCTION

Significant production gains could be made by improving metal rupture performance. A means of achieving this is by depeaking the axial flux distribution, thus reducing the maximum specific power for a given tube power. The flux traverse program has provided some knowledge of front-to-rear flux, and was instrumental in prompting a change in the equilibrium HCR pattern during February, 1958. A "before and after" comparison of in-pile flux conditions is presented, and suggestions for further improvement are given.

SUMMARY

In February, 1958, the equilibrium HCR pattern was changed to provide a more idealized front-to-rear flux distribution. Traverses taken before the rod change showed

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that ~80 per cent of the central zone was subjected to downstream flux peaking. Subsequent data indicates that ~75 per cent of the central zone now "sees" cosine or upstream flux. Further improvement could be made by either relocating the half-rods or by displacing the uranium front-to-rear charge center about eight inches toward the front.

DISCUSSION

One of the major factors restricting both equilibrium power level and total reactor production is the incident of ruptured slugs. It is generally conceded that tube power, exposure, and outlet temperature are important environment factors which affect rupture rate. Certainly there are other elements such as metal and canning integrity which are important, but these are inherent in the fuel element and, therefore, not a function of environment. Of late another factor, flux peaking (as it determines specific slug power), has been introduced, and in many respects may be an important control link in the rupture chain.

A rupture occurs in an individual slug; therefore, looking at the situation on a tube basis could be misleading as tube outlet temperature, exposure, and power may not correctly describe the ruptured slug's environment. The slug's specific power tells the story. Therefore, it is extremely important that the neutron flux density be known so that correct correlations can be made.

The front-to-rear flux within the central zone of an operating reactor is determined largely by the inserted Horizontal Control Rods (HCR). The permanent poison would have some effect, but, in general, would be much smaller.

For the purpose of this study, the pile was divided into five regions (Figure No. I), with each region given a distinct front-to-rear flux distribution as determined by the control rods. The flux distribution and relative rupture potential for each region were then compared for the two rod patterns. Obviously, the regions are not actually as clearly defined as shown, but the pile does have approximately this distribution a surprisingly large share of the time.

The flux distribution assigned to each region is based upon numerous traverses taken throughout each area during different operating periods. Figures III through VII show specific traverses and are termed "typical" since each has been verified to exist with a particular control rod pattern. It should be remembered that traverses show the flux distribution which existed only at the traverse point, and extrapolating such data to other regions could lead to error.

FLUX DISTRIBUTION PRIOR TO FEBRUARY, 1958

The equilibrium rod pattern prior to February, 1958, utilized 2, 5, 8, 11, and 14 as long rods with 1, 7, 13 short, if needed, and 3, 4, 6, 9, 10, 12, and 15 rods generally out of the pile. A visualization of H pile's HCR system (Figure No. II) shows that the long rods used were all located in the center rod bank. Since this bank is approximately 14 inches upstream of the front-to-rear center of the pile, the rods caused the neutron flux to peak downstream.

Region 1: This area is beyond the influence of control rods, and is assumed to have cosine flux distribution (see Figure No. III).

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Regions 2, 3, 4: Due to the control rod pattern (all center rods long), these regions all exhibited the same flux pattern. Traverses showed 10-15 per cent flux peaking occurring 50 inches downstream of center (see Figure No. IV). (Per cent peaking refers to the point in question compared to the peak of a cosine distribution.) The traverses were taken at points midway between rod banks. It is probably safe to assume that greater peaking took place nearer the rods.

Region 5: This region was chosen to include the near side enrichment. Since the control rods enter through this side, considerable perturbation probably takes place. No traverses are available to substantiate near-side peaking by a central bank rod; however, data are available showing the effect of a downstream rod. Making appropriate allowance for rod location and other factors, peaking of 25-30 per cent at 50-60 inches downstream of center must have occurred in this region. If short rods were in the pile (1, 7, 13) a comparable magnitude of peaking occurred in their vicinity (see Figure V), but the peak would be upstream.

Summary: Approximately 80 per cent of the central zone had downstream flux peaking of 10-15 per cent. Both upstream and downstream peaking of 25-30 per cent occurred in the near side enrichment depending upon whether short rods were in the pile.

PRESENT PILE FLUX DISTRIBUTION

The undesirable pile rupture potential associated with downstream flux peaking prompted a change in the basic control rod configuration. In February, 1958, the equilibrium rod pattern was changed to include 4, 10, 2, 8, 14 as long rods. Basically, rods 4 and 10 were swapped for 5 and 11 to provide the downstream control necessary to offset the downstream peaking influence of the centrally located half-rods.

Looking at the pile by regions as was done for the old rod pattern shows the effect of the rod swap.

Region 1: This region shows no change. A cosine flux distribution should exist.

Region 2: This area is still influenced most strongly by the half-rods. The width varies according to the depth of 4 and 10 rods. The flux peak of 10-15 per cent occurs about 50 inches downstream.

Region 3: This region is the most improved. The overlapping of the long downstream rods with the half-rods gives maximum flux occurring about 30-40 inches upstream. There is no peaking, however. (See Figure VI.)

Region 4: Rods 4 and 10 cause upstream peaking in their vicinity. If 1, 7, or 13 is in the pile the same effect is noted. Probably 10-15 per cent (average) upstream peaking occurs in this region.

Region 5: The enrichment loading now being used tends to exaggerate the normal peaking along a control rod. Flux traverses taken along 4 rod show 30-35 per cent peaking about 45 inches upstream of center (see Figure V).

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It is logical that this condition exists along 1, 7, and 13 rods when they are in the pile. The situation is alleviated somewhat in that No. 7 rod is seldom used and, even though 1 and 13 are usually in as short rods, their physical location and hence normally lower flux density, causes the peaking to have less effect than if it occurred near the pile center. The use of 5 and 11 rods greatly reduces the flux peaking, and improves all of Region 5 (see Figure VII).

Summary: Approximately 25 per cent of the central zone has downstream peaking of 10-15 per cent. About 50 per cent has cosine or upstream flux (no peaking), and 25 per cent has varying degrees of upstream peaking.

COMPARISON OF PROBABLE PILE RUPTURE POTENTIAL BETWEEN THE TWO ROD PATTERNS*

The relations which are given should not be construed as absolute numbers, but should be viewed only as "orders of magnitude and direction" of relative rupture potentials. The only variable considered was the front-to-rear flux distribution effect on the slug residing at the flux peak. A rigorous analysis would require computing the rupture potential of every slug in each region, summing the potentials, and then comparing the sums.

Region 1: No flux change took place so no change in rupture potential occurred.

Region 2: This region generally was not affected by the rod change. During periods of high excess reactivity when 4 and 10 rods were extremely long, there would be considerable improvement.

Region 3: This area which did have downstream flux peaking now has maximum flux occurring upstream (no peaking). A comparison of relative rupture potential existing at the maximums of the two distributions shows an improvement by a factor of six.

Region 4: This region now exhibits upstream peaking instead of downstream. This should improve rupture performance by a factor of two.

Region 5: In both cases peaking of 25 per cent existed. With peaking of such magnitude, front-to-rear location has little effect on rupture potential. Therefore, any improvement of rupture performance in this region depends upon the insertion of 5 and 11 as short rods (compare Figures V and VII). With these rods in, the near side rupture potential would be reduced by a factor of ten.

Summary: As was previously mentioned, the numbers used in the foregoing comparison certainly are not absolute, but are to be used only as orders of magnitude and direction. Trying to assign a definite relative rupture potential to the pile for the two cases in question could be grossly inaccurate. The important point is that front-to-rear flux distribution and hence relative rupture potential was improved by the rod change.

* Private communication with R. R. Bloomstrand.

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RUPTURE DATA

First, a few words concerning Tables I and II. The ruptures which occurred in the past five years in the regions of interest are listed. Since there are many factors which influence rupture rate, and only one (flux distribution) has been considered, the tables may have little significance. Probably the most interesting (and valid) statistic is the "per cent of total ruptures" which occurred in a region. This number could be indicative of flux distribution.

For Table II the area of influence of a rod was taken to be three lattice units on each side. Rods which are normally run as pairs were considered together.

Tables I and II are on the following two pages.

TABLE I

Year	Total Ruptures Considered	Ruptures in Region #1	Per Cent of Total Ruptures Occurring in Region #1	Ruptures in Region #2	Per Cent of Total Ruptures Occurring in Region #2	Ruptures in Region #3	Per Cent of Total Ruptures Occurring in Region #3	Ruptures in Region #4	Per Cent of Total Ruptures Occurring in Region #4	Ruptures in Region #5	Per Cent of Total Ruptures Occurring in Region #5
1954	32	5	15.6	3	9.4	2	6.3	13	40.6	9	28.1
1955	19	6	31.6	8	42.1	5	26.3	0	0	0	0
1956	31	12	38.7	12	38.7	5	16.1	2	6.5	0	0
1957	16	0	0	5	31.3	6	37.5	3	18.8	2	12.5
1958	7	2	28.5	3	42.8	1	14.3	1	14.3	0	0

COMMENTS:

The ruptures considered were those occurring between top and bottom rod banks. Ruptures during 1958 were considered only for tubes charged after 2-9-58 (when rod pattern was changed). Since this included only seven ruptures the statistics are certainly doubtful. Possibly the number of ruptures which occurred may be quite significant. Anyway, it is interesting to note that in Regions 1 and 2, which were unaffected by the rod change, the failure per cent is in good agreement with those of the preceding four years. In Regions 3, 4, and 5 which should have benefited from the change only two ruptures occurred. Even considering these as statistically valid, the frequency per cent is still less than the average of the preceding four years.

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TABLE II

Year	Total Number Ruptures Considered	Number Ruptures on 5 & 11	Per Cent of Total Ruptures on 5 & 11	Number Ruptures on 8	Per Cent of Total Ruptures on 8	Number Ruptures on 2-14	Per Cent of Total Ruptures on 2-14	Number Ruptures on 4-10	Per Cent of Total Ruptures on 4-10
1954	32	23	71.8	5	15.6	4	12.5	--	--
1955	23	13	56.5	3	13.0	7	30.4	--	--
1956	38	14	36.8	12	31.6	12	31.6	--	--
1957	20	6	30.0	7	35.0	7	35.0	--	--
1958	6	0	0	3	50	0	0	3	50

COMMENTS:

During 1958 (metal changed after 2-9-58) six ruptures occurred in the regions of interest. One rupture each occurred adjacent to rods 4, 8, and 10, and three ruptures occurred between 8 and 4 and 10 (these three ruptures were adjacent to water-filled PCCF tubes).

It is interesting to note that the average rupture rate for rods 5, 8, and 11 is practically identical. This would be expected since these rods all have the same relative position in the pile, and their downstream peaking tendencies would compliment each other. The lower rupture rate along 2 and 14 rods possibly could be due to lower flux at these positions.

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SUGGESTIONS FOR FUTURE IMPROVEMENT

The present philosophy is to operate at the highest possible power levels while accepting a tolerable rupture rate. Providing better in-pile environment in the form of improved front-to-rear flux distribution, should reduce rupture potential thus allowing optimum power levels. There are two readily available methods for improvement: (1) change the equilibrium rod pattern, and (2) displace the entire pile loading.

CHANGING THE ROD PATTERN

From a flux distribution viewpoint it is unfortunate that the half-rods are all located in the center bank. A large share of the time these are the only long rods in the pile. This means that a sizeable portion of the central zone is subjected to downstream flux peaking (note the high per cent failure rate in Region 2 of Table I, and also the high failure rate along 8 rod as given in Table II). Some possible changes which should improve flux distribution are:

- (A) Change the half-rods from the 2, 8, and 14 positions to 1, 7, and 13. Swap 5, 11, for 4, 10 as long rods.

Comment: Flux would peak upstream of half-rods instead of the present downstream peaking. During periods of high reactivity when center rods 5 and 11 were long, flux would approach cosine. Short rods 2 and 14 would cause downstream peaking on near side; however, this peaking is of such magnitude (twenty-five per cent) that the condition would be no worse than at present. The same near side flux control as is now used could be continued. The main advantage of this configuration would be that Region 2 (Figure No. I), the high rupture rate region, would see an upstream flux instead of the present downstream peak.

- (B) Change 4 and 10 to half-rods; change 2, 8, 14 to full rods.

Comment: The results of this change would be somewhat the same as for (A). A disadvantage would be having two half-rods instead of three. This wouldn't be so bad as the PCCF pattern could be changed to compensate. This pattern has the advantage of offering more near side flux control through the use of short-rod combinations.

- (C) Change the half-rod from No. 8 position to the No. 7 position.

Comment: The present No. 8 rod position is important since it is practically in the center of the pile. The rupture frequency along this rod is the

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highest of all the rods. Changing to a downstream position should move the flux upstream thus providing an improved front-to-rear distribution.

(D) Change 4 and 10 to half-rods; keep 2, 8, 14 as half-rods.

Comment: With the present pile loading, this could possibly provide the optimum control rod pattern. A half-rod in each horizontal bank would provide excellent far-side control, and their physical locations would give good front-to-rear flux distribution.

DISPLACING THE PILE LOADING

An alternative to manipulating control rods to improve flux distribution would be to displace the full pile loading upstream so that the front-to-rear charge center would be four to eight inches upstream of the center rod bank. This would allow use of all center bank rods and yet maintain a relatively good flux pattern. The charge center is currently five inches upstream of the pile center, but is nine inches downstream of the center rod bank. Before such a change could be made it would be necessary to consider such factors as graphite shrinkage and growth plus radiation levels on the front face.

G. R. Gallagher

Operational Physics Sub-Section
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

GR Gallagher:mwe

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FIGURE I

This figure shows the five pile regions as determined by flux distribution. The width of each region is determined by the available excess reactivity in control rods. A typical condition is as shown.

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FIGURE II

This drawing shows the physical location of the Horizontal Control Rods. Rods #2, #8, and #14 are half-rods; all other rods are full length.

FIGURE III

Flux traverse taken in tube #3288. This distribution should be typical of region 1.

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FIGURE IV

This traverse was taken in tube #2071. Only center bank rods were in the pile.
This flux distribution existed in regions 2, 3, 4 and 5 before the rod change.

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FIGURE V

This is the flux occurring adjacent to #4 rod and the enrichment (tube #3056). Peaking is 30 %. This shape flux would exist in regions along any downstream rod which is in the pile. A similar shape flux exists in region 4, but the peaking is much less.

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FIGURE VI

This is the result of a traverse in tube #2776 after the rod change. This distribution exists in the "overlap" of rods #4 and #10 with the half-rods. This flux is typical of region 3 (figure #I). During periods of large excess reactivity region 3 would expand to include region 2.

FIGURE VII

This is the flux distribution in region 5 when a short center rod (#5 or #11) is used in combination with a long downstream rod (#4 or #10). Compare this traverse with figure V.

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