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K REACTOR MIXER STUDY ALUMINUM SPLINE TUBES

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K REACTOR MIXER STUDY
ALUMINUM SPLINE TUBES

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1. Hough, C.G., K Reactor Mixer Recommendation, Aluminum Spline Tubes, February 27, 1964, HW-81041 (Secret).
 2. Corlett, R.F., letter to R.W. Reid, Use of Concentric Aluminum Tubes at KW Reactor, March 4, 1964.
 3. Clough, R.G., letter to A.R. Maguire, Use of Mixer Elements, April 20, 1964.
 4. Hough, C.G., K Reactor Mixer Study, April 23, 1964, HW-81965, (Secret).
 5. Medcalf, A.W., personal communication, Enriched Metal Requirements for Mixers, May 7, 1964.
 6. Nelson, R.H., letter to C.G. Hough, K Reactor Mixer Study, May 19, 1964.

INTRODUCTION

Reference 1 gave mixer recommendations for aluminum spline tubes at the K reactors. On completion of the study, R. F. Corlett requested a more detailed economic study of mixer usage at KW reactor². R. G. Clough also requested additional information on use of mixer elements in fringe tubes³. In order to answer these requests, additional information was needed and requested⁴. A. W. Medcalf replied giving enriched metal requirements in support of mixers⁵. No other information was received so it was not possible to make the economic study requested by R. F. Corlett.

This report presents more detail on tube-life estimates associated with use of the eccentric and concentric-wall tube designs in central- and fringe-zones and the results of five downstream thermocouple probes that operated in concentric-wall tubes at KW reactor. Also, modification of the concentric-wall tube (milling down of the ribs) is discussed.

SUMMARY

The TUBE-3 Fortran Program⁷ was used to calculate tube life for two tube designs (concentric-wall, eccentric-wall), 6.2, 6.6, and 7.0 pH, and for mixer positions

⁷Jensen, R. D., Tube-3 Fortran Program: Technical Description, November 4, 1963, HW-79518, Secret.

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previously determined to give maximum tube life¹. Input data assumptions are given on page 5. Limitations of the TUBE-3 code are given on page 9. The results are displayed graphically in Figures 1-5. Based on Figures 1-5, the following conclusions are made:

1. If the central-zone contains all eccentric-wall tubes (KE reactor), seven-from-rear is the recommended mixer position. However, any position between seven- and twelve-from-rear will give approximately the same tube life.
2. If the central-zone contains a mixture of eccentric-wall and concentric-wall tubes, selection of one mixer pattern for all tubes is difficult. Three main factors should be considered:
 - a. the outlet-temperature range for each tube design,
 - b. the number of tubes of each design installed,
 - c. the worth of differences in conversion losses.

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At KW reactor, 44 concentric-wall tubes and about 240 eccentric-wall tubes are installed in the central-zone. Since the concentric tubes appear to be operating at outlet temperatures less than 90°C and because tube life is about the same for eccentric tubes operating with a mixer between seven- and twelve-from-rear, twelve-from-rear is the best choice for all central-zone aluminum tubes at KW reactor. If the concentric tubes operate at temperatures much higher than 90°C, two mixer patterns should be used; nine- and fourteen-from-rear for concentric tubes and seven-from-rear for eccentric tubes. However, twelve-from-rear might still be a reasonable choice for both tube designs, provided the 44 concentric tubes are monitored frequently with the probolog.

3. Eventually it will be necessary to install concentric-wall tubes in the central-zone at both K reactors. The concentric tubes can then be operated with two mixers or the ribs could be milled down about three mils and the tubes then operated with one mixer. Another possibility is to increase flow in all central-zone spline tubes* and operate the present concentric tube with one mixer (or with two mixers for the first 6 to 12 months). The latter would be satisfactory if outlet temperatures of spline tubes could be kept below 100°C.
4. No mixers are needed in fringe-zone tubes. Details are given on page 8. In order to learn more about fringe-zone tubes that are corroding most rapidly, it is recommended some fringe-zone tubes that probolog less than 45 mils be removed and saved for examination. Additional studies can then be made to determine whether mixers would be beneficial in such tubes.

* Perhaps by a fuel-size reduction.

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DISCUSSION

Input Data Assumptions

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The TUBE-3 Fortran Program⁷ was used to calculate tube life for two tube designs (concentric-wall, eccentric-wall), 6.2, 6.6 and 7.0 pH and for mixer positions previously determined to give maximum tube life¹. The following sections give tube and fuel dimensional data and reactor operating conditions used in this study.

1. Tube Dimensions

Tube dimensions used were the average dimensions obtained from micro-meter measurements made by Central Maintenance on all new tubes prior to installation. The average dimensions and R values are summarized below for both tube designs.

	<u>Concentric Wall</u>	<u>Eccentric Wall</u>
R-top	1.40	1.25
R-bottom	0.72	0.79
R-hole	1.04	1.03
*Top wall	0.072	0.077
*Bottom wall	0.063	0.058
Rib height	0.125	0.120
*Rib plus wall	0.188	0.178
Top annulus	0.082	0.090
Bottom annulus	0.131	0.122
Tube I.D.	1.673	1.672
*Tube O.D.	1.808	1.807

*The dimensions marked with an asterisk are measured with micrometers, and the remaining dimensions are calculated from geometric considerations.

In order to simulate tube corrosion in fringe-zone tubes (eccentric design), it was necessary to select a tube having top wall, bottom wall, and rib corrosion profiles typical of today's fringe-zone tubes. Most fringe-zone tubes have minimum wall thicknesses greater than 55 mils, but some are down to about 45 mils. The following tube profile was selected for this study.

<u>Distance From</u> <u>Outlet Flange (Feet)</u>	<u>Top Wall</u> <u>(Inches)</u>	<u>Bottom Wall</u> <u>(Inches)</u>	<u>Rib Plus Wall</u> <u>(Inches)</u>
7.5	0.070	0.052	0.165
9.0	0.062	0.050	0.163
12.0	0.062	0.050	0.163
15.0	0.068	0.053	0.167
20.0	0.078	0.057	0.172
40.0	0.079	0.058	0.173

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By far the majority of fringe-zone tubes are thicker than 50 mils, so that fringe-zone tube life estimates obtained using the above profiles are conservative.

2. Fuel Dimensions

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 estimates fuel growth and can wall corrosion. Heat split, flow split, and cross sectional area are assumed to be the same for both tube designs.

3. 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	4,400 mw
Power of average tube	1370 kw
No. of active tubes	3213

4. Tube Operating Conditions

Outlet temperature distributions for KW reactor obtained from April 1964 temperature maps were provided by Production Computing. The data were divided into groups according to flow zone and tube design within flow zones. The groups are:

<u>Flow Zone</u>	<u>Flow gpm</u>	<u>Tube Type</u>	<u>Approximate No. of Tubes</u>
1	68	eccentric	273
1	68	concentric	36
1	66	fringe eccentric	80
13	42	fringe eccentric	141
14	37	fringe eccentric	339

The distributions of outlet temperatures for the five groups are given in Figure 6. The relationship between outlet temperature and tube factor is given in Figure 7. KE temperature distributions were assumed to be the same as KW except no concentric tubes are installed at KE reactor. New tube dimensions were used for the first two central-zone groups. The corroded dimensions given in (2) above were used for the three fringe-zone groups. Other tube operating conditions of interest are:

Goal exposure	650 MWD/T
Mixer efficiency	50%
Skewing	-1.0 (upstream)
Peaking	-5.5%
Replacement wall thickness	30 mils.

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Outlet temperature was varied over the complete range given in Figure 6 for each group. Mixer position and pH were varied also. The resulting tube life curves are shown in Figures 1-5.

Results

1. Concentric-Wall Design

Approximately 44 of these tubes are installed at KW reactor, none at KE reactor. Tube life curves are shown in Figure 1. The effect of mixers is shown for 6.6 pH only. The effect is similar at 6.2 and 7.0 pH. The best single mixer position was previously determined to be twelve-from-rear¹, and the best double mixer positions were nine- and fourteen-from-rear. Figure 6 indicates outlet temperatures vary between 57 and 88°C. Reading from the curves for 6.6 pH and 88°C, tube life is estimated to be 4.2, 9.4, and 10.3 years (100% TOE) for no mixer, twelve-from-rear and nine- and fourteen-from-rear, respectively. As long as outlet temperatures are not greater than 88 to 90°C, twelve-from-rear is a reasonable choice. If outlet temperatures exceed 90°C, nine- and fourteen-from-rear is the best choice from a tube life standpoint.

2. Results of Thermocouple Probes in Concentric Tubes

Five T/C probes were installed at KW reactor in concentric design tubes. Two tubes were charged with mixers twelve-from-rear, and three tubes were charged with mixers nine- and fourteen-from-rear. The initial R-top value for these tubes with no mixer is 1.40. The TUBE-3 code was used to calculate the end-of-charge R-top values using the appropriate tube and fuel dimensions and mixer positions. The calculated values are compared to the observed thermocouple probe values below.

<u>Tube No.</u>	<u>Mixer Position</u>	<u>End-of-Charge R-Top Value</u>		<u>Bulk Tube Outlet Temperature</u>
		<u>Calculated</u>	<u>Observed</u>	
0758W	12	1.24	1.16	83
0761W	12	1.24	1.11	82
0764W	9-14	1.15	1.17	79
0770W	9-14	1.15	1.15	81
0782W	9-14	1.14	1.07	84

The observed T/C probe data indicates one mixer is as effective as two mixers. This is contrary to past thermocouple probe data in similar tubes at C reactor and the good performance of high-rib C reactor tubes installed during March, 1962 and operated with two mixers. The TUBE-3 program correctly predicted the effect of two mixers but failed to predict the effect of one mixer. Some additional TUBE-3 runs were made, and it was determined the mixer efficiency would have to be about 90 per cent in order to predict the observed values of 1.16 and 1.11.

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The disagreement is probably associated with the low-bulk tube-outlet temperatures. Optimum mixer placement (for maximum tube life) varies with outlet temperature. The mixer positions twelve- and nine- and fourteen-from-rear were determined¹ to be optimum for much higher outlet temperatures. Furthermore, the empirical correlations inherent in TUBE-3 are based on data obtained at higher outlet temperatures. All this indicates that two mixers at nine- and fourteen-from-rear offer very little additional protection over one mixer at twelve-from-rear in tubes operating at relatively low temperatures.

3. Eccentric-Wall Design

Most of the spline tubes at KW and all at KE are relatively new eccentric-wall design tubes. Tube life curves are shown in Figure 2. The best single mixer position was previously determined to be seven-from-rear¹. Twelve-from-rear offers some additional protection over seven-from-rear for high temperature tubes. But, seven-from-rear is probably the best over-all position for the complete temperature range, (57°C to 105°C) shown in Figure 6.

4. Fringe-Zone Eccentric-Wall Design

The majority of aluminum process tubes are located in the fringe-zone of both reactors and are original tubes with the eccentric-wall design. They are located in three different flow zones. Tube life estimates were made for each flow zone and are shown in Figures 3, 4, and 5. The same initial tube-wall dimensions (section 2 above) were used in each flow zone, and the tube life shown in the figures is the additional tube life that can be expected from today onward. Since bottom corrosion is limiting in all cases, it can be said that Figures 3, 4, and 5 give the time in years (100% TOE) to corrode from an initial minimum bottom-wall thickness of 50 mils to a bottom-replacement-wall thickness of 30 mils. Most of today's fringe-zone tubes have bottom walls thicker than 50 mils, so the additional tube-life estimates in Figures 3, 4, and 5 are conservative.

The curves indicate that mixers give very little additional tube life; in fact, mixers are detrimental at the higher temperatures. For this reason, it was previously recommended¹ that mixers are not needed in fringe-zone tubes. The only argument in favor of continued use of mixers in fringe-zone tubes is to provide protection against "oddball" corrosion. Such corrosion is usually top-wall corrosion caused by fuel warp/and or misalignment or graphite distortion. It is difficult to imagine how these factors would result in increased bottom-wall corrosion. About the only way to learn more about this problem is to remove some fringe-zone tubes that probolog less than 45 mils and save them for ex-reactor examination. Additional studies can then be made to determine whether mixers would be beneficial in such tubes.

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Limitations of Tube-Life Estimates

The tube-life curves shown in Figures 1-5 were obtained with the TUBE-3 code⁷. The corrosion equations in the code are based on empirical correlations obtained from analysis of laboratory test data and in-reactor corrosion data. Tube life calculated with the TUBE-3 code takes into account many factors known to affect tube corrosion and is a significant improvement over any other calculational method. However, the code has limitations that should be considered. The following is a list of such limitations and the effect they might have on Figures 1-5.

1. The effect of pH is based on the results of the low pH test at D reactor where half of the reactor was operated at 7.0 pH and half at 6.6 pH. The pH effect is included in TUBE-3 as follows:

$$F = (0.1018)(10^{-6}) \exp (2.30)(\text{pH})$$

F is 0.16, 0.29, and 1.0 for 6.2, 6.6, and 7.0 pH, respectively. Relative to 7.0 pH this represents 2.5 and 6.2 factors of improvement for 6.6 and 6.2 pH, respectively. The uncertainty here is whether the extrapolation to 6.2 pH is valid and whether data obtained at D reactor is valid for the K reactors.

2. The effect of fuel element growth on local annulus water temperature is included in the TUBE-3 code. It is based upon pre- and post-irradiation fuel diameter measurements of fuel elements (PT216) operated at 7.0 pH. Thus, the "growth effect" is really the difference between fuel growth and can-wall corrosion at 7.0 pH. Therefore, the amount of "growth" calculated by the TUBE-3 code will be slightly in error at pH other than 7.0. The simulation thus uses a larger top-annulus dimension than would really exist when the can walls are corroding at 6.2 and 6.6 pH corrosion rates. This means that tube-life estimates in Figures 1-5 would be slightly less than indicated for those parts of the 6.2 and 6.6 curves that are limited by top-wall corrosion.
3. The TUBE-3 code was developed primarily from corrosion data obtained in central-zone process tubes. The question arises as to whether the TUBE-3 code can be applied to fringe-zone tubes. In the TUBE-3 code, the difference between central-zone and fringe-zone corrosion is taken into account by the following relationship:

$$0.600 + 0.781 \phi,$$

where: $\phi = P / [(TOD)(SL)(\pi)]$ = relative radiation intensity, kw/in²

P = slug power, kw

TOD = tube outside diameter

SL = slug length

The above effect of radiation intensity was shown to be an important factor⁸ and should take into account the difference in corrosion between

⁷Ibid.

⁸Richmond, R.B., Radiation Effects on Aluminum and Corrosion, February 20, 1963, Unclassified.

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central- and fringe-zone tubes. However, we do not know how accurate the calculations are. It is possible the absolute tube-life values given in Figures 3, 4, and 5 could be in error. But the curves should be accurate relative to one another. Thus, the conclusion that mixers are not needed is valid.

CONCLUSIONS

Central-Zone

If the central-zone contains all eccentric-wall tubes (KE reactor), seven-from-rear is the recommended mixer position. However, any position between seven- and twelve-from-rear will give approximately the same tube life, as shown in the following table.

EFFECT OF MIXER POSITION ON TUBE LIFE, 6.6 pH
YEARS AT 100 PER CENT TOE

<u>Outlet</u> <u>Temperature</u>	<u>Concentric Design</u>			<u>Eccentric Design</u>			
	<u>No</u> <u>Mixer</u>	<u>12R</u>	<u>9-14R</u>	<u>No</u> <u>Mixer</u>	<u>7R</u>	<u>12R</u>	<u>9-14R</u>
110	0.5	1.65	2.6	1.75	2.4	2.4	2.6
100	1.25	3.6	5.0	4.3	4.4	4.4	4.2
90	3.5	7.8	9.2	7.4	7.5	7.3	7.2
80	9.5	14.9	15.4	11.6	12.3	11.8	12.2

If the central-zone contains all concentric-wall tubes, nine- and fourteen-from-rear are the recommended mixer positions. It is interesting to note the concentric-wall tube with two mixers gives more tube life than the eccentric-wall tube with one mixer. It was not determined whether the additional production loss and enriched metal requirements associated with two mixers would negate the advantage the concentric-wall tube (with two mixers) has over the eccentric-wall tube (with one mixer).

If the central-zone contains a mixture of eccentric- and concentric-wall tubes, selection of one mixer pattern for all tubes is difficult. Three main factors should be considered:

1. the outlet temperature range for each tube design,
2. the number of tubes of each design installed, and
3. the worth of differences in conversion losses.

At KW reactor, 44 concentric-wall tubes and about 240 eccentric-wall tubes are installed in the central-zone. Since the concentric tubes appear to be operating at outlet temperatures less than 90°C and because tube life is about the same for eccentric tubes operating with a mixer between seven- and twelve-from-rear, twelve- from-rear is the best choice for all central-zone aluminum tubes at KW reactor. If the concentric tubes operate at temperatures much higher than 90°C, two mixer patterns should be used: nine and fourteen for concentric tubes and seven-from-rear for eccentric tubes. However, twelve-from-rear might still be a reasonable choice for both tube designs provided the 44 concentric tubes were monitored frequently with the probolog.

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Fringe-Zone

Mixers are not needed in fringe-zone tubes. However, in order to provide protection against "oddball" corrosion in some tubes, it is recommended that several tubes that probolog less than 45 mils be removed and saved for examination during the next six months. The results would be studied to determine whether mixers would prolong tube life.

Modification of Concentric-Wall Tubes

Eventually it will be necessary to replace central-zone eccentric-wall tubes with concentric-wall tubes. The concentric tubes can then be operated with two mixers, or the ribs could be milled down about three mils and the tubes then operated with one mixer. Tube life with two mixers in the present tube would be a little greater than the milled tube with one mixer. Another possibility is to increase the flow on all central-zone spline tubes* and operate the present concentric tube with one mixer (or with two mixers for the first 6 to 12 months). The latter would be satisfactory if outlet temperatures of spline tubes could be kept below 100°C.

C. G. Hough

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* Perhaps by a fuel-size reduction.

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FIGURE 1
OUTLET TEMPERATURE VS TUBE LIFE FLOW ZONE I = 68 gpm

FIGURE -2
OUTLET TEMPERATURE VS TUBE LIFE
FLOW ZONE I = 68 gpm

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FIGURE - 3
OUTLET TEMPERATURE VS TUBE LIFE
FLOW ZONE I= 66 gpm

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FIGURE - 4
OUTLET TEMPERATURE VS TUBE LIFE
FLOW ZONE 13 - 42 gpm

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FIGURE-5
OUTLET TEMPERATURE VS TUBE LIFE
FLOW ZONE 14 - 37 gpm

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FIGURE 6

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FIGURE 7

Tube Factor

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