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SUMMARY OF K REACTOR GRAPHITE TREATMENT FOR THE ZIRCONIUM TUBE PROGRAM

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K. D. Coughren
Reactor Design
FACILITIES ENGINEERING SECTION

February 8, 1963

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FOR THE ZIRCONIUM TUBE PROGRAM

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SUMMARY OF K REACTOR GRAPHITE TREATMENT
FOR THE ZIRCONIUM TUBE PROGRAM

I. INTRODUCTION

The purpose of this document is to summarize the graphite treatment studies conducted under Design Test 1136 in connection with the program for the retubing of the K Reactors with zirconium tubes.

II. SUMMARY AND CONCLUSIONS

The most significant results from the K Reactor graphite process channel treatment tests are that:

- A. A zirconium tube life of 10 years can reasonably be expected using the presently designed KVN self-supported fuel elements.
- B. Channel treatment tooling has been developed which will remove the necessary amount of graphite from the process channels to allow the 10 year tube life.
- C. Zirconium tube bending stresses, based on present best estimates of future graphite shrinkage, will not exceed the yield point of 20% cold worked zirconium during the 10 year tube life. The maximum bending stress in 10 years is expected to be approximately 31,500 psi.
- D. Maximum graphite temperatures could be increased by the removal of graphite from the locations of high heat generation. The calculated maximum graphite temperature is 1100 C with reactor operation at 5000 MW. This exceeds the presently imposed limit of 700 C. In reactor graphite temperature measurements will be required to verify the calculated values.
- E. The graphite removal process will not greatly change the integrity of the graphite channel. On reactor tests have shown that surface condition and block breakage are not greatly changed by drilling.
- F. Major alterations to the centering flanges are not necessary. Freedom in the centering flanges, after the prescribed setting, will allow for tube motion, caused by continued graphite contraction, beyond 10 years.
- G. The effect of graphite removal on reactor physics is negligible.
- H. The graphite reconditioning process meets the Design Criteria as set forth in HW-73906.

All references to tube life are in terms of years future from 1962 and at the 1962 rate of exposure accumulation. Higher reactor power levels will result in proportionately shorter tube life due to the increased rate of graphite contraction.

III. DISCUSSION

- A. Definition of Terms

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Tube Life - The length of time in years, in which the zirconium process tube will successfully permit charge-discharging of the presently designed KVN self-supported fuel elements without binding or sticking in the tube. Tube life is based on rails of the fuel element being oriented in the "+" position.

Channel Reconditioning (treatment) - The process of removing graphite from the process channel while the channel is in its present distorted condition. Graphite removal shall permit future stack contraction while limiting future process tube bending and flattening.

"+" Position - The orientation of the fuel element in the process tube such that one set of rails, 180 degrees apart, are in the vertical plane.

"X" Position - The orientation of the fuel element in the process tube such that one set of rails, 180 degrees apart, are 45 degrees clockwise from the vertical plane, and the other set of rails 45 degrees counterclockwise from the vertical.

Drilling - Same as channel reconditioning or boring.

Sticking - A resistance of the simulated fuel element probe movement in the process tube.

Angles Between Adjacent Tube Blocks - The angle between the centerline on one tube block and the extended centerline of the adjacent tube block.

B. Background

The graphite moderator is composed of layers of graphite bars stacked in a criss-cross matrix. Alternate layers of graphite are layed perpendicular to the proceeding layers. The composite stack is supported by the bottom cast iron thermal shield. The front and rear cast iron thermal shield blocks are supported by "gunbarrels" which are inserted through the biological shield at each process tube location and bear on the graphite. The process tubes, horizontal control rods and the top thermal shields are supported by the graphite stack. Graphite keys, strategically located near control rod channels and at the edges of the stack are utilized to restrain movement between adjacent layers of graphite. Figure 1 shows the typical graphite layup and keying pattern near a vertical rod channel for each K Reactor. The problems resulting from graphite moderator distortion have provided the subject matter for intense study since the early days of reactor operation. Graphite shrinkage associated with high temperature irradiation has posed threats to continued long term operation.

The graphite contraction phenomena became apparent after the reactors had operated for some time with higher graphite temperatures and higher power levels. Graphite contraction at temperatures above

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300 C is primarily a function of cumulative exposure. Since the flux levels and therefore contraction rates are higher at the mid-point of the process tube channel this portion of the channel becomes depressed. The fringe regions of the graphite core, being at both lower temperature and power levels, exhibit less depression and in some cases a slight inlet hump.

C. Present Graphite Conditions

Continued operation at graphite temperatures above 300 C and power level above 4000 megawatts has produced graphite shrinkage at the K Reactors. Analysis of traverse data taken on the reactor indicates this graphite shrinkage to be proportional to exposure.⁽¹⁾ Higher levels of exposure are experienced in the middle half of a majority of the process tube channels giving higher rates of graphite shrinkage at these points. This variation in shrinkage rates results in vertically distorted channel front-to-rear profiles as shown in Figure 2. The amplitude of this distortion increases progressively toward the top of the reactor. The most severe distortion of process tube channels exists at the top center of the reactor. In the regions of the outer tube columns the exposure levels produce a resultant vertical and horizontal distortion skewed at some angle from the vertical.

The original process channel is shown in Figure 3. The bending of the process tube in the graphite channel changes the clearance between the graphite blocks and the tube. In the regions of the 1st and 7th trunnion blocks the tube tends to rest on the bottom of the channel, shown in Figure 4, while in the regions of the 3rd, 4th and 5th trunnion blocks the tube tends to bear on the top of the graphite channel.

The bending of the process tube also effects the clearance between the tube and fuel element. Should the bend become sharp enough, a fuel element of the present design would stick or lodge in the tube. The present distortion of the graphite channel, using the ribbed aluminum tube, does not produce the sharp bends required to stick a current fuel element. However, as the center tube block strings continue to shrink, larger angles between adjacent tube blocks will develop and cause bending and flattening of the process tube. It is the combination of bending and flattening that is the chief cause of fuel element sticking. For the ribbed aluminum process tube now being used the radius of curvature at which binding of the 8" I&E fuel element can occur is approximately 100 inches. No radii of curvature of this small magnitude exist at the present K Reactors, but as depression of the center tube block strings continues it is possible to experience fuel element binding in 8 to 9 years if no channel treatment has been done. Considerations such as coolant flow and tube corrosion rather than channel distortion are the dominant factors in the life of the present aluminum process tubes.

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Recent observations of graphite conditions before and after channel conditioning have been performed.⁽²⁾ Results show that approximately half of the trunnion blocks in KW Reactor are damaged to some degree before channel treatment. This damage is mostly in the downstream end of the trunnion which is the section of reduced diameter that centers the tube, shown in Figure 5. At KE approximately one-fourth of the trunnion blocks are cracked or broken. Half of the trunnion blocks had reduced inside diameters. The causes of graphite damage may be from a) radiation induced preferential expansion-contraction, b) distortion, c) tube removal or d) a combination of all three. No damage to the tube blocks was observed. However, a total gap of two to three inches between the trunnion and tube blocks was observed at each of the 1st trunnion locations that were inspected in KW Reactor. In KE Reactor, similar 3" gaps were observed in the 1st and 7th trunnion locations, while smaller gaps were observed at the 2nd and 4th trunnion locations.

During normal operation the maximum measured graphite temperature is approximately 625-635 C. These measured temperatures are below the P.I.T.A. operating limit of 700 C in the bulk of the graphite and 850 C in the region of the second tube block which is cored to .130" radial clearance.⁽⁴⁾ It is to be noted that the graphite temperatures were measured by graphite stringer thermocouples, and do not accurately monitor the .130" coring zone. It is not possible with presently installed instrumentation to monitor the high localized temperatures resulting from excessive graphite to tube clearances.

Assuming that future graphite contraction continues at the same rate that has existed over the past five years, the most severe distortion of strings of tube blocks will continue to be at the top center of the reactor. This is because the tube block depression is cumulative from the bottom to the top of the reactor. Estimated graphite contraction rates based on traverse data from the Y-2 hole (top center) indicate that 58 row tube channel total shrinkage may be approximately 12.5" at the channel mid-point 10 years from 1962.⁽¹⁾ This produces future sharp bends at the 1st, 4th, 5th and 7th trunnion locations. As time progresses, these angles become sharper since various regions in the reactor are shrinking at different rates. For example, at the 4th trunnion the deflection between adjacent tube blocks, measured by projecting the centerline of one tube block past the adjacent tube block centerline, now is 2.6" in 48". This angle is approximately 4 degrees, but in 10 years this angle will be 4.3" in 48" or approximately 5 degrees. Future graphite shrinkage rates are based on the assumption that present power levels continue, therefore, the time element will have an estimated tolerance of ± 2 years.

The latest traverse data of the top center of the reactor is shown in Figure 2. Continued depression of the graphite will result in tube centerline profiles shown in Figure 6 by 1974.

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IV. DESIGN REQUIREMENTS

The design requirements of graphite moderator reconditioning for the installation of zirconium tubes in the K Reactors are intended as guide lines for the evaluation of graphite removal measures. The predicted future graphite distortion during the extended corrosion life of the zirconium process tube may produce excessive bending of the tube within the graphite channels. Fuel sticking during charging or discharging or structural failure of the tubes could result unless corrective graphite removal measures are accomplished prior to the zirconium tube installation. These design requirements are: (5)

- A. The effects of the future graphite distortion on the tube operational capabilities shall be evaluated.
- B. Locations and amounts of necessary graphite removal shall be established to insure appropriate tube life.
- C. Necessary graphite removal measures shall be determined to provide an appropriate operational life for the process tube.
- D. Effects of predicted graphite distortion on tube life shall be assessed from allowable stress considerations.

V. GRAPHITE TREATMENT

Extensive reconditioning of the graphite process channels is necessary to meet the objectives, bases and functional requirements of the Design Criteria. The evaluation of the graphite removal measures and their effect on the process tube operational capabilities are presented below.

A. Required Channel Treatment

The continued depression of the center tube block strings will require channel treatment to relieve to some extent the increasing angles* between adjacent tube blocks. This treatment will be in the form of graphite removal at the location of these large angles* before zirconium tube installation. In 10 years assuming no graphite removal, the tube location at the 1st trunnion will be approximately as shown in Figure 4, however, if 1/2" of graphite has been removed (Figure 7) the tube location will be approximately that shown in the lower part of Figure 4. In order to reach an economical tube life a predetermined amount of graphite must be removed from each of the sharp bends (angles larger than 20°) in the graphite channel. The amount to remove at each of these angles was determined by machining out the channel in the machine shop in increments of 1/8" as shown in Figure 7. Between each machining the blocks were assembled in the mockup and a tube

* See definitions

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was tested to determine if the necessary amount of graphite had been removed. This process was continued, beginning at an estimated amount, until a reasonable tube life was reached.

The amount of graphite removal to allow a 14 to 16 year tube life, determined by testing of the 58th row configuration is:

<u>Trunnion</u>	<u>Amount Removed</u>	<u>Location</u>
1	1/2	Bottom of channel
2	1/4	Bottom of channel
3	1/4	Top of channel
4	5/8	Top of channel
5	5/8	Top of channel
6	0	-
7	5/8	Bottom of channel

In effect, the removal of graphite has the purpose of decreasing the effective angle between adjacent tube blocks. Graphite removal must be accomplished in the reactor with present channel distortion if the expected tube life is to be realized. Sufficient graphite must be removed at each small bend angle to allow continued distortion over a 10 year period without exceeding curvatures which cause fuel element binding. It is estimated that the upper two-thirds of the reactor will require channel conditioning⁽⁶⁾ or all the tubes above the 20th row. Mockup testing has shown that graphite can be removed from the sharp bends and it is possible to remove approximately .4" from the most severe bends in the channel. This is not as much as the preliminary tests indicated was necessary, however, it is enough to allow a tube life of 10 years.

Figure 8 shows a trunnion block before and after it was drilled in the mockup. The graphite removal can be seen displaced to one side of the channel showing a displacement of the horizontal centerline in that direction. The trunnion block shown is from the 4th trunnion location where the graphite removal is from the top of the channel. The slight skewing of the hole is caused by the drilling process. The surface condition of the trunnion block is shown in Figure 9, where a comparatively smooth surface has been formed by the cutting tool. It is to be noted that the blocks used on the mockup are oversized 1/2" on the outside. The inside dimensions are that of the original K Reactor channels.

The expected tube life in years can be determined from Figure 11. The data for this chart was determined by testing in a two block mockup using blocks which had been milled in a milling machine.⁽¹⁾ ⁽¹³⁾ The results are approximately two years conservative when compared to the tube life as determined, in the same manner, on the full scale mockup. Figure 11 shows that for approximately 1/2" of graphite removal at the 1st trunnion a 12 year tube life could be expected. Mockup testing, to a large degree, was done using zirconium tubes made from sample extrusion runs. Later testing has been done using production run

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tubes which seem to be of higher quality. Each of these later tubes tested has shown a tube life expectancy of 10 years or better for the same amount of graphite removed.

Three channels of blocks were bored in the present distorted conditions of the 25th, 40th and 58th tube rows using the 6 ft tapered boring bar. After boring, three tubes were tried in each set of blocks to determine the expected tube life at the particular tube row. The tests indicate that a nominal tube would last approximately 10, 11, and 10 years respectively, at the 25th, 40th and 58th tube rows.

The increase of the tube flattening per year of continued distortion was examined at the 25th and 58th tube rows for the period 8 to 11 years of tube life. The average increase in flattening per year was 2 mils at the 58th row and 1.3 mils at the 25th row.⁽¹⁴⁾ The results of these flattening tests are shown in Figure 10. It should be noted that in the regions of the reactor where channel conditioning is necessary it makes little difference on future tube life if a zirconium tube of one particular minimum diameter is placed at the top of the reactor or at the elevation at which channel conditioning begins. However, in general, if all of the new tubes of the larger minimum diameter were placed in the region of the reactor that has received channel conditioning the tendency would be to prolong the expected tube life. This can be accomplished by separating the tubes according to their minimum diameter into groups of one-third and inserting that third which has the smaller minimum diameter into the reactor below the 20th row and the other two-thirds into the reconditioned region.

Figure 10 also shows the tube row at which channel treatment must begin to permit an expected life of 10 years. Adding a + 2 year tolerance to the expected 10 year tube life indicated, from Figure 10, the channel treatment must begin at row 20.

Tests have been performed on the reactor, using the latest available drilling tools, i.e. the tapered drilling bar, to determine the condition of the graphite channel after graphite removal.⁽⁷⁾ The channels were borescoped before and after and boregaged after the drilling. Before drilling observations revealed that some of the downstream ends of the trunnion blocks were broken and there was separation between the first tube block and trunnion block. Observations after drilling revealed no major change in the number of cracks and broken blocks. The surface was equal to that produced in mockup testing.

B. Centering Flange Setting

The continued shrinking of the center graphite blocks requires that the arc length of the process tube be continually increasing. This causes the gunbarrels to be pulled in toward the graphite core. The available amount of gunbarrel pull-in is limited by the clearances in the centering flange keyway. The gunbarrels will be set to

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allow a maximum of $3/8$ inch for thermal expansion which leaves a minimum of $15/16$ inch for graphite contraction on each gunbarrel keyway. That is

$15/16$ " available for total contraction,
less $1/16$ " required for thermal contraction,

leaves $7/8$ " available for graphite contraction at each end
(see Figure 18)

then $7/8 \times 2 = 1-3/4$ inch total both ends.

$1-3/4$ inch will give approximately 15 years tube life at the 58 tube row as shown in Figure 19. Lower tube rows will have a longer expected tube life with respect to the keyway. An allowance for one extra Van Stone leaves $1-7/16$ " for contraction or a tube life of 13 years. An allowance for two extra Van Stones on the tube leaves $1-1/8$ inch for contraction or a tube life of 11 years.

C. Zirconium Tube Life

The useful life of the zirconium tubes is measured by the length of time the tubes will permit use of the present KVN fuel elements. The limiting factors of tube life are determined by:

- a. Radius of curvature of the bend of the tube centerline.
- b. Point loads on the tube such as those at locations where the tube comes in contact with the graphite, causing premature point flattening. Usable tube life is reduced by as much as four or five years by these loads which are primarily at the trunnion locations.
- c. End loads on the tube cause increased flattening. These loads are caused by a stuck gunbarrel or the clearance in the centering flange having been used up by tube depression. Tests have shown a 500 lb. axial load on the tube at graphite depressions representing a 6 year distortion condition produces up to 3 mils flattening of the tube⁽⁸⁾.
- d. Fuel element loading on the tube tends to accentuate the sharp bends at the inlet and outlet ends. A tube loaded with a complete charge of KVN fuel elements rests on the bottom in the middle half of the drilled out channel at the 10 year graphite distortion condition. As the loaded tube is further depressed it begins to approach the top of the channel in the regions of the 4th and 5th trunnions while still touching the bottom of the channel between these trunnions.
- e. The difference in tube inside diameter, when within purchase specifications, can vary the usable life of the tube. Considering simulated fuel element sticking when oriented in the "+" position,*

* See definitions

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the inside diameter variance could make a difference of 2 years in the usable tube life. This difference in life does not consider the tolerance in years placed upon the estimated future graphite distortion rates.

- f. The orientation of the rails on the fuel element with respect to the process tube has significant although somewhat undefined, effect on usable tube life. Usable tube life is based exclusively on the orientation of the fuel element being in the "+" position in the tube. However, this position is basically unstable and it may be reasonable to expect the fuel element to seek a more stable position, such as approximately the "X" position* while in the tube. Tests in the mockup have demonstrated that fuel elements charged in the "X" position tend to stay in the "X" position, that is, when they exit from the tube they are still in this position with only an occasional one unexplainably coming out in the "+" position. Charging the fuel elements in the "X" position has allowed a tube life of 18 years to be reached, however, it cannot be guaranteed that the fuel elements will remain in that position.⁽⁹⁾ Further mockup testing is being conducted to determine the effect of radiation induced fuel element distortion on projected tube life.

D. Zirconium Tube Stresses

Stresses will be produced in the process tube by bending as the tube follows the depressed graphite channel. Tube bending stresses have been calculated to be approximately 31,500 psi when the tube is distorted to the 10 year and 58 row conditions.** This is the point at which fuel elements are initially expected to stick. If the tube was to continue deforming to the 20 year condition the stresses would be approximately 63,000 psi. Cyclic stresses due to start up and shut down have been calculated to be approximately 9000 psi, which is well below the cyclic stresses allowed by the ASA Piping Code under similar conditions. Due to the small amount of clearance between the tube and fuel element, tube stresses will not be limiting. Tube flattening due to bending and point contact with the graphite have been shown to be the major causes of fuel element binding. Permanent flattening has been experienced when tube flattening exceeded the 13 mil maximum fuel element clearance. This indicates that the yield stress has been reached at this particular point. However, the general stress level of the tube, based on radius of curvature, does not exceed yield.

Tests were conducted to determine the amount of tube flattening caused by contact with the trunnion blocks at the bend locations. The results show that a significant amount of tube flattening will occur with lateral loads of approximately 100 lbs or greater. The flattening is relatively independent of the length of the trunnion. The amount

* See definitions

** Based on channel conditioning to limit tube bending radii.

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of flattening appears to saturate above 200 lbs. of load. This is thought to be due to the fact that the horizontal diameter has increased enough to make contact with the sides of the trunnion. Thus, the dimensions of the trunnion have prevented any further flattening of the tube as the applied load is increased.⁽¹⁵⁾

In the event the trunnion has been destroyed during the reconditioning process, or before, the tube flattening will not saturate at the 200 lb. lateral load.

E. Graphite Temperature Effects

Graphite temperature is primarily due to the internal generation of heat in the graphite when under irradiation. Since the K Reactors have no graphite coolant as such, all the graphite cooling must be done by the process tube water flow. The thermal resistance of the path of heat flow (Figure 12) depends on the clearance between the tube and the graphite. Where the tube contacts the graphite the major mode of heat transfer will be conduction; where the tube does not contact the graphite a majority of the heat transfer will be by radiation.

During normal operation the maximum measured graphite temperature is approximately 625-635 C. It is to be noted that graphite temperatures are measured by graphite stringer thermocouples, and do not accurately monitor the .130" coring zone. These measured temperatures are below the operating limit of 700 C in the bulk of the graphite and 850 C in the .130" coring zone, i.e., second tube block.

The magnitude of the graphite temperature is dependent on parameters such as a) process tube coolant temperature, b) graphite heat generation rate, c) reactor gas composition, d) diameter of the original process channel, e) position of the tube in the channel and f) the amount of graphite removed.

The temperature distributions for various process tube and graphite system geometries were determined for the K Reactors with the aid of a FORTRAN two dimensional, steady state heat transfer program. Calculations were performed, using the above parameters, for assumed reactor operating levels of 4,000 and 5,000 MW.

The major conclusions from the graphite temperature study are:

- a. A graphite temperature of 1100 C is possible for 5,000 MW operation after the completion of the retubing project, based on predicted graphite contraction and a reactor gas composition of 100% helium. A temperature increase of about 140 C may be effected by changing the gas composition from 100% helium to 70% helium and 30% nitrogen.
- b. This 1100 C graphite temperature will far exceed the presently imposed maximum graphite temperature limit of 700 C.

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- c. Graphite temperatures at points of maximum neutron flux will exceed the present maximum limit by some finite amount with reactor operation at 5,000 MW regardless of whether or not the reactors are cored and retubed. These temperatures will depend on the system parameters of the channel geometry.
- d. The volume average graphite temperature following completion of the zirconium retubing program will remain sufficiently below 1000 C to retard the deleterious graphite water gas or oxygen reactions in the bulk of the graphite for 4000 MW or 5000 MW power level operation.
- e. A re-evaluation of the present maximum graphite temperature limits, as imposed on a measured temperature point value, should be made to determine the need for such a limit. (10)

It should be noted that the maximum graphite temperature of 1100 C will not occur unless the proper parametric conditions are met and that this temperature exists only at a given location in the graphite, it is not the temperature of the bulk of the graphite. In reactor measurements of the graphite temperatures will be required to substantiate the calculated values.

F. Reactor Physics

The effects of the high graphite temperatures associated with the change in channel geometry can be expected to have a significant effect upon production and product specification data in extreme cases. However, the effect is expected to be sufficiently masked by the preponderance of unmodified and slightly modified channels to cause only a slight total effect upon the production and goal exposure of the K Reactors. Factors such as conversion ratio, U^{235} depletion and Pu buildup change less than 1%. (11)

G. Channel Treatment Tooling

Until 1962, the method used to renovate or restore a graphite channel involved pulling a broach through the channel. As many as five passes of the broach were needed to remove the necessary amount of graphite. Much difficulty, even with multiple passes of the broach, was encountered in recent years in replacing tubes. Finally, the need for massive tube replacement was realized in early 1962. At this time, additional effort was directed towards development of a more efficient and reliable means of opening graphite channels for installing tubes. Thus the technique of drilling instead of broaching was developed from the 1960 experience in overboring and was continued through the tube replacement drilling development in calendar year 1962. This technique for graphite channel restoration is planned, with some major modifications, for use at the two K Reactors.

Several different types of cutters have been examined as candidates for the types of in-reactor graphite removal. These can be classified as:

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1. Overboring (concentric, total channel enlargement)
2. Coring (concentric counter-boring front and rear, for graphite growth control).
3. Retubing (simple restoration of channel to original I.D.).
4. "Conditioning" for length of tube life (preferentially removing graphite to correct for current and future distortion peaks and valleys).

The overboring cutter was developed and successfully used for overboring more than 40 channels at C Reactor. A number of the over-bore channels at C were recently cored, using an expanding cutter called a "flopout" cutter.

Another type of bar, the cutting bar, is a dual purpose tool which restores the straight sections of a graphite channel to the desired diameter and provides some channel straightening at block junctions. From the use of these types of cutters has evolved the boring bar which will be used at K Reactor.⁽¹²⁾

Initial mockup tests were done with two cutting bars, a 4 ft bar using evenly spaced cutters and a 4 ft. bar using a flopout cutter. Both of these bars produced unsatisfactory results such as little graphite removal, a very rough surface and excessive chattering in the channel. A 6 ft. bar with 11 cutters (Figure 13) was later tested, showing a marked improvement, however, the surface condition was still quite rough.

Further tool development resulted in the 6 ft. tapered cutter bar shown in Figures 14 and 15. To date this bar has produced very good results in terms of graphite removal, surface finish and minimizing graphite damage. The maximum amount of graphite removed by all of the 6 ft. bars has been approximately .4", however, the tapered bar has produced a longer tube life in terms of years.

Early mockup tests using both the 4 ft. and 6 ft. bars yielded inconsistent results. The difference in usable tube life varied as much as 4 years when testing with the same cutter bar and tubes. The reasons for this wide spread in tube life are yet unknown, however, it is felt to be the result of poor surface conditions after drilling and inconsistent tube qualities. New and superior quality zirconium tubes were available for mockup testing about the same time as the tapered bar was tested. Along with this, new power equipment, shown in Figures 16 and 17, with reduced speed was available for test drilling. These three improvements resulted in a longer tube life and the better surface finish as that shown in Figure 9. All of the channel tooling has been tested in the full scale channel mockup shown in Figure 20.

The 6 ft. tapered cutter bar (Figure 14) is the final design of cutter bars and will be used in the retubing of the K Reactors. An

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earlier model of this bar was tested on the reactor during a November outage where nine channels at the 49, 50 and 51 rows were successfully drilled. Some difficulty was encountered in getting the bar through the front gunbarrels. This was not a fault of the bar but due to galling of the rear guide on the power transmission shaft shown on Figure 14. This difficulty has since been eliminated.

H. Stack Stability

The proposed reconditioning of the K Reactors must be analyzed for future effects on the stability of the stack. Both K Reactors were designed on the basis of expected future growth, resulting in what is known as a "loose stack" internally. In addition to the internal looseness, an initial three to four inch gap was left between the graphite and the shields around the periphery of the moderator.

Evidence shows that the stack has suffered severe displacements both front to rear and side to side. The largest separation seems to be between the reflector and the active zone.

The channel reconditioning process concerns mainly alterations to the trunnion blocks. These blocks have the following functions 1) to provide continuity of the process channels, 2) to provide side to side spacing due to their resistance in growth in this direction, 3) to locate the undercut tube blocks in the center of the process channel, and 4) to support the process tube in a centered position within the coring pattern of each channel. Three of these functions are maintained by the collar of the trunnion (see Figure 5 and Figure 7). It is evident that general contraction of the stack will permit movement of the trunnion blocks from their intended position. Drilling and tube insertion will supply the force necessary to displace these trunnions. The forces which tend to distort the stack would not succeed without the additional problem of longitudinal contraction evident by voids of greater magnitude than pre-designed "growth spaces". Removal of the downstream end of the trunnion aided by longitudinal contraction eliminate all of the functions of the trunnion block. However, this in itself is not a serious condition. The major concern of the stability of the graphite stack evolves from the safety standpoint, which concerns the ability of the safety rods and backup 3X system to operate within the time limits required.

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VERTICAL CONTROL ROD OPENING

FIGURE 1
K REACTOR
GRAPHITE LAYUP ARRANGEMENT

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FIGURE 2
K REACTOR
PROCESS TUBE DISTORTION CURVES

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PROCESS TUBE CHANNEL CROSS SECTION

FIGURE 3
K REACTOR
PROCESS TUBE AND HCR CHANNEL SECTIONS

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BEFORE GRAPHITE REMOVAL

AFTER 1/2" GRAPHITE REMOVED

FIGURE 4
K REACTOR
1st. TRUNNION SHOWING TUBE LOCATION

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FIGURE 5.

II REACTOR DAMAGED THUNICK BLOCK

FIGURE 6
FUTURE GRAPHITE DISTORTION

FUTURE YEARS

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FIGURE 7
K REACTOR
GRAPHITE REMOVAL AT THE 1st. TRUNNION LOCATION

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FIGURE 8
K REACTOR
COMPARISON OF AS-BUILT AND RECONDITIONED TRUNNION BLOCK

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FIGURE 9
K REACTOR
SURFACE CONDITION OF A RECONDITIONED TRUNNION BLOCK

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FIGURE 11
CHART OF EXPECTED TUBE LIFE

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FIGURE 12
HEAT FLOW PATHS

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FIGURE 13
SIX FOOT - ELEVEN CUTTER DRILLING BAR

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FIGURE 14
TAPERED CUTTER BAR

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FIGURE 15
FORWARD CUTTERS OF THE TAPERED CUTTER BAR

FIGURE 16
POWER EQUIPMENT FOR GRAPHITE DRILLING BARS

FIGURE 17
POWER EQUIPMENT FOR GRAPHITE DRILLING BARS

FIGURE 20
K REACTOR
PROCESS CHANNEL MOCKUP

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