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NOTES ON REACTOR OPERATION
WITHIN A PRODUCT SPECIFICATION

By

L. W. Lang
W. I. Neef

IRRADIATION PROCESSING DEPARTMENT

June 9, 1961

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NOTES ON REACTOR OPERATION
WITHIN A PRODUCT SPECIFICATION

INTRODUCTION

A product specification will impose operating problems for the HAPO reactors and the separation facilities. A preliminary analysis of several methods of operating have been considered using a linear program analysis.⁽¹⁾ This document considers some of the implications.

SUMMARY

A linear programmed study of HAPO reactors was made in which six percent Pu was maximized under the following reactor plans.

Plan No. 1A - Divide K, C, and old reactors into different power zones. Allow discharge exposure to vary by pile, zone and metal type to give maximum production. Use present metal quality.

Plan No. 1B - Use factor of ten improved metal with 1A assumptions.

Plan No. 2A - The production is maximized with two metal types for C, K, and old reactors. All metal is assumed discharged at a constant goal exposure for a specified reactor and metal type. Present metal quality.

Plan No. 2B - Same as 2A, but with a factor of ten improvement in metal.

The analysis indicated the following production achieved by the various plans.

<u>Plan</u>	<u>Annual Production(10⁻³)</u>
1A	4429
1B	4708
2A	4170
2B	4665

Machine selected exposures under the various plans are as follows:

Plan	Reactor Metal Type	K		C		Old	
		N	E	N	E	N	E
1A	Exp. MWD/T % Pu-240	500-1300 5.66	400-900 3.93	600-1500 6.13	600-1500 4.64	500-1300 6.66	500-1500* 5.83
1B	Exp. % Pu-240	600-1100 6.14	600-1200 4.70	600-1500 6.37	700-1500 4.44	600-900 6.02	700-1200 6.30
2A	Exp. % Pu-240	700 6.09	500 3.45	700 6.23	700 4.70	740 6.35	800 5.46
2B	Exp. % Pu-240	600 5.33	700 4.65	690 6.23	900 5.87	800 6.75	900 6.05

* A metal quality assumption was used that is slightly more restrictive than that being currently used in the optimization model. If this were changed to current values, the exposure ranges would probably be reduced somewhat.

(1) HW-69847 RD, "Variable Goal Plans to Meet the Product Specification",
Reef, W. L., 6/12/61.

SUMMARY (Cont'd.)

Slightly enriched U columns if randomly distributed in the reactor would operate at highest tube powers and be most rupture-prone. As would be expected, they would tend to operate at lowest exposure levels to minimize ruptures and maximize production. Thus, the greatest advantage from improved metal would be expected to accrue to these tubes. Additional incentive to change-out E-metal columns to improved bumper fuel elements is inherent in the Birch program. Supplementary Birch obtained from re-cycling E-metal is directly proportional to the ratio, $\frac{\text{Time in Reactor}}{\text{Time for Complete Fuel Cycle}}$, which, in turn, is a direct function of the goal exposure.

CONCLUSIONS AND RECOMMENDATIONS

1. The only practical way of achieving a target specification in CPD and yet allow some flexibility in reactor operation would seem to be for IPD to guarantee an isotope level for each type of metal from individual reactors. CPD could then so choose their metal for processing that it would blend to limits.
2. There appears to be definite incentives with present quality metal for a variable goal discharge plan that may operate over an even wider exposure range than has existed using an optimization model. Although it will be hard to guarantee isotope from a specific reactor, gain from a variable goal plan is large enough to warrant special pick-up measures.
3. There is a strong incentive for either partial change-out or a complete change-out to self-supported elements (or bumper slugs). This incentive appears greatest for E-metal columns and warrants change-out at the earliest possible time for all tubes routinely charged with E-metal.
4. When the reactors have better quality metal, a constant goal discharge exposure may be desirable. Although a slight reduction (less than 1 percent) in production is indicated for the fixed exposure case, the administrative difficulties may more than outweigh the production loss.
5. The analysis accomplished by the linear programming technique does not completely answer many questions. Although the average cost of the production gained by the different plans was less than \$20.00, the production was maximized at an isotope level rather than optimized at a marginal cost. Further analyses will be required before optimum operating conditions can truly be established. The linear program method of analysis should be further explored in obtaining these answers.

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DISCUSSION

In operating under the product specification recently defined by the Commission, CPD must deliver and in turn fabricate materials of a given isotope content. The simplest way to do this as far as CPD is concerned would be to have all Pu delivered at the specified quality. However, the reactors stand to gain appreciable quantities of production by irradiating metal to exposures above and below that required to give the desired product specification. The reactors can gain operating efficiency from reduced ruptures and charging losses by using such a variable exposure. The charge-discharge losses vary from reactor to reactor, but are relatively constant per tube for a specified type of metal once the reactor has been designated. The probability of loss from ruptures, however, varies with metal type, and tube power as well as from reactor to reactor. Thus, each tube of some 20,000 could operate at a unique exposure in order to give maximum production efficiency and still aggregate at the desired 6% ^{240}Pu level. Practically, it is impossible, to keep track of the isotope content of each tube discharged and they must be aggregated in some manner prior to CPD processing.

A simple system of administrating the product specification might be to discharge all of the natural uranium at one type of reactor at an exposure and then ignore the tube variations. This would become a problem of optimizing with six variables. All old reactors would be considered the same. The two K Reactors would be considered identical and C Reactor would be considered unique. Variation within the three types of reactors would be by metal types; namely, natural uranium and slightly enriched uranium. To determine the incentive for unlimited variation (tubes and reactors) with that of the limited case discussed above (reactors and metal type only) a linear program was used in which each reactor was defined by zones and metal types. The production of Pu was determined for the fixed goal plan, and the variable goal plan, and for two levels of metal performance.

Substantial increases in production are concluded if universal variation of exposure is allowed with present quality. As the metal quality improves, not only does the range of exposures decrease but likewise the incentive for variable goal discharge decreases.

This can be more readily seen if we consider two metal types, 1) rupture-prone, and 2) rupture-free. For a single enrichment, the rupture-free metal would obviously be all discharged at exactly the same goal exposure. The goal exposure, of course, would be that required to meet the product specification. Variation between natural U and slightly enriched U would be due to their reaching specification at different exposures. However, if we consider the K Reactors and old reactors, we find that the production losses for the complete reactor complex from

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DISCUSSION (Cont'd)

charge-discharge could be reduced by operating the K Reactors slightly above the indicated exposure and the old reactors slightly below. This is apparent because of the greater number of tubes in a K Reactor as compared to an unit. Thus, the optimum exposure for K and Old, natural and enriched fuel, is shown in Sketch #1.

The rupture-prone material would also be effected by charge-discharge loss but the over-riding variable would be tube power as related to rupture losses. These losses can be reduced by lowering the exposure of the highest power tubes and increasing the exposure of the lowest power tubes. The efficiency of a K Reactor will be more adversely affected by a high rupture rate than an old pile, since a greater number of tubes are involved. Its optimum tube exposure would be lower than the optimum exposure of a tube at the same power in an older reactor. This is shown in Sketch #2.

The E-metal, if operating to the same flow rate and column length as natural U, will be at higher specific powers than natural U and thus would tend to have an optimum even lower than natural U. The present metal would be expected to operate between the terminal limits that we have developed. The I&E slugs will naturally more closely approximate the rupture-prone metal than the bumper slugs. Thus, the range of exposure expected for most efficient operation will be greatest with the I&E slugs. The linear program analysis indicated that some 10% increase in production could be gained by use of the variable discharge optimization plan

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DISCUSSION (Cont'd.)

over the fixed goal plan. The solution, however, is quite sensitive to metal quality assumptions and should only be used as indicative of the absolute values. By assuming a factor of 10 improvement for bumper slugs, a much smaller degree of improvement is shown for the variable goal plan (less than 1%).

In the past, the greatest pay-out from improved metal quality did not occur until the reactor change-out was nearly complete, since the rupture-prone material acted as a bottle-neck limiting production. This relationship is changed somewhat with a product specification. Each tube of improved metal can operate at higher exposures thus allowing reduction of the goal exposures of the rupture-prone material. In effect, then, a partial change-out of improved quality metal will allow reduced ruptures for both the new fuel and the remaining rupture-prone material. Thus, there would appear to be substantial incentive to fractionally change-out a reactor to bumpers, where a complete change-out was not possible or desirable. After the complete change-out had occurred, the goal exposure differences between individual tubes within a reactor would be reduced.

Effect of NPR Coming on Stream

When N Reactor comes on stream it will change none of the above relationships but rather tend to reduce all exposures approximately 50-100 MWD/T. As could be expected those tubes operating at the lowest exposures will be the least affected and those tubes operating at higher exposures will make larger goal exposure decreases. The indicated exposure that N would operate at would probably be between 1000 and 1200 MWD/T, which is near the marginal cost of the other reactors. If N should have exposure related rupture problems, the optimum exposure would be lower than indicated.

Problems

The variable goal method of pile operation appears to have adequate pay-out for present quality metal. With the wide exposure ranges indicated for this type of operation, however, it will be extremely hard to furnish CPD uniformly reliable numbers for isotope content of specific metal discharges. The high exposure pieces will naturally be discharged from fringe areas, and are apt to remain separated from central zone tubes in pick-up. Thus, if no attempt is made at randomizing during pick-up, wide variations from bucket-to-bucket and even from discharge-to-discharge may be expected in the irradiated metal. Increasing the frequency of discharges does not help the situation any, because the primary variation is due to a geographical isolation of the high exposure tubes in the pile. This isolation may be maintained in the basin as well. For example, a pile of discharged uranium in the basin would tend to be high exposure at the ends of the pile and low exposure in the center. However, with the incentives that exist for the variable goal method of minimizing rupture outages, some solution to this problem should be attempted. All discharges should average the goal exposure that will typify the type of reactor. This typical exposure then can be represented to CPD as the guaranteed isotope level of K Reactor, for instance. CPD could then manage the two types of metal from three types of reactors to give an average of 6% ²⁴⁰Pu from our button line. Once bumper elements are available at all reactors, however, unusual charge-discharge precautions will not be so necessary. At this point the variable goal discharge could probably be abandoned, since the incremental gain from it with improved metal quality is rather small.

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Metal Requirement Forecasting

Forecasting metal with requirements under a product specification will not be as difficult or as subject to wide variation as existed under the old optimization model. Once the power level and product mix has been established, the tonnages can be determined for the reactors by simple division. The only variation will be due to production efficiency. This variation might be as high as 5 or 10%, but would be expected to be considerably less with improved metal.

The only substantial reduction that can be made in metal requirements short of a change in product specification is to increase the percentage of E-metal to natural U by blanket or E-N loading.

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