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TITLE

K REACTOR MIXER RECOMMENDATION
ALUMINUM SPLINE TUBES

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February 27, 1964

R. G. Clough, Manager
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K REACTOR MIXER RECOMMENDATION
ALUMINUM SPLINE TUBES

INTRODUCTION

Approximately 285 ribbed aluminum process tubes will have been installed in the central zone of each K reactor on completion of the zirconium tube replacement program. This report recommends the use of mixer fuel elements in the ribbed tube and discusses the basis for the recommendation. The recommendation is complicated by the fact that two tube designs having different dimensions will be used,² and the optimum mixer location for the two tube designs is different also.

RECOMMENDATION

1. Mixers should be charged in the nine and fourteen positions from the rear of the active charge in central-zone tubes having the uniform-wall design (drawing H-1-33277) and charged with natural or enriched uranium fuel.
2. Mixers should be charged in the seven-from-rear position in all central-zone tubes having the eccentric wall tube design (drawing H-1-21906) and charged with natural or enriched uranium fuel.
3. No mixers are needed in fringe-zone aluminum tubes.
4. The nine and fourteen positions should be used when both tube designs are used in the central-zone if it is necessary to have the same mixer placement for charging convenience and uniformity.
5. The TUBE-3 program³ used to calculate the effect of mixers on tube life is an empirical calculation primarily based upon small-reactor corrosion experience. While application of the models to K reactor is considered appropriate, there is a possibility the calculations could be significantly in error. In order to detect unexpected tube and fuel corrosion problems in the uniform wall design tube at an early date, it is suggested five tubes be charged with downstream thermocouple probes during the first metal cycle,

¹Van Wormer, F.W., letter to G. J. Rogers, Process Tube Design Dimensions, February 1, 1962.

²Hough, C.G., letter to W. H. Nicks, Inspection of Process Tubes, February 24, 1964.

³Jensen, R.D., TUBE-3 Fortran Program: Technical Description, November 4, 1963, HW-79518, Secret.

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and with PT-216 natural fuel if the fuel is available. This work is authorized by PT-481⁴ and PT-216.⁵

DISCUSSION

The TUBE-3 Fortran Program³ was used to calculate optimum mixer usage in both tube designs. TUBE-3 is used to estimate wall thickness and rib heights down the entire tube length. This is accomplished by estimating local water temperature at the top, bottom and sides of each fuel element and applying appropriate corrosion models. The relationships used to calculate local water temperatures take into account the effect of variables such as tube dimensions, tube distortion, fuel dimensions, fuel growth, charge position, water mixer location(s), axial flux distribution, and metal cycle length. The corrosion models incorporate water acidity (pH), flux intensity and local water temperature.

The effect of changes in any combination of these variables on local water temperatures and/or tube corrosion can be studied by simply varying input data to the program. Since variations in the input data have a significant affect on tube life, the following section gives the tube and fuel dimensional data and reactor operating conditions that were used in this study.

INPUT DATA ASSUMPTIONS

1. Tube and Fuel Dimensions

Tube dimensions used were the average dimensions obtained from micrometer measurements made by Central Maintenance on all new tubes prior to installation.⁶ The average dimensions and R values are summarized below for both tube designs together with the standard deviation of each dimension or R value.

	<u>Uniform Wall</u>		<u>Eccentric Wall</u>	
	<u>Ave.</u>	<u>Std. Dev.</u>	<u>Ave.</u>	<u>Std. Dev.</u>
R-top	1.40	0.027	1.25	0.022
R-bottom	0.72	0.011	0.79	0.012
R-hole	1.04	0.002	1.03	0.005
*Top wall	0.072	0.0012	0.077	0.0036
*Bottom wall	0.063	0.0012	0.058	0.0035
Rib height	0.125	0.0017	0.120	0.0025
*Rib plus wall	0.188	0.0018	0.178	0.0031
Top annulus	0.082	0.0015	0.090	0.0020
Bottom annulus	0.131	0.0013	0.122	0.0012
Tube I.D.	1.673	0.0010	1.672	0.0020
*Tube O.D.	1.808	0.0008	1.807	0.0013

³ibid.

⁴Hough, C.G., Production Test IP-481-I, Measurement of Process Tube Annular Temperature Distribution, May 17, 1962, HW-72351, Secret.

⁵Hall, R.E., et al, PT-IP-216-A, Evaluation of Performance of Normal Production I&E Fuel Elements, HW-58271, January 6, 1959, Secret.

⁶Barnes, G.P., Frantz, C.E., and C. G. Hough, Measurement and Acceptance Testing of New Process Tubes, HW-78844, September 5, 1963.

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The dimensions marked with an asterisk are measured with micrometers and the remaining dimensions are calculated from geometric considerations. The standard deviations include micrometer measurement error as well as the variation in the tube dimensions.

The R-top value characterizes the tube dimensions in a single number. A uniform-wall tube with a high R-top value of 1.45 would have a low ratio of top annulus to bottom annulus while one with a low R-top value of 1.35 would have a comparatively high ratio of top annulus to bottom annulus. Generally speaking, R-top values for the uniform-wall tubes range between 1.35 and 1.45 while 1.20 to 1.30 is the range for the eccentric wall tubes. Since tube life calculations in this report are based on the average values of 1.40 and 1.25, respectively, individual tubes with different R-top values would have different local water temperatures and tube life than shown in this report.

In all calculations, initial fuel dimensions are assumed to be the nominal dimensions for K4N fuel, namely 8.865" effective length, 1.460" O.D. and 0.385" I.D. During each simulated metal cycle, the TUBE-3 program calculates fuel growth and can wall corrosion. Heat split, flow split and cross-sectional area are assumed to be the same for both tube designs.

2. Reactor Operating Conditions

Operating conditions during the month of June were selected to represent average reactor conditions with respect to tube corrosion, namely:

Reactor flow	206,000 gpm
Bulk outlet temperature	93°C
Inlet temperature	12°C
Power level	4400 MW
Power of average tube	1370 kw
No. of active tubes	3213
pH	6.6

The corrosion conditions would be expected to be more severe than above during July, August, September and October and less severe during the remaining seven months of the year.

3. Tube Operating Conditions

Although a tube with average dimensions was used in this study, the operating conditions selected were relatively severe:

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	<u>Uniform Wall</u>	<u>Eccentric Wall</u>
R-top	1.40	1.25
Flow	70 gpm	70 gpm
Tube factor	1.20	1.20
Tube power	1640 kw	1640 kw
Inlet temperature	12°C	12°C
Outlet temperature	101°C	101°C
Goal exposure	650 MWD/T	650 MWD/T
Mixer efficiency	50%	50%
Skewing	0	0
Peaking	-2.0	-2.0

Therefore, tube life in this study is for tubes with average dimensions, average seasonal operating conditions and a severe tube factor of 1.20. A relatively high power tube was selected because such tubes need and benefit the most from mixer fuel elements.

RESULTS

Numerous corrosion simulation runs were made with the TUBE-3 code to determine how many mixers and what mixer locations gave maximum tube life and maximum reduction in top-of-annulus temperatures at the rear of the active section. Tube life is defined as the time required for either the top or bottom wall to reach 30 mils of wall thickness. Maximum top-of-annulus temperatures occur at or near the end of the first metal cycle when fuel element growth is maximum and the top annulus is more restricted than at the beginning of the first cycle.

1. Uniform-Wall Design

Figure 1 shows the effect of mixer position on tube life for the uniform-wall design. Maximum tube life with one mixer is 1250 days at 100 per cent TOE when the single mixer is positioned twelve from rear. This corresponds to 22 metal cycles at a goal exposure of 650 MWD/T. At the end of the last metal cycle the top wall was 30 mils and the bottom wall 47 mils.

When two mixers are used, maximum tube life is 1750 days at 100 per cent TOE when two mixers are positioned nine and fourteen from the rear. This corresponds to 31 metal cycles at a goal exposure of 650 MWD/T. At the end of the last metal cycle the top wall thickness was 30 mils and the bottom wall 31 mils.

Figure 2 shows the reduction in top annulus temperature caused by one mixer at the end of the first metal cycle. Figure 3 shows the reduction in top annulus temperature caused by two mixers at the end of the first metal cycle. One mixer causes a reduction of about 14°C at the end of the charge in a tube with an initial R-top value of 1.40 and a tube factor of 1.20. Two mixers cause a reduction of about 21°C at the end of the charge.

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Figure 4 shows the reduction in R-top value caused by one mixer twelve-from-rear, and two mixers nine and fourteen from rear, at the end of the first metal cycle. One mixer reduces the end of charge R-top value to about 1.20 and two mixers reduces the R-top value to about 1.12.

Figures 5 and 6 show the remaining top and bottom wall thickness, respectively, at the end of the last metal cycle.

2. Eccentric Wall Design

Figure 7 shows the effect of mixer position on tube life for the eccentric-wall design. Maximum tube life is 1630 days at 100 per cent TOE with a single mixer in the second-from-rear position. In all cases, tube life with two mixers was less than tube life with one mixer. Although the difference in tube life between one mixer and no mixer-at-all is less than one metal cycle for the tube studied, variation between tubes and other factors must be considered.

Figure 8 shows the reduction in top annulus temperature caused by one mixer. One mixer causes a reduction of about 10°C at the end of the charge in a tube with an initial R-top value of 1.25 and a tube factor of 1.20.

Figure 9 shows the reduction in R-top value caused by one mixer at the end of the first metal cycle. One mixer reduces the R-top value to about 1.11.

Figures 10 and 11 show the remaining top and bottom wall thickness, respectively, at the end of the last metal cycle. One mixer effectively causes the top wall corrosion to level out or "plateau" sooner depending on the mixer location and has little effect on bottom wall corrosion.

CONCLUSIONS

The results shown in Figures 1-6 indicate the most effective mixer location for the uniform-wall tube design is nine and fourteen from the rear of the charge.

The results shown in Figures 7-11 indicate the most effective mixer location for the eccentric-wall tube design is seven from the rear of the charge. While no mixer at all gives very nearly the same tube life as one mixer, a mixer is needed to protect those tubes that have unusually high R-top values, operate at high tube factors or have unusual tube distortion, fuel growth or misalignment. One mixer in the seven-from-rear position will keep the top wall thickness greater than 35 mils, in most cases, with tube failure occurring between-the-ribs. The probability of tube and fuel abnormalities suggest continued mixer use even though calculations for the average eccentric tube would indicate increased tube life through mixer elimination after a few metal cycles. Since the average uniform-wall tube fails at its top, no later change in mixer use or position is indicated.

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It should be noted that tube life in the uniform-wall tube design with two mixers is greater than tube life in the eccentric wall tube with one mixer by about 15 per cent.

No TUBE-3 runs were made to determine optimum mixer location in E-metal columns. Seven-from-rear in a natural column is approximately equivalent to eight-from-rear in an enriched column (with respect to temperature), and nine and fourteen in a natural column is about the same as eleven and seventeen in an enriched column. It is desirable to have the same mixer position for both natural and enriched columns for changing convenience. Since the difference between seven and eight or nine and fourteen and eleven and seventeen is probably small in terms of tube life, the seven-from-rear and nine and fourteen-from-rear positions are recommended for both natural and enriched columns.

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FIGURE 1
EFFECT OF MIXER POSITION ON TUBE LIFE
K REACTOR UNIFORM WALL TUBE DESIGN
R TOP = 1.40

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TOP ANNUOUS TEMPERATURE
MAXIMUM AT END OF FIRST METAL CYCLE

130
120
110
100
90
80
70
60
50
40
30
20
10
0

MIXER POSITION	TUBE LIFE DAYS AT 100% TDE
NONE	427
4	490
6	545
8	606
10	960
12	1381
14	1164

OPERATING CONDITIONS		
	REACTOR	TUBES
FLOW	205,250	70
INLET TEMP	12	12
OUTLET TEMP	93	101
POWER	4400	1640
ACTIVE TUBES	3213	
TUBE FACTOR	-	1.20
MIXER EFF.	-	50%
GASL EXP.	-	650
INITIAL RTOP	-	1.40

38 PC. Natural Fuel Charge

DISTANCE FROM REAR V.C. FLANGE, FT.

FIGURE 2
EFFECT OF ONE MIXER ON TOP ANNUOUS TEMPERATURE
K REACTOR UNIFORM WALL TUBE DESIGN

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FIGURE 5
EFFECT OF MIXER ON TOP WALL THICKNESS
K REFORME UNIFORM WALL TUBE DESIGN

REMAINING TOP WALL THICKNESS (MILS)
AT REPLACEMENT - 30 MILS

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FIGURE 6

EFFECT OF MIXER ON BOTTOM WALL THICKNESS
K REACTOR UNIFORM WALL THICKNESS DESIGN

38 IN. UNIFORM FUEL CHANNELS
DISTANCE (INCHES)

REMAINING BOTTOM WALL THICKNESS (INCHES)

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FIGURE 7

EFFECT OF MIXER POSITION ON TUBE LIFE
K REACTOR ECCENTRIC WIRE TUBE DESIGN
 $R_{TOP} = 1.25$

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MIXER POSITION	TUBE LIFE	DIFF. AT 10% TOP
NONE	1562	
2	1626	
4	1681	
6	1526	
8	1515	
10	1515

FIGURE 8

EFFECT OF ONE MIXER ON TOP ANNULUS TEMPERATURE
IN REACTOR ECCENTRIC WALL TUBE DESIGN

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NO MIXER

MIXER 2 4 6 8 10 FROM REAR

38 P. NATURAL FU-1 CHANGES

STOP, END OF FIRST METAL CYCLE

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FIGURE 10
EFFECT OF MIXER ON TOP WLL THICKNESS
K REACTOR ECCENTRIC WITH THE DESIGN

WLL THICKNESS (MILS)
DISTANCE FROM REAR - 30 MILS

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FIGURE 11

EFFECT OF MIXERS ON BOTTOM WALL THICKNESS
K REACTOR ECCENTRIC WALL TUBE DESIGN

WALL THICKNESS (INCHES)

68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
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18
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