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OCTOBER, 1961, THRU DECEMBER, 1962

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ENGINEERING BASES FOR POWER LEVELS AND EXPOSURES
OCTOBER, 1961, THRU DECEMBER, 1962

by
Process Engineering Unit
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

September 18, 1961

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ENGINEERING BASES FOR POWER LEVELS AND EXPOSURES
OCTOBER, 1961, THRU DECEMBER, 1962

INTRODUCTION

It is the purpose of this document to provide assistance to the Manufacturing Section personnel in determining their future operating plans. In general, the inter-relationship of such engineering parameters as projected flow rates, reactor orificing pattern, fuel element performance, and process limits have been considered. Based on these engineering parameters and related process economics, suggested reactor "Operating Plans" are graphically presented in this document. It is emphasized that these plans do not reflect operational considerations which may modify the desirability of the indicated power level increase nor has allowance been made for major projects, major maintenance outages, etc. Many factors which only Manufacturing personnel are capable of evaluating may make it desirable to operate above or below these operating plans. These plans are designed to present reasonably achievable but perhaps optimistic power levels together with process limits which will be approached or will possibly limit reactor power levels unless limit revisions can be effected.

These plans are based on incremental metal costs and burnout costs on estimates obtained from L. W. Lang and are predicated on optimizing plant net return subject to the current six per cent Pu-240 product specification.

It should be noted that the engineering parameters and basic assumptions which have been factored into these plans are subject to continual re-evaluation and revision. In a strict sense, these plans are out-dated even as they are published. However, their value will lie primarily in illustrating the approximate conditions under which each reactor can be operated during CY-1962; thus, permitting some perspective of individual and collective reactor operation. The Process Engineering Unit will continue to make specific power level or operational severity recommendations on a current basis as changes in engineering parameters, i.e., rupture performance, flow and loading considerations, process limits, etc. dictate.

DISCUSSION

The power level plans presented in this document represent a slightly optimistic estimate of reactor power levels achievable during CY-1962 based on technical and economic considerations. In the past, these plans have reflected an exploratory stepwise increase in operating severity in the direction of maximizing plant return. This stepwise piloting was considered prudent in view of the many uncertainties that were initially associated with I&E fuel element performance. Recent estimated improvement in fuel element quality together with the estimated benefits obtainable through bumper fuel element use negates the necessity of further stepwise fuel performance exploration in order to reach current bulk outlet temperature limits. During this past summer, all reactors have operated on bulk outlet temperature limits and it is predicted that all reactors except C reactor can continue bulk outlet temperature operation through this coming

winter and probably through the winter of 1962. C and DR reactors' operation on bulk outlet temperature limits does not appear economically attractive from December, 1961, until March, 1962. This is discussed more fully later in the document. The following table presents a comparison of previously high operational severity index values⁽¹⁾ and OSI's predicted for this winter.

TABLE I

	Previous High OSI	Predicted High OSI	Natural Metal	
			Previous High Δ RI	Predicted High Δ RI
B	4.5	9.4	5.8	24.0
C	3.5	8.0	2.3	5.6
D	5.0	6.7	6.1	23.0
DR	4.5	14.5	9.0	22.0
F	6.5	9.3	4.5	22.0
H	3.5	11.5	5.3	24.0
K's	6.5	14.6	22.0	49.0

Also included in the table is a comparison of previously high average "delta rupture index" values⁽²⁾ as compared with the projected high "delta rupture index" values for the planning period. It will be noted that OSI's for this winter will be approximately a factor of two higher than previous highs at B, C, D, F, and the K reactors, and a factor of three higher for DR and H reactors. At the old reactors, where bumper fuel use is assumed, the goal exposures predicted are higher than previous values resulting in a factor of four increase in Δ RI's in the fuel element over previous highs. To effect this rather sizeable change in OSI and Δ RI in a relatively short period at all reactors may seem inconsistent with the past and more cautious stepwise operating severity index increase recommendations. However, because of substantial estimated improvement in fuel element quality (a factor of 2.5 since March, 1961) together with increased confidence in the rupture model relating to I&E fuel element performance, these severity increases

- (1) It will be recalled that OSI is a relative measure of reactor environmental effects on fuel element performance; namely, power temperature, and is calculated by the following equation:

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

where: P = tube power in KW

T = tube outlet temperature in °C.

- (2) The "delta rupture index" value on RI is a measure of the relative operating severity to which fuel elements of a given type are subjected and includes fuel exposure effects as well as power and temperature terms.

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are believed justified. A greater than a factor of two increase in operating severity without the benefit of the improved fuel performance anticipated with bumper fuel elements, however, does not seem prudent. Therefore, at DR and C reactors, winter operation at non-bulk limited power levels is indicated until beneficial use of bumper fuel elements is available.

Fuel Quality Assumptions

The following table presents estimates of relative fuel element quality through December, 1962. The past reference point was chosen as March, 1961, as this month is associated with previous high operational severity indexes. A quarterly ten per cent improvement in fuel element quality is predicted for a long-term trend by Process Analysis Unit for all fuel element types. An additional factor of five improvement for bumper slugs has also been assumed. The assumption has been made in these plans that beneficial use of bumper slugs at the old reactors for both natural and E-metal tubes will be available in March, 1962, and that beneficial use of E-metal bumper slugs at the K reactors will commence in June, 1962. Continued use of bumper slugs at H reactor following discharge of the E-N goal is also assumed.

TABLE II

Relative Metal Quality
(Estimated Factor of Improvement Using March, 1961, as Base)

	<u>Non-Bumper Fuel Elements</u>	<u>Bumper Fuel Elements**</u>
March, 1961	1.0	
October, 1961	2.5*	
January, 1962	(2.7)	
April, 1962	(3.0)	(15.0)
July, 1962	(3.3)	(16.5)
October, 1962	(3.7)	(18.5)

* Demonstrated

** A factor of five improvement in bumper fuel is assumed.

() Predicted relative improvement in metal quality at a rate of ten per quarter.

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Optimum Power Levels and Goal Exposures

Prior to the current Pu-240 product specification, optimum power levels and goal exposures were determined independently for each reactor by IBM computer calculations using the mathematical optimization model. Under a product specification restriction, it is obvious that in order for the total plant product to meet a fairly rigid specification, significant changes in product specification for individual reactors must be balanced by compensating changes in the product specification at all other reactors. Thus, to comply with product specification requirements, independent changes in reactor operating conditions (principally fuel element goal exposures) are not possible. It was first believed that maximum plant return could be obtained by operating all reactors under equal marginal cost at the marginal cost value which would result in compliance with the Pu-240 specification. Recently, it has been determined that this is not a strictly correct assumption. However, it is believed that the goal exposures determined under this assumption and included in these plans will not be significantly in error. The optimum power levels and exposures included in these power level plans were determined by computer calculations for all reactors at a series of marginal cost figures. These results were examined to determine the marginal cost at which the collective product output from all reactors would comply with the six per cent Pu-240 specification. The following table presents a schedule of goal exposures for E-metal and natural tubes for selected months during the planning period.

TABLE IIIEstimated Natural Metal Goal Exposures

	<u>Oct.</u>	<u>Dec.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>Jan.</u>	<u>Sept.</u>	<u>Dec.</u>
B	730	710	700	840	810	790	790	
C	660	720	680	600	600	590	610	590
D*	900	900	900	900	900	900	900	900
DR	610	600	600	710	710	710	710	710
F	730	740	700	840	830	790	770	820
H	(750)	(750)	740	690	690	670	660	710
K	730	730	730	670	660	650	660	650

* Since the power level plans were proposed, it was learned that the non-representative fuel program at D reactor was no longer required. Thus, the 900 MWD/T goal exposure for D reactor natural metal is higher than optimum and the goal exposures at the other reactors may also be reduced slightly.

() Discharge exposure for second E-N core load.

It is interesting to note that in February, 1962, the indicated natural goal exposures at C reactor are approximately 700 MWD/T thus preventing operation of C reactor on bulk outlet temperature limits because of rupture considerations. In March, however, when bumper fuel loading was assumed for B, D, DR, and F, optimum goal exposures for these reactors were increased and thus could be compensated by a sufficient goal exposure decrease at C reactor to permit bulk limit operation.

It should be recognized that there is somewhat more risk involved in operating at higher operating severity with a product specification than has been experienced in the past. In the past, metal availability permitting, substantial reduction in fuel element goal exposures have been possible in the event of an unusually high rupture frequency. With product specification, arbitrary reductions in goal exposure could not be met with nearly the same degree of flexibility; and should rupture problems be encountered at a given reactor, power level adjustments rather than goal exposure reductions may be necessary.

Estimated Fuel Element Failure Rates

Assuming the fuel element quality schedule discussed above, the following table represents the estimated rupture frequency for selected months during the planning period. The reduction in the expected number of ruptures in March, 1962, from February is due to the assumption of beneficial use from bumper loading in B, DR, and F reactors.

TABLE IV

Predicted Rupture Rate
(Ruptures per month)

	<u>1961</u>		<u>1962</u>				
	<u>Oct.</u>	<u>Dec.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>June</u>	<u>Sept.</u>	<u>Dec.</u>
B	0.7	1.1	1.1	0.5	0.3	0.2	0.4
K	1.1	1.7	1.6	1.3	0.7	0.5	0.8
K	1.1	1.7	1.6	1.3	0.7	0.5	0.8
H	0.7	0.9	0.7	0.5	0.2	0.2	0.2
F	0.7	1.1	1.1	0.5	0.2	0.1	0.3
DR	0.8	1.2	1.3	0.6	0.3	0.2	0.4
D	0.3	0.5	0.5	0.5	0.3	0.3	0.3
C	<u>1.4</u>	<u>1.8</u>	<u>1.7</u>	<u>1.6</u>	<u>1.0</u>	<u>0.8</u>	<u>1.1</u>
Total	6.8	10.0	9.6	6.8	3.7	2.8	4.3

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Bulk Outlet Temperature Limit

The bulk outlet temperature limits of 95 C at DR, C, and K reactors have been assumed. Continued administrative control of bulk outlet temperatures of 93.5 C for B, D, F, and H reactors was also assumed.

AEC Administrative Limit

The current AEC administrative limit will be reached by C and the K reactors by the spring of 1962. It is estimated that only C reactor has the potential for operating significantly above the current limit. Although power levels at the old reactors will closely approach the current AEC limit, no potential production loss for these reactors is envisioned. By the winter of 1962, following water plant expansion at the K reactors, significant K reactor product losses will be experienced without an upward revision of the current limit. If optimism is factored into the potential flow increases for the old reactors, production limitations for these reactors could also be experienced at the end of 1962. Process and Reactor Development is preparing a request to the AEC for limit revision.

Graphite Temperature Limit

Graphite temperature restrictions on reactor power levels may be experienced at the old and C reactors this winter. Ballpark graphite temperature limits are shown on the operating plans. At the K reactors it is estimated that with the use of an outboard horizontal rod pattern, graphite temperatures will not limit reactor power levels. Further refinement of the methods for estimating ultimate graphite temperature limits is in progress together with continued evaluation of the basis for graphite temperature limits.

TAI Limit

Generally, TAI limits should not restrict the power level increases illustrated in these operating plans. In some cases, however, the approach to limits may be close enough that re-venturing or orificing changeout may be necessary to provide an adequate margin between TAI limits and normal tube outlet temperatures.

High Tank Support Levels

At the B, D, and F reactors, high tank support levels will be reasonably close to projected reactor power levels although adjustment of reactor power levels on the basis of high tank considerations is not foreseen. Further work planned to provide improved definitions of high tank support levels include analysis of the DR reactor heat generation test, analysis of high tank line high velocity flushing and screen plugging data, together with planned high tank flow tests at two of the old reactors to detect possible increased line resistance from corrosion product buildup.

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Tube Corrosion

One major consideration which may modify the desirability of reactor operation at the power levels indicated in these plans is that of process tube corrosion. Recent data from all reactors indicate that process tubes may be corroding at a higher than expected rate. The average tube corrosion rate implicit in the calculation of optimum power levels for these plans is approximately 0.75 mils per month. If actual process tube corrosion rates are determined to be significantly in excess of this value, re-appraisal of the desirability of operating at the power levels depicted in these plans would be necessary.

Supervisor, Process Engineering
Research and Engineering

SM Graves:md

[REDACTED]

Ruptures per Month	0.7	1.0	1.1	1.
Shield Flow - GPM	←			
Reactor Flow - GPM	← 88,800			
Central Tube Flow - GPM	← 47.4			
Number of Pumps	←			
Average Inlet Temperature - °C	16.8	13.2	9.5	7
	Oct.	Nov.	Dec.	J

1961

1962

Pile Power - MW

Ruptures per Month	0.3	0.3	0.5	0
Shield Flow - GPM	←			
Reactor Flow - GPM	86,800	86,900	87,000	87,
Central Tube Flow - GPM	←			
Number of Pumps	←			
Average Inlet Temperature - °C	16.8	13.2	9.5	7.
	Oct.	Nov.	Dec.	Ja

1961

1962

Power Level - MW

2100

2000

1900

1800

1700

Operating Plan
at 95°C Bulk
Temp. Limit
with Bumper Fuel

OSI = 10.8

Operating Plan
without Bumper Fuel

OSI = 9.0

OSI = 7.3
M_I = 610
M_E = 980

Ruptures per Month	0.8	1.0	1.2	1.4
Shield Flow - GPM	←			
Reactor Flow - GPM	←			
Central Tube Flow - GPM	←			
Number of Pumps	←			
Average Inlet Temperature -°C	16.8	13.2	9.5	7.0
	Oct.	Nov.	Dec.	Jan.

1961

Pile Power - MW

Ruptures per Month	0.7	0.8	1.1	
Shield Flow - GPM	←			
Reactor Flow - GPM	←			
Central Tube Flow - GPM	←		49.0	
Number of Pumps	←			
Average Inlet Temperature-°C	16.8	13.2	9.5	7
	Oct.	Nov.	Dec.	

1961

Ruptures per Month	0.7	0.8	0.9
Shield Flow - GPM	←		
Riser Quench Flow - GPM	0	0	←
Reactor Flow - GPM	85,000	85,000	←
Central Tube Flow - GPM	←		
Average Inlet Temperature °C	16.8	13.2	9.5
	Oct.	Nov.	Dec.

1961

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1962

PROCESS TUBE
REPLACEMENT

Pile Power - MW

1961

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1962