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TITLE

REVIEW OF REACTOR GRAPHITE DISTORTION PROBLEMS

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AUTHOR

K. D. Coughren
F. J. Kempf
C. A. Munro

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K. D. Coughren
F. J. Kempf
C. A. Munro

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REVIEW OF REACTOR GRAPHITE DISTORTION PROBLEMS

I. INTRODUCTION

The purpose of this document is primarily to discuss the effects of current retubing programs on the graphite moderator of the K Reactors. A secondary purpose of this report is to present general information related to graphite arrangement and keying patterns at the other operating reactors and to review, in a limited way, the types of graphite distortion observed at these reactors.

II. BACKGROUND

The graphite moderator at each reactor is composed of layers of graphite bars stacked in a criss-cross matrix. Alternate layers of graphite are layed perpendicular to the preceeding layers and 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. 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. Figures 1 through 5 show the typical graphite layup and keying patterns near a vertical rod channel for each of the operating reactors. The design details of the graphite vary from one reactor to another but in general, can be classified in five groups. The B, D, and F Reactors are similar in graphite layup; as are the K Reactors. The remaining reactors, DR, H and C are different in keying, coring and other more or less significant construction details.

The problems resulting from graphite moderator distortion have provided the subject matter for intense study since the early days of reactor operation. Graphite growth, associated with low operating temperatures, and graphite contraction under high temperature irradiation have both posed threats to continued long term operation.

When it became apparent that the graphite growth phenomenon observed at the B, D, and F Reactors was temperature dependent, graphite temperatures were raised by adding carbon dioxide to the reactor gas atmosphere. Thermal annealing reversed the growth trend, in the high temperature regions, but expansion continued in the lower temperature fringe regions of the stack. Measurement of the relative expansion of tube blocks and filler blocks showed the tube blocks to be sustaining a major portion of the expansion.⁽¹⁾ It was also determined that the effects of expansion could be reduced to a tolerable level by isolating the tube blocks. This isolation was termed undercutting.^{(1) (2)} Subsequently, the concept of coring was evolved and later graphite lattice designs incorporated the coring concept to give a more uniform front to rear temperature distribution along the process tube channels.

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Figures 6 through 10 show longitudinal cross sections through typical process tube channels and horizontal rod channels at each reactor. It will be noted from a comparison of the various process tube cross sections that at B, D, F and DR Reactors the channels were bored to an essentially constant diameter and that the C and K Reactors were the first to utilize the coring concept to obtain more uniform front to rear graphite temperature distribution.

The graphite contraction phenomena became apparent after the reactors had operated for some time with higher graphite temperatures and at higher power levels. ~~Graphite contraction at temperatures above 300 C is primarily a function of cumulative exposure.~~ Since the flux levels and therefore contraction rates are higher in the center of the process tube channel, this portion of the channel becomes depressed. The fringe regions of graphite, being at both lower temperature and exposure levels, exhibit a characteristic inlet and outlet hump. *Noted*

III. PRESENT GRAPHITE CONDITIONS AT K REACTORS

A. Graphite Distortion

Experience has shown that the exposure of graphite to reactor conditions, as at K Reactor, causes graphite shrinkage. Analysis of traverse data taken on the reactor indicates this graphite shrinkage to be proportional to exposure.⁽³⁾ The shrinkage and shrinkage rates are not uniform since the exposure level is not uniform for any given reactor core cross section. 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 11. 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 reactors. 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 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, (Figure 12) while in the regions of the 3rd, 4th. and 5th trunnion blocks the tube tends to bear on the top of the graphite channel. These changes in tube to graphite clearance effect the graphite temperature distribution in the tube and filler blocks.

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

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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 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 sticking can occur is approximately 100 inches. No radii of curvature of this small magnitude exist at the present at K Reactor, but as depression of the center tube block strings continues it is possible to experience fuel element sticking in approximately 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 process tubes.

B. Graphite Cracks

Recent observations of graphite conditions both before and after channel conditioning have been performed.⁽⁴⁾ These 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 (Figure 13). Longitudinal cracks, circumferential cracks at the chamfer leading to the reduced diameter, and pieces broken out of the reduced diameter, were observed. At KE Reactor approximately one fourth of the trunnion blocks are cracked or broken. Half of the trunnion blocks had reduced inside diameters. These observations were made at the 29, 30, 42 and 43 tube rows. The lowest tube row, 29, was the only one that showed broken trunnion blocks while in the upper tube rows the reduction in inside diameter was more pronounced. The cause 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 in KW Reactor. In KE Reactor, similar gaps were observed in the 1st., 2nd., 4th. and 7th trunnion locations.⁽⁵⁾

C. Graphite Temperatures

During normal operation the maximum measured graphite temperature is approximately 625-635 C. 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 in the region of the sharper bends. These measured temperatures are below the (P.I.T.A.) operating limit of 700 C⁽⁶⁾ in the bulk of the graphite and 850 C in the second tube block which is cored to .130" radial clearance.

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IV. CHANNEL CONDITIONING AT K REACTORS

A. Future Graphite Distortion

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 now.⁽³⁾ This produces future sharp bends at the 1, 4, 5 and 7 trunnion locations. As time progresses, these angles become sharper since various regions in the reactor are shrinking at different rates. For example, at the #4 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° , but 10 years from now this angle will be 4.3" in 48 or approximately 5° . The deflection between adjacent tube blocks at the #3 trunnion now is 0.7" in 48" but 10 years from now will be 2.1" in 48". Graphite shrinkage rates are based on the assumption that present power levels continue. For reasons such as this, the time element will have a tolerance of ± 2 years attached.

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 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.

$15/16$ available for total contraction,
 less $1/16$ required for thermal contraction,
 leaves $7/8$ available for graphite contraction at end (Figure 14)

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

$1-3/4$ inch will give a 12-14 year tube life at the 58 tube row. Lower tube rows will have a longer expected tube life with respect to the keyway. An allowance for a second Van Stone on the tube to be put on at a later date will reduce the expected tube life to approximately $10\frac{1}{2}$ years at the 58 tube row.

B. Zirconium Tube

The zirconium tubes to be installed in approximately 2400 of the K Area graphite channels have nominal physical dimensions of 1.724 inches

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inside diameter, by 1.810 in. outside diameter. This allows a nominal wall thickness of 43 mils which is only 2.4% of the diameter. The thin walled zirconium tube is vulnerable to distortions caused by bending and point loads. Tests on the tube have shown that a bend with a radius of curvature (calculated by graphical methods from mock-up data) of 560 inches produces an inside diameter reduction of 8 mils. Theoretical calculations show this radius of curvature should produce approximately 2 mils flattening or inside diameter reduction. Therefore, the 8 mil inside diameter reduction must be a combination of flattening due to bending and deformation due to point loads on the tube. These tests were conducted with a zirconium tube deflected in a two tube block mock-up which explains the deformation at points where the tube came in contact with the graphite. As shown in Figure 12, these points are usually at the trunnion locations of the deflected graphite channel. Other factors such as tube hardness and percent of cold work are also expected to effect the amount of tube flattening.

The ideal clearance between the KVN fuel element maximum support circle and the zirconium process tube is 9 to 13 mils. Bending and flattening of the tube as it rounds a bend in the channel reduces this clearance. For example, bending of the tube to a radius of curvature of 560 inches will reduce the ideal fuel element clearance approximately 4 mils.⁽⁷⁾ This added to the flattening of the tube reduces the clearance around the fuel element approximately 11 to 12 mils which is more than the nominal clearance of 11 mils, therefore, the fuel element becomes lodged or deformed in the tube. As the radius of curvature of tube bending becomes smaller, fuel element binding becomes more of a problem primarily because of the small clearances around the fuel element and the low resistance of the zirconium tube to flattening.

C. 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 initial zirconium tube installation. If the proposed zirconium tubes and KVN fuel elements were in the K Reactors at the present time, assuming no channel treatment had been done at their installation; there would be fuel element sticking now in the upper portions of the reactor. Mock-up tests have indicated that under these conditions KVN sticking may have occurred six months ago. In 10 years the tube location at the 1st. trunnion will be approximately as shown in Figure 12, however, if 1/2" of graphite has been removed as shown in Figure 15, the tube location will be approximately as shown in Figure 12. 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 2°) in the graphite channel. The amount of graphite removal in the bends, to allow a

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14 to 16 year tube life, is as follows:

<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

The above dimensions are based on graphite removed in the machine shop from blocks which were used in the K graphite channel mock-up. The blocks were machined (Figure 15), such that graphite removal started at the ends and tapered to zero at the center of the blocks. The above table represents the 58 tube row graphite distortion configuration.

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.

On reactor drilling results have shown that damage which existed before drilling was aggravated by the drilling operation. Existing cracks and broken pieces were made larger and some undamaged blocks were cracked. (4)

Vertical stack stability does not depend on the amount of graphite removed, however, graphite damage could affect the horizontal stability. The horizontal movement of the tube block is held in check by the positioning of the trunnion blocks. If these were destroyed, for example in a complete row of tubes, the maximum horizontal movement could be 7". This movement is enough to open up a VSR channel to some sizable void between a filler block and a tube block. Generally, the stack stability is determined by the filler blocks, which are not effected by channel conditioning except in the event of destroyed trunnion blocks. It can be safely assumed that channel conditioning will not greatly affect vertical stack stability, particularly when compared with the effect from channel distortion.

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D. 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 is 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. These point loads are primarily at the trunnion locations.
- c. End loads on the tube. These loads are caused by a stuck gun-barrel or the clearance in the centering flange keyway setting having been used up. Mock up tests have shown a 500# axial load on the tube during distortion conditions representing a 6 year tube life produces an average of $1\frac{1}{2}$ -2 and up to 3 mils reduction of the tube inside diameter. (8)
- d. Fuel element loading. The weight of a tube loaded with fuel elements will tend to pull the tube away from the graphite at points where it bears on the upper side of the channel. This in turn tends to cause a sharper angle at the 1 and 7 trunnion locations.

Based on continuation of the present rates of graphite shrinkage, the use of the KVN fuel element, and proposed channel treatment, the zirconium tube life can be expected to be approximately 10 years.

E. Graphite Temperature Effects

Graphite temperature is primarily due to the internal generation of heat in the graphite when under irradiation. The magnitude of the graphite temperature is dependent on parameters such as neutron flux level and reactor gas composition.

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 16) 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. A calculated maximum graphite temperature of approximately 1240 C can occur if the worst possible conditions resulting from channel conditioning exist. These worst conditions are that the tube must be in the region of maximum heat generation, and that approximately 1/4" graphite has been removed from the channel in the .130 coring region.

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It should be noted that a) this maximum temperature will not occur unless these conditions are met and, b) that this temperature exists only at a given location in the graphite and is not the temperature of the bulk of the graphite. The 1240 C is primarily based on, a) 70% helium, 30% nitrogen reactor gas composition, b) process tube centered in the conditioned channel (Figure 12 Section A-A shows the tube resting on the bottom of the channel), c) maximum neutron flux density and d) 5000 megawatts power level. Lowering the tube to the bottom of the channel reduces the maximum graphite temperature approximately 300 C. The combined effect of the above parameters could reduce the temperature as much as 400 C. (9) The technical criteria indicates the maximum graphite temperature shall not exceed the presently permitted Process Standards. (10)

F. 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 a tube is distorted to the 10 year and 58 row condition.* 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 stress would be approximately 63,000 psi. (11) The yield point for 35% cold worked zirconium is 94,000 psi. Cyclic stresses due to start up and shut down have been calculated to be approximately 9,000 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.

G. Reactor Physics

Reactor core physics has shown that graphite removal and increased graphite temperature will have a very small effect upon the production and goal exposure of the K Reactors. Factors such as conversion ratio, U²³⁵ depletion and Pu buildup change less than 1%. (12)

V. TOOLING FOR PROCESS CHANNEL CONDITIONING

A. Historical

Continued thermal cycling of the graphite stack, coupled with the growth/shrinkage characteristic, has over the years physically

* Based on channel conditioning to limit tube bending radii.

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distorted the individual graphite tube blocks as well as the entire stack. The resultant block distortion appears as an elliptical hole through the graphite bar. In DR Reactor, the minor axis of the elliptical hole has been observed to be 1.715 inches as compared to the 1.744 inch diameter of the original hole. This distortion or warpage has required that the channel be renovated to return the hole to a circular shape large enough to accept, without immediate damage, a 1.729 diameter process tube.

Until 1962 the method used to renovate or restore a graphite channel involved pulling a broach through the channel. As many as 5 passes of a broach were needed to remove the necessary amount of graphite. The number of passes was determined by casual observations of the difficulty encountered by the power pulling tool, generally an air tugger. This technique is still in use at B, D and F Reactors.

Much difficulty, even with multiple passes of a broach, was encountered in recent years in replacing tubes in DR and H Reactors. Finally, the need for massive tube replacement in all reactors was realized, and in early 1962, Special Outage Services was organized and assigned tube replacement responsibility. At this time, additional effort was directed towards discovery of a more efficient and reliable means of opening graphite channels for installing tubes, especially in DR and H.

The technique and knowledge of drilling instead of broaching (as a means of channel restoration) has developed from the 1960 experience in overboring and has continued through tube replacement drilling development in calendar 1962.

Presently the drilling technique for graphite channel restoration is being used at DR, H, and C for aluminum tube installation, and is planned, with some major modifications for use at the two K Reactors. It should be noted that there is as yet little reason for channel restoration at K, referring to ovality of the channel bore and other obstacles to tube installation. Rather, the future need for reasonably straight channels must be anticipated years ahead of time, and the channel bends alleviated or "conditioned" before long-lived zirconium tubes are installed. The "conditioning" need at the K Reactors is as vital as the restoration required at other Reactors, considering that K's long-term planning and costly zirconium tubes simply do not permit future channel restoration within the foreseeable future, in spite of the expected continued graphite contraction.

B. Types of Cutters

A number of different types of cutters have been examined as candidates for the several types of in-reactor graphite removal. Cutter types can be catagorized 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.
- (5) Combinations.

Each type presents particular problems. The overboring cutter (Figure 16) was developed and successfully used for overboring more than 40 channels at C Reactor.

A number of the overbore channels at C were recently cored, using an expanding cutter called a "flopout" cutter. Controlled coring was accomplished by reversing the direction of rotation of the boring shaft, causing the cutter to expand. This is the only type of expanding cutting device for reactor graphite channels that has been successfully demonstrated at HAP0. The flopout has two disadvantages; (1) when the direction of rotation is reversed, the blade is forced out and into the graphite with considerable force, which is apt to fracture the graphite block, (2) those cutters used have had only one or two cutting teeth, which tends to produce a rough surface in the graphite material. A combination drilling and coring cutter blade with flopout blade is shown in Figure 19.

Retubing: The cutting bar which has been used to aid retubing at DR, H and C Reactors is shown in Figure 20. This is a dual purpose tool which restores straight sections of a graphite channel to the desired diameter and provides some channel straightening at block junctions by virtue of the four cutters and the 36 inch bar length. The same type of tool was proposed for use at the K Reactors for zircaloy tube installation.

Two other promising concepts of cutting (boring) bar are shown in Figures 17 and 18. The graphite boring bar (Figure 17) has replaceable cutters at 11 longitudinal points along its length. The tapered cutter bar, (Figure 18) has a helical cutter at the center. Both bars have been tested in the K graphite channel mockup. The tapered cutter bar showed superior performance.

The lifetime of a process tube-channel-and fuel element complex, as "conditioned" by any of the several possible methods of graphite channel reshaping, can be loosely measured in years. According to a plausible theory which has been confirmed by many reactor measurements, the graphite blocks' distortion rate is dependent on

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total reactor exposure (to high temperature irradiation). In terms of present K Reactor power levels, one can predict the increased angle between tube blocks which can be expected at any future time. If a particular graphite tool is used to "condition" or relieve these bends in advance, one can hazard a lifetime for that channel complex. Using the worst, or top center, K process channel as an example, a rough comparison of expected zirconium tube life can be estimated, depending on the reshaping tool chosen, as indicated:

<u>Tool</u>	<u>Estimated No. of Years of Expected Channel Life (58th Tube Layer)</u>
1. No tool used	0
2. 4 ft. bar	5
3. 4 ft. bar with 1/4" flopout cutter, very rough surface,	9
4. 6 ft. bar, 11 cutters. (Has had only experimental trial on-reactor in 2 channels (10-22-62)	7
5. 6 ft. tapered bar with helical cutter. (Has had only a single lab. trial, not yet ready for on-reactor use.)	8

The above estimates are based on calculations described in HW-75003 and for a limited number of mockup tests. The majority of the test results fell within ± 2 years of the listed expected number of years. It should be noted here, that these tolerances are in addition to those placed on graphite shrinkage rates since the expected number of years is based on the later.

The surface condition after a cut from a 3 foot or 4 foot bar is rough, but not as rough as is produced by a coring tool. The helical reamer used on the tapered bar makes comparatively a smooth, well-machined surface.

C. Future

Work on the bars described above will continue, for application in the K retubing program. Objectives are to improve the surface finish, increase the depth of cut at the critical block junctions and minimize block damage through tool impact.

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Exotic means, as well as more common machining methods, will be investigated for preferential removal of graphite from the process channels. A number of mechanical innovations are being explored. Representative of these are, 1) a shot-loaded bar for stabilization and reduction of whipping action, 2) a mandrel guided bar which could be used to program the cut in the desired location, and 3) cutters which could be mechanically positioned at any location for a cut radial to the hole centerline. Still more exotic approaches which may be less harmful to the graphite will be explored. These will include but are not limited to flame cutting, ultra-sonic cutting, abrasive jet blast, high speed abraiding, diamond cutting mechanisms and tube cleaner tool.

VI. VSR CHANNEL DISTORTION AND DAMAGE

A. C and K Reactors

Graphite growth and contraction has resulted in both overall channel distortion and broken blocks in the vicinity of the vertical rod channels. The graphite blocks around the vertical rod channels are no longer restrained from moving into the rod channels by the keys originally installed for this purpose. Numerous broken or protruding blocks have been observed in channels located primarily, but not exclusively, in the fringes of the rod patterns at both the C and K Reactors. Recent examination of a channel located in the center of the rod pattern at C Reactor has indicated that block protrusion can also be expected in any of the central VSR channels.

In general, the graphite distortion phenomena is similar at each reactor. Vertical rod binding occurs predominantly in the rod pattern fringes where the observed overall channel curvature is greatest. Slip planes have been observed at the C and K Reactors which indicate that relatively large sections of graphite have shifted toward the central portions of the graphite stack. The resulting protrusion of both graphite filler and tube bearing blocks into the vertical rod channels at the slip planes is again greater in the fringe of the rod pattern.⁽¹³⁾ Figures 21 and 22 show typical observations obtained by borescoping vertical rod channels #41 and #58 at C Reactor.⁽¹⁴⁾ Keying diagrams have been reproduced on these figures to show how the ends of filler blocks apparently break and are allowed to fall into the rod channel. The graphite debris, resulting from breaking the obstructing block ends and allowing these pieces to fall to the channel bottom, is also shown on Figures 21 and 22. Traverse data, obtained by viewing with an optical transit the displacement of a target in the channel, has been obtained on a number of vertical rod channels.⁽¹⁴⁾⁽¹⁵⁾ Figure 23 shows a typical presentation of these data for #41 VSR channel at C Reactor. Subsequent to efforts in mid 1961 which allowed the vertical rods in channels #41 and #58 to be returned to service, equipment has been developed to allow debris removal, on a scheduled basis, from the bottom of any obstructed C Reactor VSR channel.

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B. B, D, and F Reactors

Protrusion of the ends of graphite filler bars into the vertical rod channels has not been a significant problem to date at the B, D or F Reactors. Examination of Figure 1 will show the probable reason to be the relatively massive bars of graphite which were originally installed vertically at each VSR channel. These liners, which are keyed into the graphite stack effectively prevent bar protrusion into the channels. There have been occasions, however, of channel blockage resulting from liner block breakage.⁽¹⁶⁾ In the past, this breakage has been attributed to application of jacking forces during process tube removal. Forces sufficient to break the liner blocks can be transmitted from an adjacent tube bearing block via the key between the two blocks. More recent evidence of similar liner block damage has been reported on #35 VSR channel at B Reactor.⁽¹⁷⁾

Rod binding at B, D and F Reactors has in the past been attributed primarily to overall channel curvature. Replacement of the originally installed rigid rods with flexible rods of the same size has long been an acceptable interim solution to this problem. More recent application of broaching to remove controlled amounts of graphite from the rod channel has also been a beneficial method of maintaining existing vertical rod insertion time within Process Standard requirements.

C. DR Reactor

At DR Reactor, the inadvertent 3X ball drop incident in July 1961 caused considerable localized damage to filler blocks near the vertical rod openings. A developed view showing typical channel damage subsequent to the ball drop incident is appended as Figure 24. This diagram shows the relative position of graphite damage, block separations, ledges and trapped 3X balls obtained from borescope examination of two channels.

With regard to the graphite damage at DR Reactor, several conclusions have been derived from the borescope data obtained on ten channels and television traverse data from all vertical rod channels. These conclusions are summarized as follows:⁽¹⁸⁾

1. Only blocks located in the front or rear of the channels were broken.
2. Using statistical procedures, the total number of broken blocks in DR Reactor has been estimated at between 300 and 350. In general, the most breakage was noted in the upper portion of the channels.

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3. The observed breakage and graphite keying arrangement at DR Reactor makes it unlikely that broken pieces will completely obstruct the channel as was noted at C Reactor.
4. Numerous gaps between adjacent graphite blocks were observed. Based on the number of gaps noted in the ten borescoped channels, it is estimated that there are between 525 and 575 possible ball trap locations near the 29 vertical rod openings. Subsequent efforts during the ball drop outage removed significant quantities of trapped balls. However the gaps between adjacent blocks remain potential trap locations in the event of any future inadvertent ball drops.

DR Reactor has also experienced vertical rod binding as a result of overall channel curvature. Broaching and installation of smaller diameter flexible rods has been shown to be an acceptable interim solution to this difficulty.

D. H Reactor

There have been no reports of vertical rod operating difficulty at H Reactor to date.

VII. HORIZONTAL CONTROL ROD CHANNELS

Horizontal rod channel curvature resulting from graphite contraction in the central portion of the stack is aggravated by graphite growth at the outer edges of the stack. Horizontal control rod binding, attributable to progressive channel curvature has been noted in several channels at the K Reactors and is expected at the other reactors. To date, there have been no major rod operating difficulties except at the K Reactors.

Recent indications are that channel distortion may have progressed sufficiently for binding of HCR #2 at H Reactor. However the cause of this binding has not been fully established at this time.

Graphite distortion at the K Reactors has resulted in gap formation between individual blocks and provided migration paths for 3X balls to flow from the VSR channels to the horizontal control rod channels. The 3X balls become lodged beneath the HCR track blocks, (see Figure 10), thus restricting control rod motion and causing localized graphite damage. Equipment to remove the HCR track blocks has been developed and successfully used on #17 channel at KE Reactor. A segmented graphite sleeve column and sleeve compression assembly was installed on a test basis subsequent to track block removal.⁽¹⁹⁾ Operational experience since installation in September 1962 indicates that the sleeve column is an acceptable method of preventing interference between 3X balls and the horizontal rod. However, it is not believed that sleeving will provide an acceptable solution to rod binding which occurs as a result of progressive channel curvature.

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VIII. PROCESS TUBE CHANNEL DISTORTION - B, D, F, DR, H AND C REACTORS

Typical graphite distortion profiles of process tube channels are shown on Figures 25 through 28. The curves on Figure 25 for F Reactor are also typical of the channel distortion characteristics at B and D Reactors. It has been postulated that within the next five to seven years, unless corrective action is taken, increasing curvature of the top central tubes at B, D and F Reactors will necessitate charging four-inch fuel elements in the upper eight to ten rows.⁽²⁰⁾ Several methods of alleviating this problem have been proposed. Subject to further investigation of several economic and technical considerations, coring the process tube blocks appears to offer the most potential as a permanent solution.

In general form the distortion profiles at H and C Reactors, Figures 27 and 28, are similar to those observed at the K Reactors. This similarity has been attributed to undercutting and/or coring of the process tube blocks.⁽²¹⁾

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FIGURE 1
B, D, F - REACTOR
GRAPHITE LAYUP ARRANGEMENT

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VERTICAL CONTROL ROD OPENING

FIGURE 2
DR REACTOR
GRAPHITE LAYUP ARRANGEMENT

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VERTICAL CONTROL ROD OPENING

FIGURE 3
H REACTOR
GRAPHITE LAYUP ARRANGEMENT

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FIGURE 4
 C REACTOR
 GRAPHITE LAYUP ARRANGEMENT

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VERTICAL CONTROL ROD OPENING

FIGURE 5
 K REACTOR
 GRAPHITE LAYUP ARRANGEMENT

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TUBE BLOCK LAYER
 FILLER BLOCK LAYER
 TUBE BLOCK LAYER

FIGURE 6
 B, D, F-REACTOR
 PROCESS TUBE AND HCR CHANNEL SECTIONS

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FIGURE 7
DR REACTOR
PROCESS TUBE AND HCR CHANNEL SECTIONS

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FIGURE 8
H REACTOR
PROCESS TUBE AND HCR CHANNEL SECTIONS

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FIGURE 9
C REACTOR
PROCESS TUBE AND HCR CHANNEL SECTIONS

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FIGURE 10
K REACTOR
PROCESS TUBE AND HCR CHANNEL SECTIONS

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FIGURE 11
K REACTOR
PROCESS TUBE DISTORTION CURVES

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BEFORE GRAPHITE REMOVAL

AFTER 1/2" GRAPHITE REMOVED

ORIGINAL TUBE
NEW TUBE
ZIRCONIUM TUBE

SECTION
A-A

FIGURE 12
K REACTOR
1-2 TRUNNION SHOWING TUBE LOCATION

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FIGURE 13
K REACTOR DAMAGED TBUNNION BLOCK

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CENTERING FL
END 0

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FIGURE 15
K REACTOR
GRAPHITE REMOVAL AT 1-2 TRUNNION LOCATION

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FIGURE 16
HEAT FLOW PATHS

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FIGURE 17
K REACTOR
GRAPHITE BORING BAR

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FIGURE 18
K REACTOR
TAPERED CUTTER BAR

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FIGURE 19
C REACTOR
OVERBORING CUTTER

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FIGURE 20
DR, H AND C REACTORS
GRAPHITE CUTTER

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KEYING DIAGRAM
PACKING BLOCK LAYER

1/8" DEEP IRREGULAR
GROOVES IN PACKING
BLOCKS (LAYERS 83
THROUGH 87)

FIGURE 21
C REACTOR
VSR CHANNEL No. 41

FIGURE 22
C REACTOR
VSR CHANNEL NO. 58

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VSR CHANNEL #41
TRAVERSE 6-6-61

VSR CHANNEL #41
TRAVERSE 6-6-61

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7 BALLS ON LEGS

FIG. 29

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FIGURE 25
F REACTOR
PROCESS TUBE DISTORTION CURVES

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FIGURE 26
DR REACTOR
PROCESS TUBE DISTORTION CURVES

FIGURE 27
H REACTOR
PROCESS TUBE DISTORTION CURVES

FIGURE 28
C REACTOR
PROCESS TUBE DISTORTION CURVES

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