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POWER LEVEL RECOMMENDATIONS
INTERIM TO THE CURRENT TUBE REPLACEMENT
PROGRAM AT B, D, DR, F, AND H REACTORS

by

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POWER LEVEL RECOMMENDATIONS
INTERIM TO THE CURRENT TUBE REPLACEMENT
PROGRAM AT B, D, DR, F, AND H REACTORS

INTRODUCTION

The purpose of this report is to formally document interim power level recommendations for the old reactors consistent with the current tube replacement program. These recommendations were informally presented to the Processing Operations by Process Engineering.

The increasing number of process tube leaks experienced at the old reactors during the last quarter of CY-1961 disclosed a large number of tubes requiring imminent replacement. Tube replacement crews were formed and the first two-week tube replacement outage was started at DR on January 1, 1962. By March 12, 1962, 1556 tubes had been replaced out of the 4000 planned for the old reactors in CY-1962. Each of the old reactors has now had one tube outage and additional outages are planned as shown in Figure 1.

Power level reductions were initiated by the Processing Operations in December, 1961, and by January, 1962, all the old reactors had lowered power level to reduce tube leaks during this interim period of tube replacement.

Power level recommendations presented by Process Engineering last fall¹ are based upon process economics and recommend bulk outlet temperature limited operation at the old reactors during CY-1962. Additionally, a process economic analysis by Process Analysis indicates that it is economically sound to operate at bulk outlet temperature limits² (with current fuel performance) even if the tube corrosion rate is two or three times greater than currently estimated. Therefore, it is reasonable to expect that following the removal of the present incipient leakers, the old reactors can return to bulk limited operation.

In order to determine when the old reactors should return to bulk outlet temperature limited operation² and to provide power level recommendations during the period of incipient tube leakers removal, the following analysis was made.

DISCUSSION

Basic Assumptions for the Analysis

The following list of assumptions were used in this analysis:

1. It is assumed that the principal reason for operating at power levels less than bulk outlet temperature limits on an interim basis is to permit tube replacement capabilities to catch up with current tube replacement requirements.

2. The assumption was made that operation at bulk outlet temperature limits with 1960 and newer tubes is justified from process economic considerations.²
3. The leak rate model developed by Process Analysis based upon between-the-rib leak frequency as a function of corrosion index of 1956-1957 tubes was used for all tubes regardless of their installation date.
4. Confidence limits of 95 per cent were applied to the above leak rate model and are believed to be conservative limits.
5. A maximum instantaneous leak frequency of one leak per month is assumed reasonable for power dependent leaks only.
6. The standard corrosion model was used in calculating the change in corrosion index (CI) with change in tube outlet temperature.
7. The ratio of the average corroding central zone tube outlet temperature to the bulk outlet temperature was assumed at 1.3.
8. It was assumed that power dependent leaks would occur in the central zone which includes the enrichment ring.
9. The tube replacement outages for each old reactor are assumed to occur as indicated in Figure 1.
10. A reactor production efficiency of 80 per cent was assumed.

Tools Used in the Analysis

The following tools were used in the analysis:

1. Leak rate models developed by Process Analysis are shown in Figure 2 and described by N. E. Fuller as follows:

"In determining the relationship between tube leak rate and CI, the method of calculating cumulative leak rate was chosen; i.e., the leak rate calculated is the average number of leaks per tube during the time that the tube accumulates a given CI.

"In order to make these calculations, it is necessary to know the number of tubes which have accumulated various increments of CI in a selected time period, and know the number of leaks which occurred in each increment of CI. The time period considered in this study was January 1, 1956, to November 1, 1961.

"The tubes upon which this study was based were installed in B, D, DR, and H during the study time period. The CI of each tube was obtained from Production Computing Operation and the leak history was obtained from J. R. Young.

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"The leak rate models are based upon those leaks which resulted from internal corrosion, and were primarily between-the-rib failures for tubes installed in 1956 and 1957, and top-of-annulus failures for tubes installed in 1958, 1959, and 1960."

2. Distributions of corrosion index (CI) and calculated wall thickness (CWT) by year of installation for central zone (includes enrichment ring) tubes were supplied by Production Computing Operation. The lists were effective as of February 1, 1962, for B, D, DR, F; and February 12, 1962 for H.
3. The tentative tube replacement outage schedule and replacement rates shown in Figure 1 were supplied by J. R. Young, Applied Reactor Engineering.
4. The tube replacement criteria for the future tube replacement outages were obtained from the Process Engineer and represent the plans of the Processing Operation as of March 5, 1962. In most cases, the criteria used in selecting tubes for replacement are based upon the removal of low CWT tubes in the central zone. Additional criteria employed in selecting tubes employed combinations of information, e.g., CWT, probolog results, year of installation, high leak rate reactor zone.

Analysis

Applying the cumulative tube leak frequency model, Figure 3, against the CI distribution lists, the cumulative number of tube leaks was determined for the base case as of February 1, 1962. To assess the increase of cumulative tube leaks with time, evaluation of the CI list with increments of two units of CI were performed. To determine the time required to attain two units of CI for various bulk outlet temperatures, a table, Figure 4, was constructed using the following corrosion rate model,

$$CR, \text{ mils/month} = .0008 (2)^{T_0/12} (PE),$$

where it was assumed that the ratio of the average central zone outlet temperature to the bulk outlet temperature is 1.30 and the production efficiency (PE) is 80 per cent.

The number of cumulative leaks for the base case and for each increment of two CI units (mils) were plotted graphically as a function of time for 93.5 C bulk outlet temperature. If the instantaneous slope of this curve exceeded the assumption of one leak per month, the bulk temperature line which just satisfies the assumption was also determined by plotting the same cumulative leak values, but using the table, Figure 4, for the increased time increments at lower bulk temperatures.

These curves would normally be extended through CY-1962, but additional planned tube replacement outages required additional evaluations.

These additional evaluations were handled exactly as the first evaluation with the exception that the tubes which were expected to be removed during

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an outage were removed from the CI list. When CWT was the basis for removal, the CWT distribution by year of tube installation was used first to determine the number of tubes to be removed for each installation year. Then, these tubes were removed from the CI list by year of installation assuming that the higher CI values are equivalent to the lower CWT values. If the criteria for removal was indicated to be the oldest tubes, the CI list was used directly.

CONCLUSIONS AND RECOMMENDATIONS

The graphical plot of each set of tube outage evaluation values was started at February 1, 1962, and continued through the time period up to the following tube outage of January 1, 1963. Since each plotted segment represents the increase of cumulative leaks for that segment of time, the final graphs (Figures 5-10) show only the cumulative leaks accrued from February 1, 1962, to January 1, 1963. It is assumed that leaks "earned" up to February 1, 1962, have already been taken, so the number of cumulative leaks starts at zero at February 1, 1962.

The heavy line represents the cumulative leak frequency at 93.5 C bulk outlet temperature operation. The dashed line represents the recommended bulk outlet temperature. Each tube replacement outage of interest is indicated on the time scale with the expected number of tubes to be removed from the central zone. Also indicated on each graph are the number of central zone tubes and the distribution by year of installation after each tube outage.

Figure 11 is a summary of the reactor operating plans as determined from Processing Operation as of March 5, 1962, and the recommendations made at that time by Process Engineering.

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¹Engineering Bases for Power Levels and Exposures - October, 1961, thru December, 1962, HW-71096, September 18, 1961, Secret Red Label.

²It is recognized that in some cases graphite temperatures will limit reactor power levels below the bulk outlet temperature limit.

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FIGURE 1

TENTATIVE TUBE REPLACEMENT SCHEDULE
AS OF MARCH 5, 1962

<u>Week</u> <u>Beginning</u>	<u>Outage</u> <u>Reactor</u>	<u>Actual</u> <u>Tubes</u> <u>Replaced</u>	<u>Cumulative</u> <u>Tubes</u> <u>Replaced</u>	<u>Expected</u> <u>to be</u> <u>Replaced</u>
1/1/62	DR			
1/8/62	DR	142	142	
1/15/62	B			
1/22/62	B	340	482	
1/29/62	H			
2/5/62	H	308	790	
2/12/62	F			
2/19/62	F	364	1154	
2/26/62	D			
3/5/62	D	402	1556	
3/12/62	C			200
3/19/62	DR			
3/26/62	DR			250
4/2/62	H			
4/9/62	H			300
4/16/62	B			
4/23/62	B			400
4/30/62	F			
5/7/62	F			400
5/14/62	H			
5/21/62	H			300
5/28/62	K			
6/4/62	C			
6/11/62	C			400
6/18/62	DR			
6/25/62	DR			250
7/2				

Replacement Rate:

Tubes per week

B, D, F	200
DR	125
H	150
C	200
K	170

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PROCESS TUBE LEAK
FREQUENCY MODELS
FOR B, D DR & H REACTORS

FIGURE 2

FIGURE 3

Cumulative Leak Frequency -
Fraction Expected to Leak

<u>Corrosion Index</u>	<u>1956-1957 (Bottom)</u>	<u>with 20 limit</u>
10	---	.002
12	---	.003
14	.002	.005
16	.003	.008
18	.005	.012
20	.008	.02
22	.015	.04
24	.026	.07
26	.047	.12
28	.084	.22
30	.15	.40
32	.27	---

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FIGURE 4

<u>Bulk Outlet Temp., °C</u>	<u>Avg. Central Zone Tube Outlet Temp., °C</u>	<u>Delta CI, Mils/Month</u>	<u>Number of Months to Accumulate 2 Units of CI</u>
93.5	121.6	.716	2.8
91.5	119.0	.620	3.2
89.5	116.4	.533	3.75
88.5	115.0	.492	4.1
87.5	113.8	.457	4.4
85.5	111.2	.395	5.1
83.5	108.6	.339	5.9
81.5	106.0	.291	6.9
79.5	103.4	.252	7.9
77.5	100.8	.216	9.3

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D REACTOR CENTRAL ZONE
(1128 TUBES)

02-26-62 OUTAGE (417 TUBES)

CUMULATIVE NO. OF LEAKS

POST OUTAGE
NO. OF TUBES BY INSTANT YEAR

EXG	NO	POST OUTAGE
1954	26	0
55	1	0
56	32	0
57	264	0
58	44	0
59	50	0
60	69	69
61	124	124
62	510	510
	8	425

LEAK RATE MONTHLY

03-02-62

J F M A M J J A S O N D

1962

FIGURE 6

03-28-62 QW

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DO REACTOR - CENTRAL ZONE
(1226 TUBES)

PAST OUTAGE NO. OF TUBES
BY INSTALL. YEAR

	03-19	06-18	SEPT.
0616	141	133	31
0634	1	1	0
55	1	1	1
56	7	6	3
57	26	16	2
58	462	308	59
59	184	157	61
60	83	33	33
61	228	228	218
62	143	343	753

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J F M A M J J A S O N D J
1962

FIGURE 7

03-02-62 qdx

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REACTOR - CENTRAL ZONE
(1211 TUBES)

POST OUTAGE NO.
OF TUBES BY INSTANT. DATE

DATE	POST OUTAGE NO. OF TUBES BY INSTANT. DATE
02-12-62	1
04-30-62	3
05-14-62	0
05-28-62	14
06-11-62	87
06-25-62	43
07-09-62	56
07-23-62	76
08-06-62	127
08-20-62	144
09-03-62	271
09-17-62	312

CUMULATIVE LEAKS

02-12-62 OUTAGE (305 TUBES)

04-30-62 OUTAGE (329 TUBES)

FIGURE 3

03-05-62 qur

REACTOR - CENTRAL ZONE
WITHOUT 20 LIMITS

FIGURE 10

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CURRENT				To DATE		To		FUTURE	
B	PLAN	105°	86.0°	04-16			89.5-93.5		
	RECOM.		93.5	04-16			93.5		
D	PLAN	110	93.5	FUTURE					
	RECOM.		93.5	FUTURE					
DR	PLAN	110 < 32 112 > 32 CUT	86.0	04-18			93.0		
	RECOM.		87.5	03-16			93.5-95.0		
F	PLAN	105	85.0	04-30			INCREASE, POSSIBLY NOT TO BULK,		
	RECOM.		83.5	04-30			91.5 - 93.5		
H	PLAN	105	88.0	04-02		112	93.5		
	RECOM.		88.5	04-02			91.5-93.5		

FIGURE 11

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END