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HW-67340

November 7, 1960

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ENGINEERING BASES FOR POWER LEVELS AND EXPOSURE
NOVEMBER, 1960, THRU DECEMBER, 1961

AUTHOR

S. M. Graves

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ENGINEERING BASES FOR POWER LEVELS AND EXPOSURES
NOVEMBER, 1960 THRU DECEMBER, 1961

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S. M. Graves
Process Engineering Unit
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

November 7, 1960

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ENGINEERING BASES FOR POWER LEVELS AND EXPOSURE
NOVEMBER, 1960, THRU DECEMBER, 1961

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 flow, reactor orificing, rupture performance, etc. has been considered. The effect of these engineering parameters are summed up in our recommendations for "Operating Plans" shown graphically in this document. It is to be emphasized that these plans do not reflect operational considerations which may modify the desirability of the indicated level increases nor has allowance been made for major projects, major maintenance outages, or major changes in pile loadings. Many factors, which only Manufacturing personnel are capable of evaluating, may make it desirable to operate below or above these "Operating Plans."

These plans are based on incremental metal costs and burnout cost estimates obtained from L. W. Lang and are predicated on optimizing plant net return. Should some other basis be selected for examining optimum plant performance (i.e., minimizing unit cost) some adjustment in the recommended power levels and exposure would be required.

It is also to be noted that many of the engineering parameters and basic assumptions which have been factored into these "plans" are subject to continual re-evaluation and revision. Thus, in a strict sense, these "plans" are outdated even as they are published. However, their value will lie primarily in illustrating the approximate conditions under which each reactor can be operating during CY-1961; thus, permitting some perspective of individual and collective reactor operation. 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, safety limits, etc. dictate.

DISCUSSION

The power level "plans" presented in this document represent an estimate of reactor power levels that appear reasonable during CY-1961 based on technical and economic considerations. In general, these "plans" in the past 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 associated with the performance of I & E fuel elements. As a result of this stepwise approach to higher power levels, all reactors are currently operating reasonably close to the operating severities associated with maximum net return or bulk outlet temperature limits. The increase in operational severity recommended for this fall and winter at most reactors can be either supported by past operating experience or represent a confident extrapolation of rupture model relationships. Thus, the general character of these current plans is different from past issues. It will be noted that during most of CY-1961 all reactors can be limited either by bulk outlet temperature limits or can be operating at the calculated power levels associated with maximum net return.

Appreciable production gains above these "plans" does not appear possible without a significant improvement in metal quality and/or total reactor flow. It is evident that effort should be focussed upon such programs as the bumper fuel program and interim methods of increasing reactor flow prior to expansion project action.

Basis for Plans

These power level plans are based on optimizing plant performance by assuming maximization of plant net return as the principal objective. It is recognized that unit cost considerations enter into plant planning and measurements. Until recently power levels at all reactors have been sufficiently low and goal exposures sufficiently high that recommendations to increase power levels and operating severities have been in the direction of both lower plant unit cost and increased plant return. These current "plans" reflect power levels and goal exposures which exhibit some conflict between unit cost and net return objectives. However, the calculated difference in unit cost between operating at the point of maximum net return and that of plant minimum unit cost for most reactors is very slight for current metal quality levels. Process Analysis Unit is making a study in some detail of the comparative effect of operating on unit cost versus net return objectives.

Current Recommendations

The following table is a summary of the operating conditions currently recommended for each reactor. In some cases, these conditions may not be reached until December because of bulk outlet temperature restrictions. For comparative purposes, average operating conditions which prevailed for the past three months are included. It should be pointed out that the recommended I & E natural goal exposures are related to metal which has completed a full metal cycle at the recommended operational severity and are not recommendations to immediately reduce exposures to these values. It is anticipated that the normal "goal realization" plan would permit a smooth transition to the recommended levels at B, C, DR, and F Reactors where significant goal exposure reductions are indicated. If goal exposure reductions below 650 MWD/T for I & E natural metal is not acceptable, a revision to these recommendations should be made. In general, if goal exposures were restricted to near current values, the optimum OSI for this restricted throughput case would approach those shown in the table. The optimum corresponding rupture rate, however, would be increased approximately 50 per cent.

The ruptures per month, shown for the past three months, represent the best estimate of what the true rupture rate was for the experienced OSI and discharge exposure and will not necessarily match exactly with the observed rupture rate on an individual reactor basis.

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-2-B-

OPERATING CONDITIONS

	<u>Average Past 3 Months</u>	<u>Current Recommendation</u>
<u>B Reactor</u>		
OSI	2.7	4.0
Exp.	695	620
Rupt./Mo.	1.1	1.1
<u>C Reactor</u>		
OSI	1.1	1.35
Exp.	670	595
Rupt./Mo.	2.1	1.8
<u>D Reactor</u>		
OSI	2.0	2.6
Exp.	700	670
Rupt./Mo.	0.85	0.90
<u>DR Reactor</u>		
OSI	2.0	2.5
Exp.	690	590
Rupt./Mo.	1.4	1.0
<u>F Reactor</u>		
OSI	4.0	6.0
Exp.	650	600
Rupt./Mo.	1.1	1.1
<u>H Reactor</u>		
OSI	1.7	2.7
Exp.	605	600
Rupt./Mo.	0.8	1.3
<u>KE Reactor</u>		
OSI	4.2	6.0
Exp.	685	670
Rupt./Mo.	1.4	1.8
<u>KW Reactor</u>		
OSI	4.2	6.0
Exp.	685	670
Rupt./Mo.	1.4	1.8

Exposures shown are for I & E natural metal.

Basic Assumptions

The usefulness of these plans is directly dependent upon the validity of the basic assumptions which were factored into these plans. As changes in these basic assumptions could materially affect reactor operation during the balance of the year, discussion of these assumptions is presented here in some detail.

1. Inlet Temperature

It will be noted that for convenience a standardized schedule of inlet temperatures has been assumed for these plans. These inlet temperatures are based on five-year average inlet temperatures and no attempt has been made to predict exact temperatures for next year. It is important to recognize that these "plans" are related directly to inlet temperature and will not necessarily correspond exactly with the calendar period.

2. Metal Availability

During CY-1960, power levels were restricted, in part, by the available metal supply. The assumption has been made in these plans for CY-1961 that Fernald, FPD, and CPD production capacity limitations will not prohibit the plant average goal exposure from being reduced as low as 600 MWD/T if economically justified.

A schedule of the CY-1961 average goal exposure for I & E natural fuel elements for each reactor and the plant as a whole is presented below based on operating plan recommendations.

AVERAGE GOAL EXPOSURE - CY-1961

<u>Reactor</u>	<u>Natural I & E Fuel - MWD/T</u>
B	600
C	560
D	(630)
DR	590
F	610
H	(580)
KE	650
KW	<u>650</u>
Weighted Plant Average	620

It should be noted that the goal exposure shown for D and H Reactors is based on the current I & E natural fuel elements. Because of uncertainty in the timing of the planned bumper fuel loading at D Reactor, no attempt has been made to

factor the expected improved bumper fuel performance into the above goal exposure schedule. It is estimated, however, that when fully loaded, the average discharge exposure of natural bumper fuel elements at D Reactor will be in the order of 900 MWD/T.

The goal exposures shown for H Reactor are the goal exposures that would be recommended for the current fuel loading. Goal exposure recommendations for the striped E-N loading are being developed.

3. Fuel Element Performance

The current assessed level of fuel element quality is assumed to continue through CY-1961 at the old reactors. At the K Reactors, the current level of fuel quality is assumed to continue to July 1961; a 20 per cent improvement is assumed from July, 1961, to December, 1961.

As it takes longer to demonstrate improvement in metal quality at C Reactor than it does to detect a similar change when collectively evaluating performance at the five old reactors, it was assumed that current C Reactor metal quality is 30 per cent better than currently indicated by rupture control chart evaluation. This adjustment brings in the calculated metal quality change from CY-1959 at C Reactor more in line with the calculated changes in metal quality at the old reactors for the same period.

4. Tube Replacement Losses

The assumption of tube replacement losses can have a significant effect in the determination of optimum power levels and goal exposures. The tube replacement loss term in the optimization model is based on the assumption of a continuous process and does not normally consider specific tube conditions in a reactor. The assumption of a continuous process is fairly reasonable if aluminum tubes are to be used for several years and replaced for internal corrosion reasons only. Planned project action which would require, in some cases, premature tube removal is a special situation which requires a modified approach to the prediction of losses associated with tube replacement.

A method has been developed for optimizing reactor power levels and goal exposures based on an assumed calendar date for major tube replacement project action. This method, as applied to the K Reactors, is fully discussed in a separate document⁽¹⁾ to be issued by November 18, 1960. For the purpose of these "plans" a project date for zirconium tubes at the K Reactors was assumed for mid-CY-1964. An estimate of the current condition of K Reactors' tubes was obtained from J. R. Young. Based on these assumptions and the resultant calculated optimum operating levels, it is calculated that up to 900 tubes may have to be replaced at the K Reactors prior to the CY-1964 project date.

(1) HW-67391, Graves, SM, NE Fuller, "Optimization of K Reactors' Power Levels Related to a Zirconium Tube Replacement Project," November 15, 1960, (Secret).

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-2-E-

This estimate of current K tube status is considered by Young somewhat pessimistic. Since this estimate can have a direct bearing on K plant operation until a tube replacement project, there is considerable incentive to obtain additional tube probolog and "out-of-pile" examination data in order to more accurately characterize the condition of K tubes. The assumption of tube replacement losses ranging between normal tube replacement losses and zero tube replacement losses at the K Reactors has the effect of varying optimum exposures up to 100 MWD/T and optimum power levels up to 140 kw.

Tube replacement losses were assumed to be zero prior to tube replacement project action at C Reactor. This assumption was factored into determination of the power levels associated with maximum net return. Assuming zero tube replacement losses will result in higher power levels, lower goal exposures and higher rupture rates then would be calculated for optimum conditions under normal tube replacement loss assumptions.

5. Bulk Outlet Temperature Limit

From a reactor safety standpoint, a bulk outlet temperature limit of 95° could be in effect at each reactor with the installation of a deadman switch on the HCR control drive and with limitation to the PCCF tube loadings. The current bulk outlet temperature philosophy is based on the gross magnitude of damage that could occur to the downcomer, crossover, and effluent piping upon a bulk outlet temperature surge from power excursion, BPA failure, etc. Potential damage to reactor rear-face piping, i.e., crossheaders, risers, pigtails, and fittings, is not factored into the present bulk outlet temperature limit. The uncertainties connected with rear-face piping damage are discussed below. It is assumed that 95°C bulk limits will be in effect at C, DR, and the K Reactors next year, and that B, D, F, and H Reactors will be limited to 93.5°C bulk outlet because of rear-face piping considerations.

6. Rear-Face Piping Considerations

There is concern that further increases in flow and outlet temperature will result in extending the already overstressed condition of the rear-face piping at the old reactors to the point that economic losses associated with piping and component damage would offset the projected production gains. A direct relationship between increased rear-face piping damage and flow and temperature changes is very complex and difficult to ascertain. However, considering the two variables, there is a general consensus of engineering opinion that an increase in temperature will have a much greater deleterious effect on rear-face components than with the flow increases required to support a comparable operating level.

Limiting B, D, F, and H Reactors to 93.5°C bulk outlet during CY-1961 could result in loss of 18,200 MWD production or approximately \$600,000. Since operation at these reactors will be restricted by bulk outlet temperature limits for a major part of CY-1961, strong considerations will be given to re-orificing programs designed to increase total reactor flow by opening up the fringe zone. Re-orificing, however, will also result in decreased central zone tube flow which is opposed to metal performance and tube corrosion

consideration. If rear-face piping were not an area of concern, achievement of higher power levels through operating at 95°C bulk outlet would be preferable to similar power level increases permitted by re-orificing.

A detailed study⁽²⁾ on the effects of re-orificing on rear crossheader temperature and flow distribution has been completed and will be published in the very near future. The results of this study should be factored into rear-face piping evaluation. While the use of a restricted bulk outlet temperature for rear-face piping considerations is convenient, it is believed that rear crossheader joints, connectors, and fitting failures may be more closely associated with individual crossheader flows and temperatures than with bulk temperature and flow. Thus, it is possible that flow increases which would decrease the bulk outlet temperature could result in a significant increase in individual crossheader temperatures and in an increased potential for component failure. Future assessment of rear-face piping damage associated with flow-temperature changes should consider individual crossheader conditions as well as reactor bulk parameters.

7. TAI Limits

Reamed venturis are being installed at all reactors per previous recommendations. Power level restrictions from TAI limit considerations will not be encountered this year.

8. E-N Loading - N Reactor

The following assumptions relating to the E-N loading have been made on the H Reactor power level plan:

- a. The hydraulic characteristic of the E-N load (using bumper slugs) will not be significantly dissimilar to the current 32-piece I & E natural loading.
- b. Because of the effective reduction in diameter of the flattening enrichment ring, the ECT will drop (from present values) by about six per cent. This total drop will only be effective during the actual six month's period covering the striped core loading.
- c. The rupture performance of the striped core loading (particularly with bumpers) will be no worse than present rupture performance.
- d. The optimum power and exposure indicated during the E-N program are those powers required to optimize the production of plutonium (not tritium).

SM Graves:md

Supervisor, Process Engineering
Research and Engineering

(2) HW-67392, Russell, A, "Aspects of Reactor Flow and Temperature Increases," November 15, 1960, (Secret).

[REDACTED]

Tube $C_{RI} = 45.8 \times 10^{-19}$ at 45 GPM
 Tube $C_{RE} = 23.3 \times 10^{-19}$ at 50 GPM
 $T_i = 0^\circ \text{C}$
 M_I is Discharge Exposure of
 Natural Metal

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1961

Tube $C_{RI} = 5.7 \times 10^{-18}$ at 50 GPM
 Tube $C_{RE} = 1.4 \times 10^{-18}$ at 54 GPM
 $T_i = 0^\circ\text{C}$
 M_I is Discharge Exposure of
 Natural Metal

Rupture/Mo. Operating Plan	1.8	1.8	1.8	1.8	←
Shield Flow - GPM	←				
Reactor Flow - GPM	←				
Central Tube Flow-GPM	←				
No. of Pumps	←				
Avg. Inlet Temp. °C	13.2	9.5	7.1	5.5	
	Nov.	Dec.	Jan.	Feb.	M

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C - Reactor Operating Plans
1720 - ECT

By: D. L. Renberger

Bulk Limit
95°C

AEC Limit (2100 MW)

OSI=2.2
 $M_I=550$

Tube Power
at Maximum Net Return
OSI=2.65
 $M_I=540$

OSI=2.05
 $M_I=555$

Operating
Plan

$M_I=555$
OSI=2.05

2.1

1400

95,000

50.5

9

.5	8.5	11.7	13.9	17.2	19.2	19.1	16.8	13.2	9.5
Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	

1961

M_I is Discharge Exposure of
Natural Metal

Rupture/Mo. -Operating Plan	.95	1.0	←		1
Shield Flow GPM	1,000	1,000	←		
Reactor Flow GPM	81,500	81,500	←	83,000	
Central Tube Flow GPM	47.2	47.2	←	47.2	
No. of Pumps	7	7	←	7	
Avg. Inlet Temp. - °C	13.2	9.5	7.1	55	5
	Nov.	Dec.	Jan.	Feb.	M.

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Tube $C_{RI} = 45.8 \times 10^{-19}$ at 45 GPM

Tube $C_{RE} = 23.3 \times 10^{-19}$ at 50 GPM

$T_i = 0^\circ \text{C}$

M_I is Discharge Exposure of
Natural Metal

Rupture/Mo. Operating Plan	1.0	1.0	1.1	1.2	1
Shield Flow - GPM	←	←	←	←	←
Reactor Flow - GPM	83,600	83,700	←	81,300	←
Central Tube Flow - GPM	46.2	46.2	←	44.9	←
No. of Pumps	8	8	←	7	←
Avg. Inlet Temp. - $^\circ\text{C}$	13.2	9.5	7.1	5.5	5
	Nov.	Dec.	Jan.	Feb.	M

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1961

Tube $C_{RI} = 54.8 \times 10^{-19}$ at 45 GPM
 Tube $C_{RE} = 23.3 \times 10^{-19}$ at 50 GPM
 $T_i = 0^\circ \text{C}$
 M_I is Discharge Exposure of
 Natural Metal

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1961

$\text{Tube } C_{RI} = 45.8 \times 10^{-19} \text{ at 45 GPM}$
 $\text{Tube } C_{RE} = 23.3 \times 10^{-19} \text{ at 50 GPM}$
 $T_i = 0^\circ\text{C}$
 M_I is Discharge Exposure of Natural Metal

CORRECTED
 11/29/60
 FOR DISCHARGE
 EXPOSURE CURVES

ECT	1650	1625	1600
Rupture Operating Plan	1.3	1.4	1.5
Shield Flow-GPM			
Reactor Flow-GPM	86,200	86,100	84,000
Central Tube Flow-GPM	45.6	45.6	44.7
No. of Pumps	8	8	7
Avg. Inlet Temp. - $^\circ\text{C}$	13.2	9.5	7.1
	Nov.	Dec.	Jan.

1960 8.1 7.1 7.1
 Action Process
 Flow

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2 12.5 15 1961 17.5 22.5 20.5 17.5 14.5 9.0
159 1.5 200

Tube $C_{RI} = 1.17 \times 10^{-19}$ at 61 GPM

Tube $C_{RE} = 0.83 \times 10^{-19}$ at 66 GPM

$T_i = 0^\circ \text{C}$

M_I is Discharge Exposure of
Natural Metal

1961

Tube $C_{RI} = 1.17 \times 10^{-19}$ at 61 GPM
 Tube $C_{RE} = 0.83 \times 10^{-19}$ at 66 GPM
 $T_i = 0^\circ \text{C}$
 M_I is Discharge Exposure of
 Natural Metal

Rupture/Mo. Operating Plan	1.4	1.6	1.8	2.0	2.2
Shield Flow - GPM	182,000	182,000	182,000	182,000	182,000
Reactor Flow-GPM	62.1	62.1	62.1	62.1	62.1
Central Flow-GPM	6	6	6	6	6
No. of Pumps	13.2	9.5	7.1	5.5	5.0
Avg. Inlet Temp. - $^\circ \text{C}$	Nov.	Dec.	Jan.	Feb.	Mar.

1960

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