HW-79120

Cover Sheet for a Hanford Historical Document Released for Public Availability

Released 1994

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

[redacted]
(CLASSIFICATION)

DECLASSIFIED

DOCUMENT NO.
HW-79120

SERIES AND COPY NO.
[redacted]

GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION – RICHLAND, WASHINGTON

DATE
October 28, 1963

[redacted]

TITLE
INTERNAL GRAPHITE MODERATOR FORCES STUDY, C AND K REACTORS

☐ OTHER OFFICIAL CLASSIFIED INFORMATION

THIS MATERIAL CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U. S. C., SECS. 793 AND 794, THE TRANSMISSION OR REVELATION OF WHICH IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

AUTHOR
D. E. Cooley
Reactor Design
Facilities Engineering
IPD

ISSUING FILE

[redacted] OVIDED BELOW.

ROUTE TO:	PAYROLL NO.	LOCATION	FILES ROUTE DATE	SIGNATURE AND DATE
R. E. Nightingale	13280	326	[illegible]	[illegible] 64
W. C. Marks	13692	326		

DECLASSIFIED

MASTER

C-3195-MS (7 – 55) AEC-GE-RICHLAND, WASH

[redacted]
(CLASSIFICATION)

This document classified by

This document consists of 30 pages. [redacted]

INTERNAL GRAPHITE MODERATOR FORCES STUDY, C AND K REACTORS

By

D. E. Cooley
Reactor Design
FACILITIES ENGINEERING SECTION
IRRADIATION PROCESSING DEPARTMENT

October 28, 1963

[redacted]

[redacted]

 [redacted]

[redacted]

DISTRIBUTION

1. W. K. Alexander
2. T. W. Ambrose
3. E. R. Astley
4. R. S. Bell
5. R. W. Benoliel
6. R. G. Clough
7. R. F. Corlett
8. D. E. Cooley
9. R. E. Dunn
10. M. L. Faught
11. W. J. Ferguson
12. E. J. Filip
13. O. H. Greager
14. J. W. Green
15. C. N. Gross
16. R. S. Hammond
17. A. K. Hardin
18. H. W. Heacock
19. J. W. Hedges
20. D. L. Hovorka
21. P. H. Hutton
22. R. T. Jessen
23. F. J. Kempf
24. R. L. Loundagin
25. D. Marinos
26. A. R. Maguire
27. C. A. Munro
28. J. C. McKay
29. W. W. McIntosh
30. R. E. Nightingale
31. R. Nilson
32. R. S. Peterson
33. R. W. Reid
34. G. J. Rogers
35. A. Russell
36. W. Seeburger
37. C. C. Steele
38. O. C. Schroeder
39. E. E. Weyerts
40. F. W. Van Wormer
41. G. E. Wade
42. Record Center
43. 300 File
44. F. C. Schorra (Arthur D. Little Co.)

[redacted]

INTERNAL GRAPHITE MODERATOR FORCES STUDY C AND K REACTORS

INTRODUCTION

The purpose of this study was to determine the maximum forces that can be imposed by the graphite moderator on prospective VSR channel sleeves. In order to do this, both the origins and modes of transmission of the forces were determined. Forces in the moderator stack that are capable of acting on a block or group of blocks may originate from any of the following primary effects:

1. Contraction of graphite due to irradiation
2. Thermal expansion of graphite
3. Frictional resistance to motion
4. Resistance from keys
5. Gravity
6. Other

CONCLUSIONS

From the results of the hypothesis of general moderator distortion presented below it is concluded that forces which may be brought to bear on VSR channel keys or liners are quite low. At the present distortion the forces causing horizontal motion of graphite moderator blocks are in the neighborhood of 200 pounds, maximum. The presence of VSR channel liners could raise these forces to values as high as 1200 pounds, but these would be unlikely and isolated if they did exist at all. Ten years distortion would increase these forces by a factor of $2\frac{1}{2}$. It is concluded that any VSR channel sleeve must be of a material and design to withstand these forces in their most vulnerable loading condition, which is flexure. It is also suggested that as many channels be sleeved in as short a period as possible to prevent the generation of high loads on any one channel.

DISCUSSION

Origins of Force

Contraction

Appendix 1 gives the physical properties of K and C Reactor Graphites and their changes due to irradiation at reactor center zone operating temperature. It can be seen in this Appendix that the dimensions of the sample parallel to the extrusion axis contract at a rate approximately twice that of the dimensions perpendicular, or transverse, to the extrusion axis. At flux levels and temperatures as low as those found in the reflector zones of C and K Reactors, the dimensional distortion is slight and has been considered negligible in this study. The fact that the central zone of the reactor has been contracting while the fringe or reflector zone has remained relatively unchanged has caused the familiar sag observed at C, KE and KW Reactors.

[redacted]

With one or two exceptions, the keying pattern within the reactor moderator does not support tension. That is to say, one block when contracting cannot "pull" on its neighbor as there are no positive means by which this tension force can be transmitted. Therefore, any contraction of a block relative to the blocks around it will cause gaps between it and its neighbors without transmitting any force to them. The exceptions to this are bars 21 and 23 at C Reactor (See layer drawings, Appendix II.) These bars serve to connect the VSR channel keying clusters in the near-far direction.

Figure 1 shows in detail the layup pattern in the vicinity of bar 23 at C Reactor. The numbers identify blocks through which force is transmitted from key to key in the filler and tube block layers. The trunnion blocks marked "(6)", which are outside the field of view of the figure, actually support the compressive load between the keys (K-1) because the undersize tube blocks (149), which are actually in the position marked "(6)", cannot support this load. The distance L_1 represents the distance between the outside surfaces of the notches cut in Bar 23 to accept the VSR channel keys K-1. The distance L_2 represents the sum of the widths of the blocks and the keys which are designed to fit in the distance L_1.

As originally constructed, the length, L_1, at room temperature was 37.696/37.668 inches. The sum of the parts comprising the distance L_2 was 37.673/37.619 inches. This leaves a clearance (L_1 - L_2) of .077/-.005 inches, or a possible interference of .005 inches and a maximum clearance of .077 inches, at room temperature as a result of the accumulated tolerances of the parts. Assuming a normal distribution curve for the tolerances involved, and that 99 percent of the cases fall within the tolerances specified, then an interference fit would result in 1.2 percent of the cases. A selective fit was specified on the layup drawings, eliminating these few interferences, and leaving the fit at .077/.000 inches

At reactor operating temperatures, block 23 is at 590 C, the trunnion blocks (6) at 450 C average, and the remaining keys and blocks (K-1, 3, 14, 76, 82) are at 535 C, in the central zone of the reactor wherein VSR channels are situated. As stated in Appendix I, the coefficient of thermal expansion in the direction transverse to the extrusion axis of the bar is over two times that in the direction parallel to the axis of extrusion. The graphite in K-1, 14, 3, 76 and 82 is aligned perpendicular to the orientation of the extrusion axis of bar 23. The other load supporting blocks in the tube layer between keys K-1, are the trunnion blocks (6) that have their extrusion axis in the same orientation as bar 23. The variation of coefficients of thermal expansion in the two orientations causes the length L_2 to increase at a faster rate than L_1 as the moderator is brought up to operating temperatures so that the clearance (L_1 - L_2) becomes .059/-.018 inches. Assuming a normal distribution and that 99 percent of the cases fall within the calculated .059/-.018 inches fit, then an interference exists in 13 percent of the cases.

The difference in contraction rates parallel and perpendicular to the axis of extrusion of the graphite bars further compounds the problem as the designed clearance (L_1 - L_2) is being further reduced as the graphite gains exposure.

[redacted]

DECLASSIFIED

[redacted]

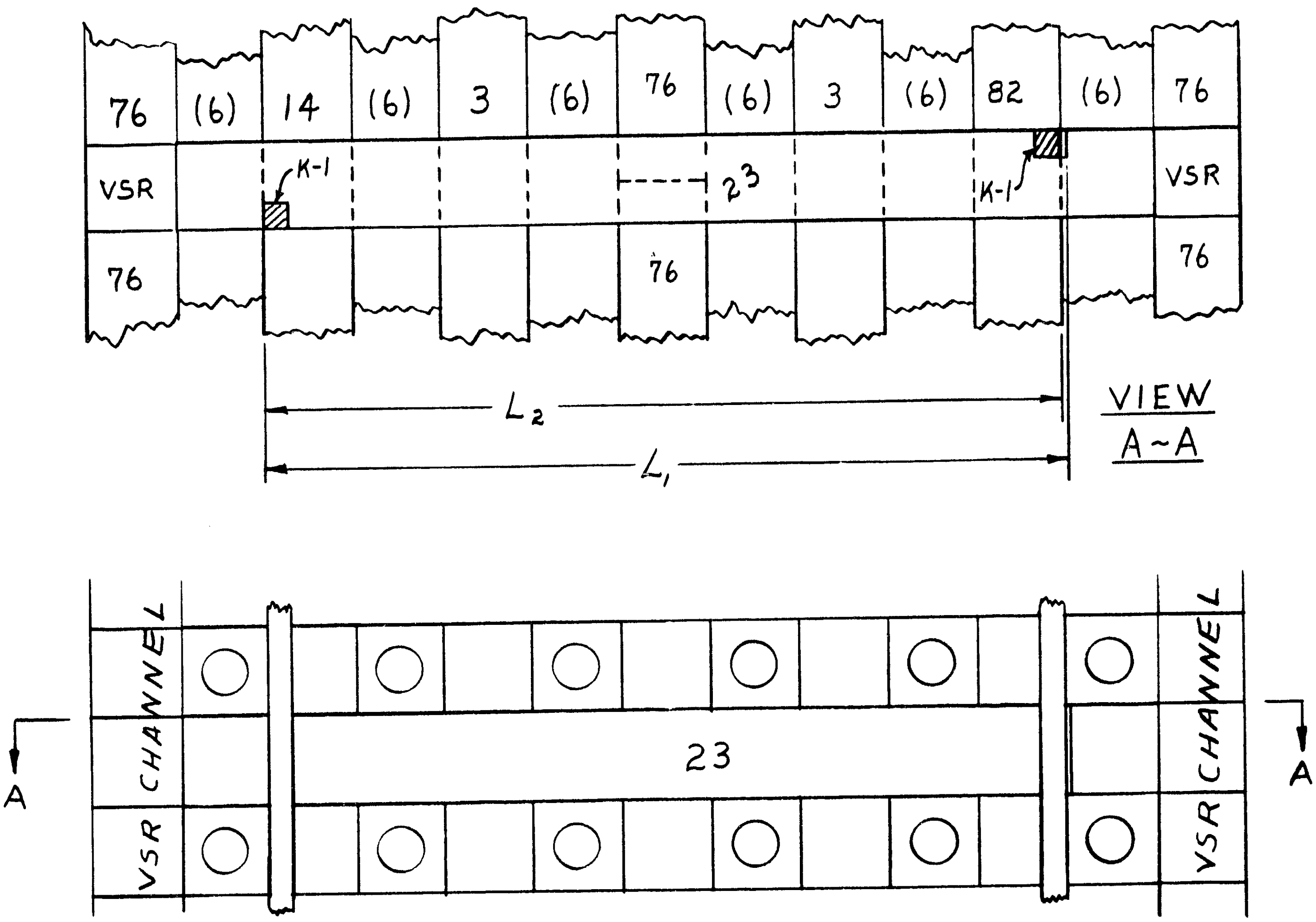


FIGURE 1

[redacted]

This proceeds at such a rate that the clearance will be totally consumed (i.e., $L_1 - L_2$ = .000/-.077 inches) at an exposure of 27,300 MWD/AT. At present in C Reactor, the central zone exposure is 20,300 MWD/AT and is increasing at a rate of about 2000 MWD/AT per year. This exposure reduces the clearance dimensions in the central zone of the reactor to .015/-.062 inches. Assuming a normal distribution and that 99 percent of the cases fall within this fit, an interference (from 0 to -.062 inches) exists in 95 percent of the cases. The layer drawings reveal that this same problem exists in bar 21 at C Reactor, but to a lesser degree. The designed clearance in this case is .070/.002 inches, with no interference. Raising the blocks to operating temperatures reduces the clearance to .059/-.009 inches, with .009 inches maximum interference. An exposure of 45,600 MWD/AT will reduce the maximum clearance to zero, so that the fit will be .000/-.068 inches. At 20,300 MWD/AT exposure the fit is reduced to .033/-.035 inches, which under the same assumptions as above, indicate that interference exists in 52 percent of the cases.

The complexity of the layup pattern provides several possible results from these interferences. The most obvious is the shearing of one of the keys, K-1. Assuming irradiated graphite, a load of 13,500# is necessary to break K-1 in double shear. Since some flexure would be involved due to the imperfect fit of the blocks, the actual force required would be somewhat lower. The calculated force required to break the end of bar 23 is 3540# assuming no stress concentration factor of 4.3 yields a required force of 825# to break block 23 (or block 21) at the key notch. A third means of failure is found in the breaking of blocks 14 or 82 in flexure; calculations indicate that a minimum value of 1837# would do this. However, these blocks are well supported by two other keys, K-1, passing through the block.

In conclusion, it appears most likely that the blocks 23 or 21 will break at one of the key notches before any other failure would occur. A particularly disadvantageous loading of the key or of blocks 14 or 82 may cause one of these to fail before block 23. The calculated deflection required to apply an 825# force to block 23 is .002 inches indicating that an interference ($L_1 - L_2$) more than -.002 would mean failure of a component of the system under discussion. The high frequency of observation "broken filler block ends" (bar 23) and "crack on front (or rear) side" (bar 21) recorded at C Reactor substantiates this. The most important result is that the sole means of supporting tension within the stack has been destroyed in 95 percent of the cases due to the failure of bars 23, 21, 14 or 82 on key K-1.

There is a possibility that a tendency for graphite to creep when under stress during irradiation could offer some relief in this situation, but data on this phenomenon are very limited at this time. For this reason, the results of this effect, if significant, have not been considered in the above.

[redacted]

Thermal Expansion

At any point in an unrestrained stack, the thermal expansion will tend to move the graphite very nearly uniformly out from center. As is the case with a hole in a block of metal, the increase in stack temperatures not only expands the stack as a whole, but also enlarges the size of the VSR channels. Therefore, any one block cannot expand into a VSR channel as the blocks around it are also expanding and moving the channel in the same direction. Unless a particular block or group of blocks is expanding and moving in a direction other than that of the rest of the stack, thermal expansion forces are not applicable to a VSR sleeve. A maximum force of 25,700 pounds would be exerted on a fringe zone VSR sleeve if a group of blocks were firmly supported against the thermal shield at startup and expanded toward the center of the stack while the stack was expanding outwards. The likelihood of this situation occurring, however, is rather remote. The original clearance between the stack and the side thermal shield was $2\frac{1}{4}$ inches at C Reactor, and 3 7/8 inches at the K Reactors and the central zone graphite has been contracting ever since. This would mean that for this crushing effect to occur a very great deal of rubble would have to exist between the blocks to provide a continuous medium from the center of the stack to the thermal shield. In addition, this rubble would have to be of sufficient density to support the crushing loads induced by the thermal expansion of the blocks. It therefore seems unlikely that this combination of situations would exist to produce these high forces, and so they should not be used as design criteria for VSR channel sleeves.

Perhaps the most important thermal expansion phenomenon causes relative motion between the blocks due to the combined effect of unequal temperature distribution from block to block and the anisotropy of the coefficients of thermal expansion in the parallel and transverse direction.

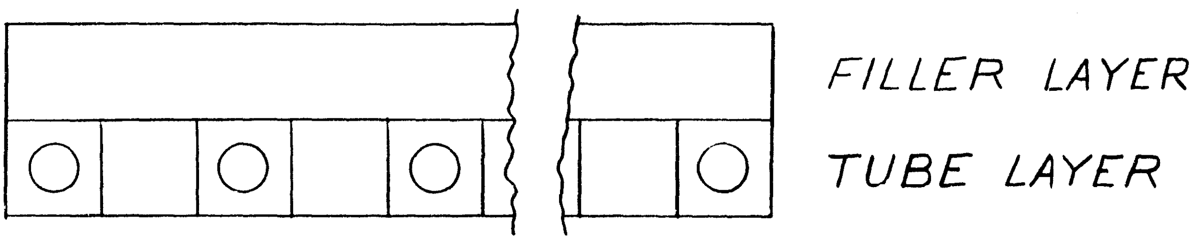


FIGURE 2

[redacted]

DECLASSIFIED

TABLE I

	Filler Block Filler Layer	Filler Block Tube Layer	Trunnion Block
C Reactor			
Length (width)	48.000	(4.188)	(4.188)
Quantity	1	6	6
Temperature - up	590 C	535 C	450 C
Temperature - down	15 C	15 C	15 C
Orientation	(‖)	(⊥)	(‖)
K Reactor			
Length (width)	49.150	(3.750)	(3.750)
Quantity	1	7	6
Temperature - up	635 C	580 C	490 C
Temperature - down	15 C	15 C	15 C
Orientation	(‖)	(⊥)	(‖)

When the reactor is not operating, or is "down", every block in the stack is at a uniform temperature of about 15 C. At operation, or when the reactor is "up", the blocks take on varied higher temperatures as shown in Table I. Although the trunnion blocks do not necessarily lie directly beneath the filler block, they are listed because they fill in space between filler blocks in tube layers. The tube blocks are smaller in width than the trunnion blocks and do not touch the filler blocks in the tube layers.

At operating temperatures at C Reactor a filler block in the filler layer expands .047 inches. The 6 filler blocks and the 6 trunnion blocks in the tube layer immediately above or below expand .050 inches and .019 inches respectively for a total expansion of .069 inches. This means that the blocks in the tube layer expand .022 inches more than the filler blocks in a 48 inch length. To resist this motion would take a force of 20,000 pounds whereas the maximum resistance to this force from friction in the bottom layer of the stack is only 4320#. This differential expansion may be taken up at one end of the filler blocks or at both ends in any proportion, but nonetheless motion does occur.

Likewise, at the K Reactors the filler block in the filler layer expands .067 inches at reactor operating temperatures. The 6 trunnion blocks and 7 filler blocks in the tube layer expand a total of .086 inches for a resulting differential expansion of .019 inches. As in the case at C Reactor, the force exerted by this differential expansion (14,250 lbs.) is very much larger than the maximum friction force (4340 pounds) available to resist it.

[redacted]

Also of interest is the difference of vertical expansion of the center of the reactor relative to that of the fringe. At C Reactor the sum of the vertical expansion of all the blocks in the full height of the pile over the range of "up" and "down" temperatures results in a rise of .793 inches at the top center of the unit. At the cooler fringe the rise is only .138 inches, meaning that the top center of the stack rises .665 inches farther than the graphite at the fringe. At the K Reactors the top center rises 1.052 inches as against a total rise of .174 inches at the fringe, resulting in a differential rise of .878 inches in the center. As cycles are experienced, this breathing or relative expansion between the center and fringe zones causes the blocks between to change their angle with respect to the horizontal causing motion of the blocks with respect to each other. This effect was noted by W. J. Love in his NPR Stack Lift Forces model test where repeated elevations of the center of his model stack above the horizontal caused the blocks to migrate out from center. In Dr. Love's studies the slope, if not horizontal, was down from the center of the stack. In our situation, where the dominant slope is up from the center of the stack, this "breathing" effect would tend to make the blocks migrate inward.

Friction Forces

The role of friction is that of resistance to motion due to positive forces, existing only during the presence of these positive forces. The maximum magnitude of this resistance force is equal to the product of a frictional factor and the normal force between the contact surfaces. For irradiated nuclear graphite this static friction factor varies between .35 and .27, approaching the latter with increase in rubbing of the two surfaces occurring before the tests. The normal force between the surfaces is determined by the weight above the surfaces in question and the angle of sag of the layer. The magnitude of this maximum resistance capability is nowhere as great as the forces causing relative motion between layers due to thermal expansion and irradiation contraction mentioned above.

Keys

The designed resistance to motion within the stack is represented by keys. The only vertical keys in the stack of appreciable length are those surrounding the VSR channels. There are eight keys per VSR channel at C Reactor and four keys per VSR channel at the K Reactors.

[redacted]

DECLASSIFIED

TABLE II

PROPERTIES OF VSR KEYS

DIMENSIONS:

C Reactor: CSGBF Graphite

Cross Section: $\frac{1.500}{1.497}$ inches square

Length: Random Whole Number Multiples of Block Widths (4.188 in.) Greater than 16 3/4 inches.

K Reactors: TSGBF Graphite

Cross Section: $\frac{1.250}{1.240}$ inches square

Length: $\frac{22.511}{22.481}$ inches

SHEAR STRENGTH:

	C	K
Force required to fail Key in Shear in One Plane	6750	4680

FLEXURAL STRENGTH:

	C	K
Moment Required to Fail Key in Flexure	1687	975 in/lb.

Assuming a VSR key is firmly supported at one end, (i.e., jammed or cantilevered) then it will break in flexure when the moment at that end reaches the values given in Table II. Table III gives the loads required to break the key at the support as a function of load distance in block widths from the support. Also given are the deflections of the keys at the points of loading resulting from the application of the force. From the data available it can be determined that VSR channel curvatures of the order of .0051 inches/inch at C Reactor and .0061 inches/inch at K Reactor are commonplace and by no means the maximum. In the last column of the table these curvatures are shown in terms of deflection of the channel at the various load distances.

TABLE III

Block Widths From Support	Forces Required To Break Key Lbs.		Deflection of Key at Load In		Deflection of Existing Channels In.	
	C	K	C	K	C	K
0	6750	4860				
1	403	260	.0078	.0078	.0214	.0229
2	202	130	.0312	.0300	.0428	.0458
3	101	65	.0526	.0505	.0642	.0687
4	51	33	.0618	.0600	.0856	.0916

[redacted]

It can readily be seen from Table III that the curvatures existing in the VSR channels are very much greater than those required to cause failure of the VSR keys. This would indicate that the keys are broken virtually at every block width over the height of the stack. The low value of the forces required to break these keys in flexure substantiate this conclusion.

It is of importance to note, however, that unless a key has broken exactly at a layer interface, it will still support shear at that interface whether or not it has broken elsewhere. This will permit motion between layers until the key segment is loaded in shear. If the key breaks at a layer interface, then the layers can move until the load was taken up elsewhere, either by another key or by butting up against other more firmly supported graphite.

At the front and rear at C Reactor and on all four sides at the K Reactors there are horizontal keys running the full width of the reactor. These keys serve to keep the reflector blocks fairly well aligned, but have no effect on the blocks within the central zones. This results because the central zone blocks are all contracting inward from the reflector zone blocks and there is no means by which the tension necessary for these keys to control the central zone blocks can be transmitted.

Gravity

The force of gravity acting upon the reactor components is of great importance in this study. Appendix III explains the manner in which the weight is distributed throughout the moderator, and enables the reader to calculate the gravity loading at any point in the stack. The sag induced in the moderator by the unequal contraction rates from central to fringe zones furnishes a non-horizontal surface on which the always vertical gravity force must act.

Since the layer interfaces are not horizontal, the vertical weight force is divided into two resultants, one normal to the inclined layer surface and the other parallel to it. This phenomenon provides an ever present force in the direction of tilt of the layer interface which is resisted only by friction and unbroken VSR channel keys. The magnitude of this force depends upon VSR channel key conditions, and is discussed below under "Movement Mechanism."

A second phenomenon induced by unequal flux distribution exists. Since the flux is higher toward the center of the stack, the blocks in the flux gradient zones contract most at their inward extremity. This results in wedge shaped blocks with their narrower dimension toward the center of the reactor. The high vertical weight force acting in the moderator, when applied to these slightly wedge shaped blocks, tends to force the blocks outward in the direction of the wider side of the block. This phenomenon may be likened to the tendency of a wet watermellon seed to shoot out between the tightly clenched thumb and forefinger of a small boy. Once again we have an ever present force which is resisted only by friction and unbroken VSR channel keys, but this time it is directed outboard or against the general tilt of the layer interface. The magnitude of this force is determined by the stack weight above the block in question and the angle of wedgedness of the block, and is discussed in greater detail below under "Movement Mechanism".

Other Forces

There are several other origins of force and motion within the moderator. The high rate of flow of process water through the process channels causes some vibration, the magnitude or frequency of which has not been determined, but a "jiggling" effect no doubt results which could contribute to block migration. Process tube stiffness appears to be negligible until the end slack of the tubes is taken up at which time the tube will be in tension. This tension has not yet been observed at C or K Reactors. Transient phenomena such as VSR drops, rupture discharges, process tube channel boring, etc. no doubt cause local block motion. These phenomena are of a highly random nature and, although useful for theorizing the cause of local discontinuities, are not too valuable for determining the cause of overall stack distortion. They may, however, supply the remaining force necessary to break a key, move a block, etc. already loaded by other means.

Movement Mechanism

As mentioned above, there are two oppositely directed, parallel, but unequal gravity induces forces acting on any block. The difference of these two forces remains as the only consistent unidirectional force acting on any block or group of blocks in a direction parallel to the layer interface. All other forces act in alternating directions (thermal cycling forces), random directions (irradiation contraction), perpendicularly (normal component of gravity), or in a direction opposing any positive force applied (keys and friction). It has been established that thermal cycling and irradiation contraction cause blocks to move very slightly with respect to each other with forces greater than the capability of friction to resist them. The resultants of the gravity force parallel to the tilted layer interfaces provide an ever present force in this direction. Whether the inward resultant of the gravity force itself or the outward resultant of the wedge effect is greater is of no importance at this point. A force exists which is parallel to the layer interfaces and which, other than for the VSR keys, is resisted only by friction. Over time, the known small magnitude relative motion of the blocks backed by very high forces, coupled with the known presence of small forces in a direction paralled to the layer interface, will overcome the frictional resistance to block motion. The sliding components of the gravity force are unidirectional and ever present, and if any opportunity is presented, regardless of its cause, the block or group of blocks will move in the direction dictated by these forces. Thus over a long period of time encompassing many thermal cycles, the effect of restraint of block motion by friction may be discounted and motion and forces due to gravity alone may be considered the mechanism of general stack distortion. An ashtray placed with one edge on a desk and the other on a book about one-half to one inch thick will not slide off onto

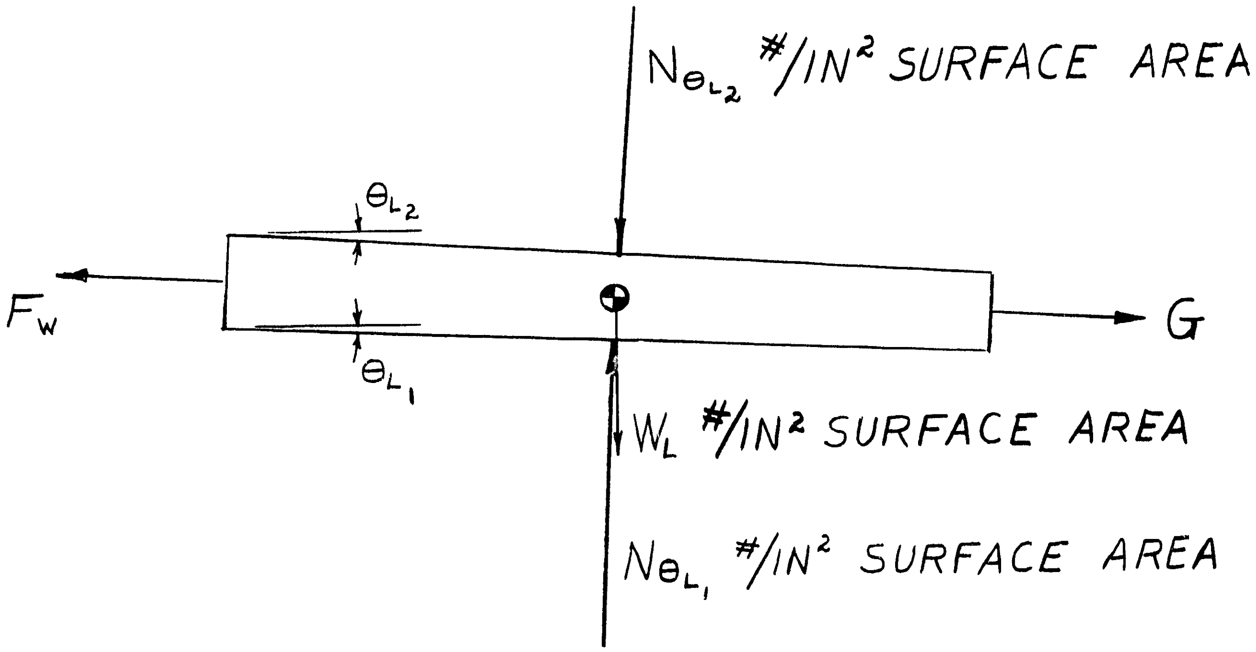


FIGURE 3

the desk. If the book is moved slightly with respect to the desk in a cycling motion, the ashtray will migrate in the direction of tilt until it falls off the book onto the desk. In this case, the capability of frictional resistance at the desk top is greater than the component of the weight of the ashtray parallel to its tilt tending to slide if off the book. As soon as the force applied to the book, a force greater than the capability of the frictional resistance to thwart, the ashtray slides off onto the desk powered only by the force parallel to its tilt. This rather crude analogy illustrates the means by which a small force when coupled with an indirectly acting high force can overcome a frictional resistance greater than itself.

<u>Derivation and Discussion of Movement Forces</u>

Figure 3 (above) shows a free body diagram of a block within the moderator stack. Its centerline is tilted at an angle $\frac{\theta_{L1} + \theta_{L2}}{2}$ due to the sag of its layer, L. The weight of the block is W_L expressed in $\#/in^2$ of layer interface area. The block is wedge shaped since θ_{L2} is greater than θ_{L1}. Acting in a direction perpendicular to its upper face is the normal component of the weight of the moderator, fuel, thermal shield, etc. shown as $N\theta_{L2}$. There are no forces imposed on this upper surface which are parallel to it. since, over time, there is no friction available to transmit this force. Acting in a direction perpendicular to the lower surface is a force equal to the component of the weight of the block in question plus the weight

[redacted]

of the moderator, shield, etc. above, which is normal to θ_{L1}, here called $N\theta_{L1}$. The two forces normal to θ_{L2} and θ_{L1} are not parallel, and their resultants which are parallel to $\frac{\theta_{L1} + \theta_{L2}}{2}$ make up the wedge force FW in $\#/in^2$ layer interface surface area.

This wedge force is written:

$$FW = N_{\theta L2} \sin \left(\theta_{L2} - \frac{\theta_{L2} + \theta_{L1}}{2}\right) + N_{\theta L1} \sin \left(\frac{\theta_{L2} + \theta_{L1}}{2} - \theta_{L1}\right)$$

$$\text{But } \left(\theta_{L2} - \frac{\theta_{L2} + \theta_{L1}}{2}\right) = \left(\frac{\theta_{L2} + \theta_{L1}}{2} - \theta_{L1}\right) = \left(\frac{\theta_{L2} - \theta_{L1}}{2}\right)$$

$$\text{So } FW = (N\theta_{L2} + N\theta_{L1}) \sin \left(\frac{\theta_{L2} - \theta_{L1}}{2}\right)$$

For one layer, $N\theta_{L1} \cong N\theta_{L2} + W_L \cos \theta_{L1}$, and call $N\theta_{L2} = N$

$$\text{Leaving } FW \cong (2N + W_L \cos \theta_{L1}) \sin \left(\frac{\theta_{L2} - \theta_{L1}}{2}\right)$$

Since $W_L << 2N$, Let $W_L \cos \theta_{L1} \doteq W_L$

$$\text{Then: } FW \cong (2N + W_L) \sin \left(\frac{\theta_{L2} - \theta_{L1}}{2}\right)$$

The component of the gravity force acting on this block which is parallel to $\frac{\theta_{L1} + \theta_{L2}}{2}$ is G $\#/in^2$ layer interface surface area. $G = W_L \sin \left(\frac{\theta_{L1} + \theta_{L2}}{2}\right)$

If an unbroken key exists between layer L and the layer above, L + 1, then the weight contributing to the gravity force parallel to $\frac{\theta_{L1} + \theta_{L2}}{2}$ would include that of the layer above. This occurs because a mechanism, the key, is provided by which the gravity force G (L + 1) from layer L + 1 can be transmitted to layer L. Thus in the case of unbroken keys, large masses of blocks may throw their weight upon a key at one point.

In a like manner the wedging force becomes additive. To calculate the net force (G-FW) transmitted by a large mass such as this, $FW = (N\theta_{L2} + N\theta_{L1}) \sin \frac{(\theta_{L2} - \theta_{L1})}{2}$ and $G = W_L \sin \left(\frac{\theta_{L1} + \theta_{L2}}{2}\right)$ where W_L is the weight of the mass and θ_{L2} and θ_{L1} are the angles with respect to the horizontal of the top and bottom surfaces of the top and bottom layers respectively of the mass. Forces of this nature would be expected at early stages of distortion but at the present state, where VSR channel curvatures indicate that keys are broken throughout the pile, the force G applicable at any one layer is limited to

[redacted]

the contribution from that layer alone. In calculating G, care must be taken in establishing the value of W_L to include only that mass which can be brought to bear in a direction parallel to $\frac{\theta_{L1} + \theta_{L2}}{2}$. In calculating W_L for a tube layer, for instance, the contribution of the fuel is included in the calculation of force in the near-far direction, but not in the front-rear direction.

From examination of the data available a maximum value for $\theta_L = 2^\circ\ 30'$ at the top of either C or K Reactors seems reasonable. Furthermore vertical bowing measurements indicate that in the regions where any slope at all exists, it is quite uniform and breaks rather sharply into zones where no slope exists. (Figure 6 - page 23 - clarifies this.) Furthermore, these slopes decrease uniformly as depth into the stack increases. Combining these factors with the assumption that negligible distortion has occurred in the reflector zones, the following expressions for θ_L as a function of layer number, L can be written.

C	K	Remarks
$\theta_L = 2^\circ\ 30'$; $102 \geq L \geq 97$	$\theta_L = 2^\circ\ 30'$; $130 \geq L \geq 123$	Top Reflector
$\theta_L = 2^\circ\ 30' - \frac{97 - L}{90}(2^\circ\ 30')$ $(97 \geq L \geq 7)$	$\theta_L = 2^\circ\ 30' - \frac{123 - L}{114}(2^\circ\ 30')$ $(123 \geq L \geq 8)$	Central Zone
$\theta_L = 0$ $7 \geq L \geq 0$	$\theta_L = 0$ $8 \geq L \geq 0$	Bottom Reflector

As is seen in Figure 6, $\theta_L = 0$ in the near far plane in the center of the reactor, whereas in the front rear plane θ_L as approximated by the above expressions exists to the center of the reactor. In the zones where slope exists in the near-far plane, θ_L may be found by the above expressions.

If the distortion continues at the present rate, in ten years a maximum θ_L at the top of the reactors should be in the neighborhood of $6^\circ\ 15'$, corresponding to a sag of 14 inches at the top center of the K Reactors. To convert the above expression to give θ_L in ten years, substitute $6^\circ\ 15'$ for $2^\circ\ 30'$.

Since G varies directly as the angle θ_L it will be maximum near the top of the stack where θ_L is near a maximum yet where W_L is also high with fuel loading. The wedging force, FW, is at a maximum near the bottom of the reactor where the wedge shape of the block persists and the normal force N, is high. Both G and FW are entirely dependent upon the interlayer surface area which is considered to act as a unit. If the mass considered to be acting on a given key is only one block, the forces will be very

[redacted]

small. However, if a large area of the layer is acting on a key, larger forces will result.

The allocation of layer surface areas to specific keys is a matter of pure guesswork. Bridging of a certain key could relieve that key of any load whatever, yet a particularly disadvantageous arrangement of key breakages could throw a very large mass of graphite on one particular key or key cluster. The gravity force is dependent upon masses outboard of the point of question, whereas the wedging force, FW, is dependent upon masses inside of the point in question. Therefore, the maximum G force will occur in the center of the pile and the maximum FW force toward the fringe. Thus the values of G and FW depend not only on height of the point in question in the stack, but also their horizontal position in regard to the center of the stack. High G forces can be expected in the top center of the pile, and high FW forces can be expected in the bottom fringe of the pile. Since the areas involved in the calculation of forces acting upon any particular key are not identical it is difficult to calculate a general level at which the net force on a given key will be zero. By setting FW = G this level may be determined for a particular block (for which the surface areas and locations involved are identical) the result is L= 74 at the K Reactors and L = 58 at C Reactor. Above this layer a particular block would be expected to migrate inward, while below it the block should migrate outward. For a particular key, however, the area effected by the G force loading the key from the outside is definitely not the same as the area effected by the FW force loading the key from the inside of the reactor.

Magnitude of Movement Forces

The actual magnitude of these forces most probably never exceeds 200 pounds. At the top of the Reactor FW = 0 at the first undistorted layer, yet θ_L is at a maximum making G a maximum. Allocating the largest loading area to a particular key yields a G force of 187 pounds in the near-far direction at the K Reactors. At the bottom of the reactor where blocks are still wedge shaped yet $\theta_L \cong 0$ yields a maximum FW of 201 pounds in the front-rear plane at the K Reactors. These forces are the maximum conceivable and actual values are probably closer to one third of those above. Due to the asymmetry of sag profile the forces in the planes opposite to these mentioned above are less because of large flat areas or applicable loading. The actual forces which apply at different points throughout the reactor for different concentrations of mass are very easily calculated with the formulas given for FW and G above and the stack loading figures (Appendix III), but the combinations are so many that no attempt at a force map is made here. The magnitude of these forces increases directly with θ_L so that in 10 years maximum forces of 500# would be anticipated.

Moderator Distortion Process

The mechanism of overall moderator distortion can be explained with the use of the forces acting within the stack as discussed above. Looking at the stack as a whole the reflector zone of relatively unchanged graphite completely surrounds the pile. In the center there exists the hotter more severely irradiated core which is contracting at a fairly well established rate. This produces a sagging or dishing effect at each layer and opens

[redacted]

[redacted]

gaps between blocks in this central zone. As the contracting graphite in the center collapses it carries with it the relatively unchanged reflector and the top thermal shield.

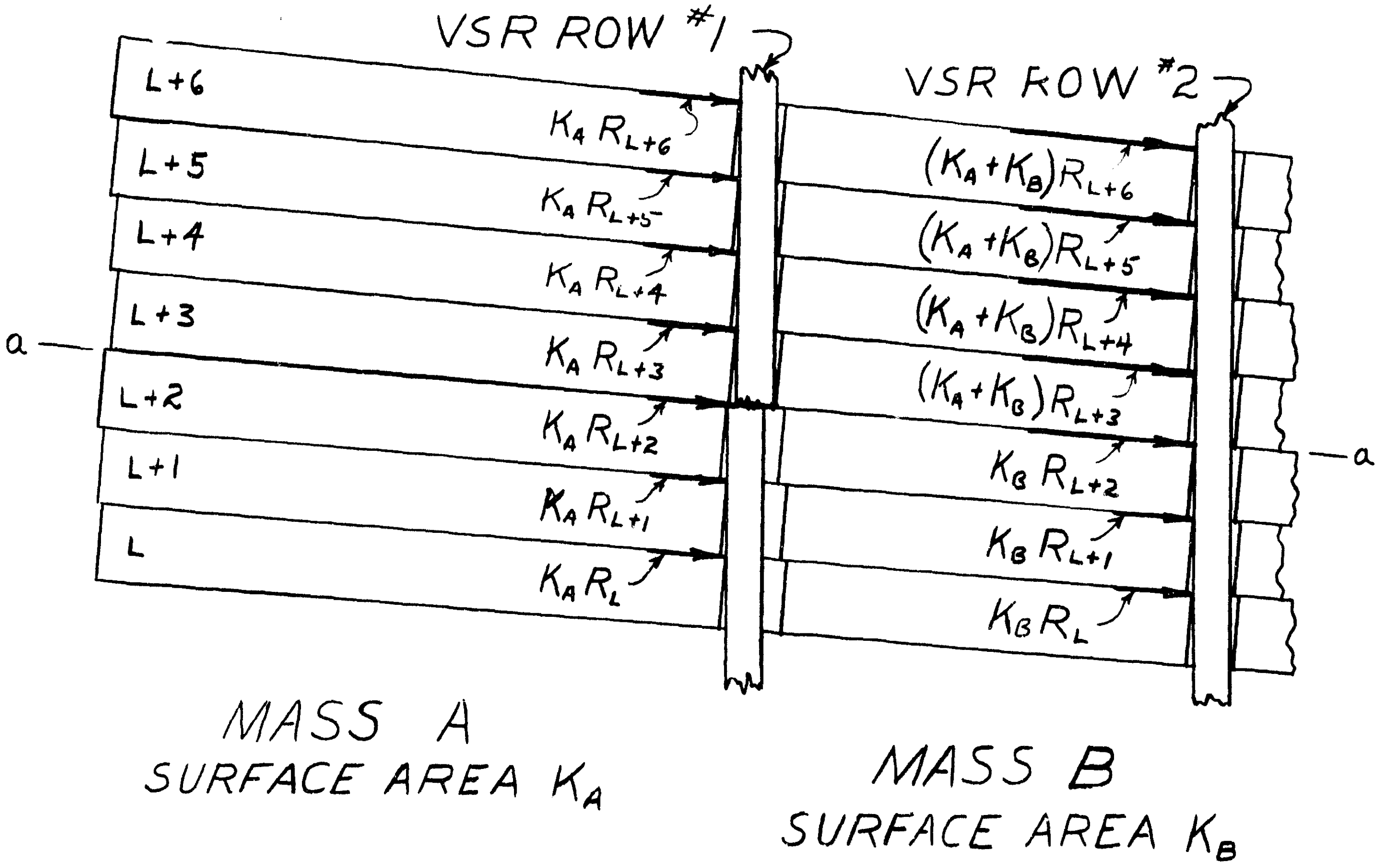


FIGURE 4

LET $R_L = (G_L - F_{W_L})$ #/IN² LAYER INTERFACE SURFACE AREA

Consider Figure 4 which depicts a segment of contracted graphite in the upper left of the central zone of the pile. At this high position the net resultant on each block is inward as G is greater than FW. Since the graphite to the right of the first column of VSR keys has contracted and

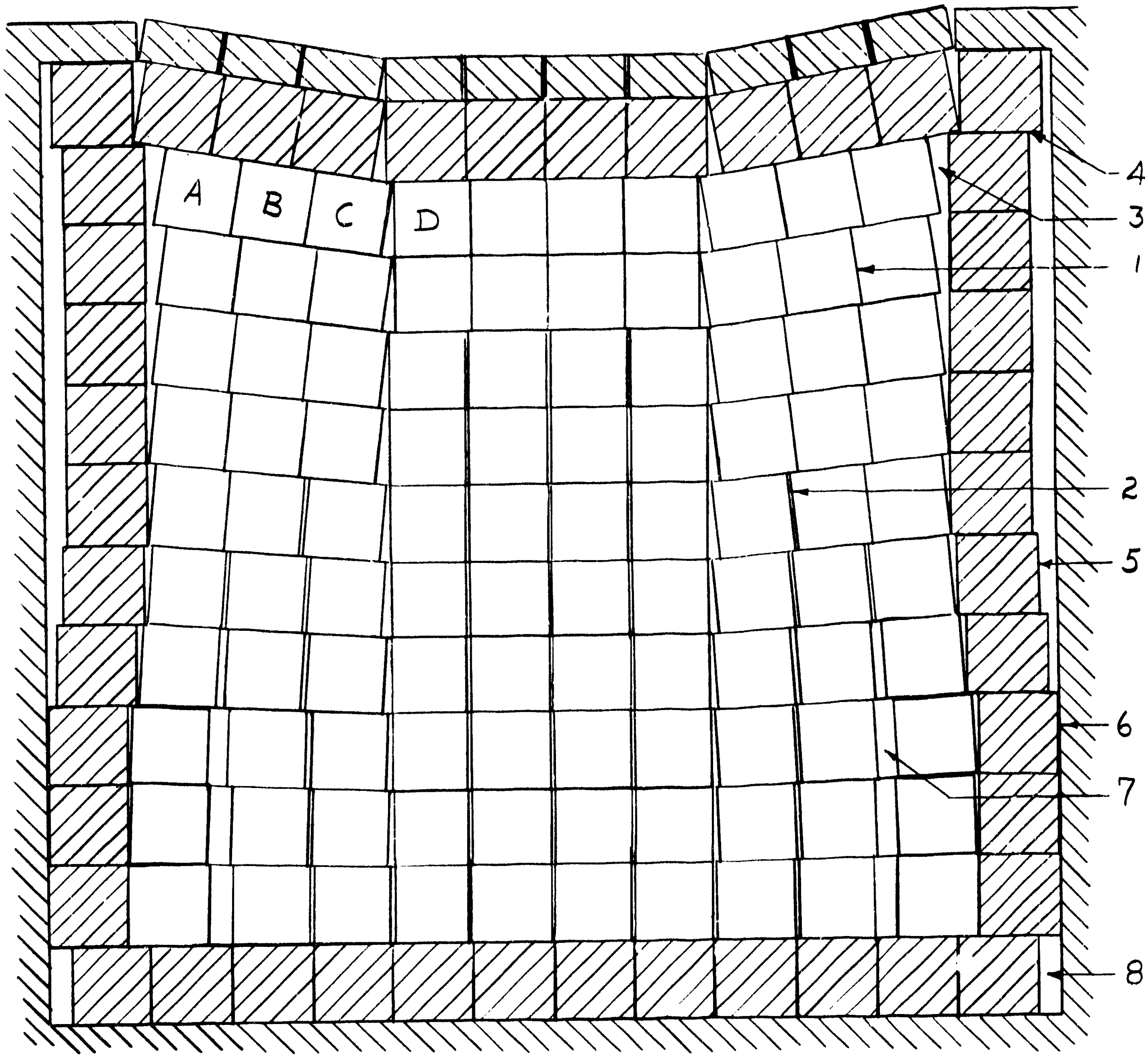
[redacted]

is also leaning to the right, there is no support for the key other than its own flexural strength which is small. Thus at some layer a-a, the parallel forces (G -FW) at each layer above will break the VSR key, and the section of graphite above a-a will migrate in towards the center of the stack until another key is reached. If this next key is in the second row of VSR channels, then it will have to support two masses of graphite, A and B. Note that according to the key flexural strength data and the calculated values of (G - FW) at present values of θ_L these failures should have occurred at least every two or three layers. This is in agreement with the observed channel curvature data which indicates key failure at at least this frequency. This process will continue until all keys across the plane a-a are broken and the graphite masses from each side of the pile meet and the horizontal forces (G - FW) balance each other at the center of the reactor (Figure 5). This same process most probably breaks keys in the fringe zone below level a-a before the graphite masses have met in the center above level a-a. Also, of course, level a-a will not necessarily be at a given layer, but may range up and down among several layers across the width of the reactor. Since the top reflector zone has not contracted, the keys will be bent outward at the junction of that zone with the central zone. This is contrary to the general bending below this junction which is inward toward the center of the reactor as shown in Figure 4. This reverse curvature is shown in the VSR channel curvature in Figure 6.

A similar phenomenon occurs at the bottom of the stack but in the opposite direction as here FW is greater than G. When the reflector is pushed out to touch the thermal shield, the motion ceases insofar as the shield is immovable. The departure of the tilted graphite from the flat central zone leaves a gap between it and the central zone. Furthermore, if the concentration of mass is not great enough to inflict breaking forces on keys then only the graphite outside of the VSR key cluster pattern will migrate outward. In the upper region of the stack the reflector, which is flat, will not necessarily follow the central graphite, thereby leaving a gap between it and the central zone. These gaps are shown on Figures 5 and 6.

If the sag in the center of the unit is of such a pattern that a steep slope changes abruptly to a flat surface as appears to be the case from near to far (see Figure 6), the discontinuity in slope may jam certain blocks at the discontinuity so that the horizontal forces created in the region of steep slope are not felt in the flat zone inside the discontinuity. In the upper reaches of the stack the blocks in the flat central zone would continue to contract but the small gaps created would not be closed by incoming graphite from the zones of high slope. Whether this discontinuity is sufficient to cause the jamming has not been determined, but in its more probable absence, the blocks migrating in from the steeper slope would push the central blocks together. As time progresses all VSR channel keys will be broken and the central zone contracting graphite will continue to be pushed together until there are no more gaps between blocks. In the upper half of the stack the graphite will slide inward layer by layer an amount proportional to the flux distribution. Since the flux distribution in the central zone of the reactor is relatively uniform, the central portion of the VSR channels would be expected to remain fairly vertical and of low curvature.

FIGURE 5



THERMAL SHIELD

GRAPHITE REFLECTOR (NOT CONTRACTED)

MODERATOR GRAPHITE (CONTRACTED)

1., 2., 3., etc., SEE NEXT PAGE

[redacted]

Notes on Figure 5

Figure 5 is a schematic representation of the distortion process within the graphite stack. The view is a near-far plane cross section somewhere near the center of the reactor in a front-rear direction. The large mass of the stack is broken into smaller masses (A, B, etc.) to facilitate representation of motion within the stack. The graphite will not move in such discrete masses, but the distortion follows a pattern shown by the motion of these masses with, of course, smoother transition between them. The graphite reflector has not contracted so its distortion is due to dimensional change of the moderator graphite. The moderator or central zone graphite has contracted to a greater or lesser degree depending on its location with respect to the high flux zones. The boundary between the reflector and the moderator is not as defined as it is in Figure 5, but is determined by the region of high and low flux zones. For the purpose of illustration it is shown as being a discrete outermost fringe of masses. The point in time represented in Figure 5 is about halfway to the point where we now stand. Figure 6 shows distortion at the present time.

1., 2. The divisions between masses within the moderator represent the location of VSR channel key clusters. Those where the keys have broken are shown as being closed (1) and those where the keys still resist motion are shown as gaps (2) since the graphite has contracted.

3. In the upper reaches of the stack where the key clusters have all broken and the inwardly directed "G" force prevails, the moderator has moved away from the reflector. In this case the reflector has remained in roughly its original position creating a gap (3), but it is conceivable that the reflector could collapse and follow the moderator.

4. This discontinuity at the reflector is caused by the bowing of the top reflector which has not contracted relative to the graphite below. If the lower reflector had followed the moderator as mentioned in 3, this effect would be further pronounced at 4.

5. The reflector has been forced outward toward the thermal shield by the outwardly directed wedging force FW acting on the moderator within. A small wedging force will move these masses outboard of the last row of VSR channel keys as there is nothing but friction to resist it.

6., 7. The wedging force has caused the outermost moderator to migrate outward pushing the reflector out to the thermal shield (6) and having a large gap (7) in the vicinity of the first row of VSR keys.

8. The bottom reflector will probably remain as constructed as there are no FW or G forces within this section due to its undistorted condition.

DECLASSIFIED

In the lower half of the stack where the fringe graphite is not pushing inward, the central graphite will remain very nearly as stacked in the near-far plane as there is no tilt, and FW = G = 0. In this case small gaps will open between blocks, but the blocks will not be pushed in any particular direction. In the front-rear plane where $\Theta \neq 0$ the blocks should tend to migrate outward. The blocks in the tube layers in the front-rear direction should migrate more or at least sooner as G is less for these hollowed blocks than for the solid filler blocks above and below. Thus in the near far plane the central graphite should tend to move inward or stay put (in the lower regions). In the front-rear plane the central graphite should tend to move inward in the top half of the stack and outward in the bottom half. The major curvature would be expected at the top and bottom of the stack where the flux gradients are high. An additional inward migration in the near to far plane may be expected in the vicinity of the E ring where flux density is higher than in the most central zone. In addition, the distortion in the fringe rod channels would be expected to be greater than in the central channels as the effect of shrinkage of the central blocks is felt at the fringe in a cumulative fashion. This is similar to the effect on the slope of the layer interfaces in the higher reaches of the stack. The top reflector does not contract as fast as the graphite below it, and the more highly contracted upper central layers would be expected to move inwards relative to the reflector above.

All of the phenomena explained above in light of and by way of demonstration of this hypothesis have been observed on C and K Reactors. VSR channel curvature, reflector behavior, and other moderator configuration are all illustrated and noted in Figures 5 and 6 as they have been observed and explained above. As may be expected with a system of so many components and variables over such a long period of time there will be many random discontinuities between the observed data and what the above basic analysis would predict in strict application. The simplicity and accuracy with which the above theory explains the majority of basic major phenomena observed to date inspires confidence in its validity.

VSR CHANNEL LINING

The hypothesis of this paper sheds a great deal of light on the problem of VSR channel liner selection. As determined above, the only forces to be born by keys and therefore by VSR channel liners are those of the component of the weight force parallel to the layer interfaces, G, and the wedge force, FW, caused by the slight wedgedness of the moderator blocks. In the event that all VSR keys are broken as is suspected from VSR channel curvatures, then the maximum forces applicable are the same as those mentioned above, 200 pounds at present. An unbroken key or a freshly sleeved channel can cause higher loads. As soon as a means is provided for shear load support between layers, then the forces generated by all the layers so joined can be delivered at one layer further in the direction of the force involved. For example if three layers are joined by a sound VSR key cluster, then the component of the weight of all three layers, which is parallel to the bottom layer interface, will be transmitted to any key or sleeve which tries

[redacted]

to resist this component inboard of the sound key. The worst possible condition of this situation wherein all blocks above layer 58 at C Reactor are keyed together generates a maximum plausible force (G - FW) of 1200 pounds in the near-far direction at the present distortion. Ten more years of distortion would put this in the neighborhood of 3000 pounds.

It is difficult to conceive of this ever occurring but at least a maximum is established. This is a shear load as there are no forces transmitted above this force and the force below is only that generated by one layer which is small in comparison to 1200 pounds.

The failing of the VSR key design is that they are very weak in flexure. If all loads imposed on VSR keys were pure shear, then they would not have failed. It therefore seems advisable when designing VSR channel sleeves to make them of such a length that they can not be loaded in flexure. As sleeve length is increased the number of modes of loading increases. A sleeve of one block width in length can be loaded only in compression or shear, but never flexure. If it were two block widths in length more modes of loading in compression and shear are added. Flexure can occur only if one end fourth of the sleeve length should become jammed in the channel so as to provide cantilever support. Inasmuch as the channels will be bored 1/8 inch oversize before sleeve insertion this seems unlikely. A sleeve three block widths in length is easier to load in flexure but due to the initial channel overbore it is still difficult compared to shear loading. A sleeve of four block widths length is highly susceptible to flexural loading. From this it is recommended that VSR channel sleeves be two block widths in length, but three block widths may be acceptable. The capability of the proposed sleeves to withstand forces of the magnitude mentioned above in the various combinations of loading which are possible should decide the proper length and material.

In an effort to distribute any forces, either already existing or occasioned by the insertion of VSR channel sleeves, among as many VSR channels as possible, it would be wise to sleeve as many channels as possible in as short a period as possible. One channel of sleeves standing alone is very much more susceptible to high loads than if there were others available to help support any large shifting masses.

ACKNOWLEDGMENT

Moderator component temperatures were obtained from J. D. Agar, Reactor Design Analysis, NRD.

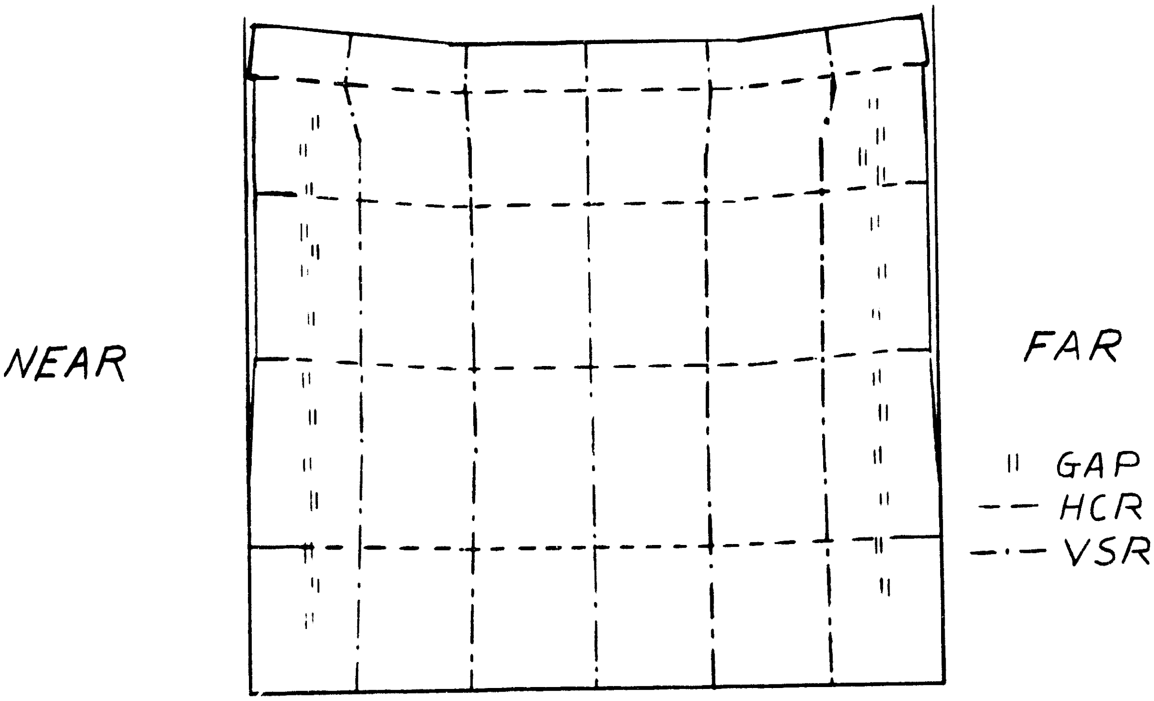
Mechanical, thermal and nuclear properties of graphite were obtained from E. M. Woodruff, Graphite Research and Development, HL and the book, Nuclear Graphite, R. E. Nightingale and Industrial Graphite Engineering Hdbk, National Carbon Co.

To L. F. Osteyee, Calif. State Polytechnic College, goes the credit for the important breakthrough engendered by his concept that there are mechanisms which enable us to ignore or at least discount the resistance due to friction with the stack over long periods of time.

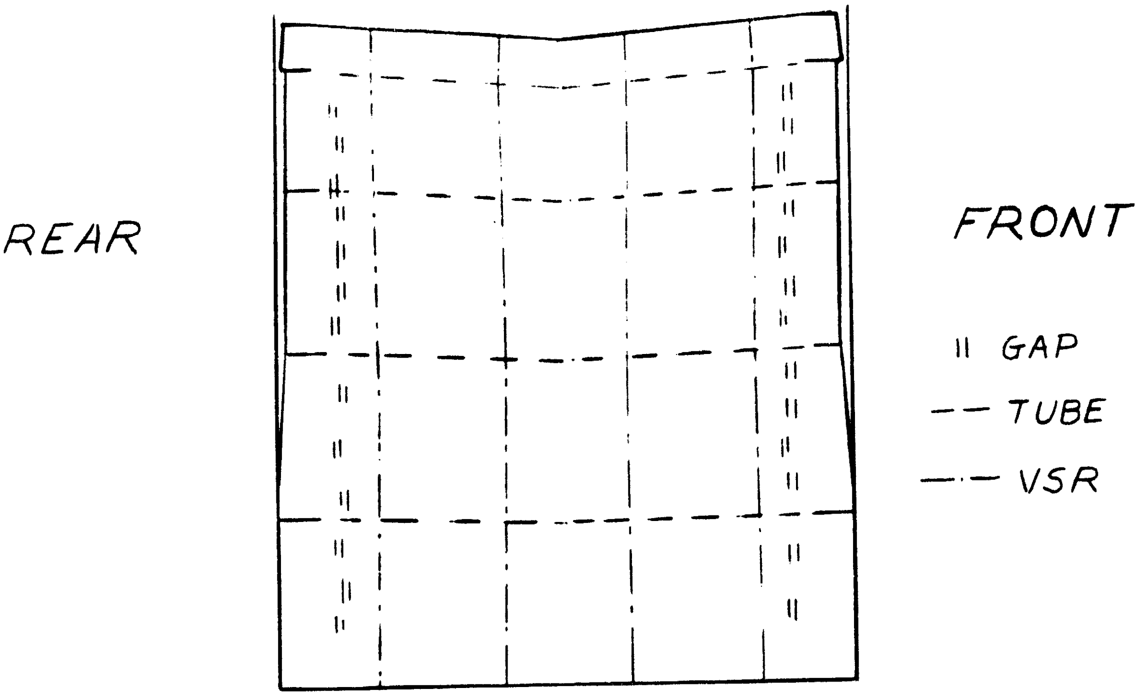
[redacted]

DECLASSIFIED

FIGURE 6
TYPICAL OBSERVED DATA CROSS SECTIONS



FRONT VIEW



SIDE VIEW

[redacted]

APPENDIX I

MECHANICAL PROPERTIES OF CSGBF AND TSGBF GRAPHITES

The best data available indicate that the mechanical properties of CSGBF (C Reactor) and TSGBF (K Reactors) graphites are similar enough to be considered identical. The table below gives the ultimate strengths at room temperature of these graphites in various means of loading, both before and after irradiation.

		Pre Irrad.	Std. Dev.	Post Irrad.	Std. Dev.
Tensile Strength (psi)	(∥)	1440	250	1800	310
	(⊥)	1260	310	1575	390
Flexural Strength (psi)	(∥)	2400	510	3000	640
	(⊥)	1970	510	2460	640
Shear Strength (psi)	(∥)	1970	510	2460	640
	(⊥)	2400	510	3000	640
Compressive Strength (psi)	(∥)	5990	640	7500	800
	(⊥)	5960	920	7500	1150
Young's Modulus ($X 10^6$ psi)	(∥)	1.49	.15	3.0	.30
	(⊥)	1.11	.10	2.2	.20

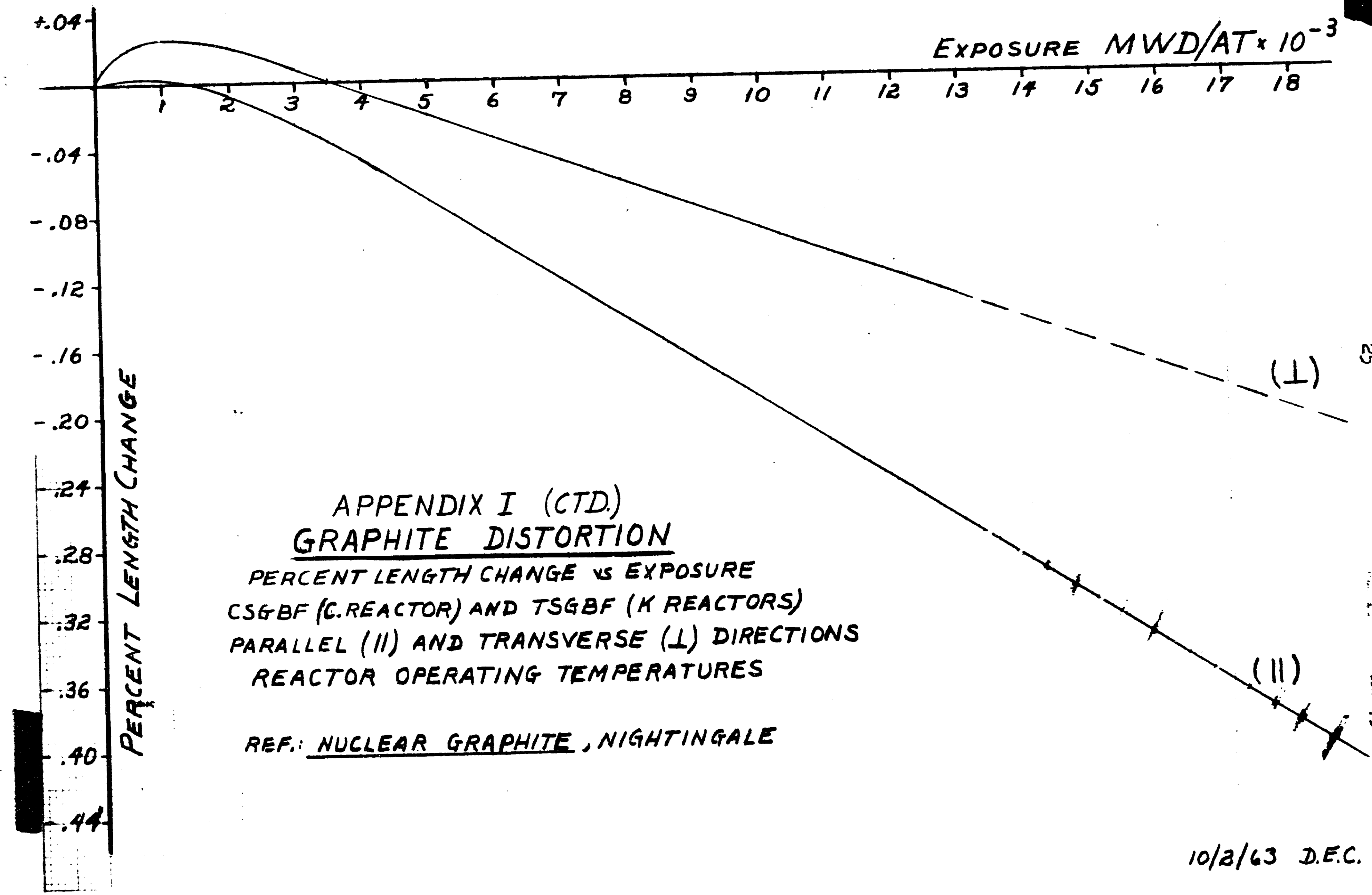
Ref. 1. Nuclear Graphite, Nightingale
2. Industrial Graphite Engineering Handbook, National Carbon Co.

The coefficients of thermal expansion of CSGBF and TSGBF graphite are listed below. These values are accurate from 25 C to 525 C and are found in HW-43395.

Coefficient of Thermal Expansion, In/In. C		
CSGBF	(∥)	1.7×10^{-6}
	(⊥)	3.8×10^{-6}
TSGBF	(∥)	2.2×10^{-6}
	(⊥)	4.2×10^{-6}

The graph on the following page shows the percent length change in CSGBF and TSGBF graphites due to irradiation. The curve shown for distortion in the parallel direction is valid for irradiation temperatures from 200 C to 600 C. The curve shown for transverse direction distortion is valid for temperatures from 400 C to 600 C, but would show more expansion at low exposures and less contraction at high exposures for temperatures below 400 C.

[redacted]



APPENDIX I (CTD.)

GRAPHITE DISTORTION

PERCENT LENGTH CHANGE vs EXPOSURE
CSGBF (C.REACTOR) AND TSGBF (K REACTORS)
PARALLEL (||) AND TRANSVERSE (⊥) DIRECTIONS
REACTOR OPERATING TEMPERATURES

REF.: NUCLEAR GRAPHITE, NIGHTINGALE

10/2/63 D.E.C.

[redacted]

APPENDIX II

GRAPHITE MODERATOR LAYER DRAWINGS

APPENDIX III

Stack Loading

The figures listed below permit the calculation of the gravity loading anywhere in the stack. There are several different zones within the stack and the contribution of each of these zones to the gravity force per square inch of layer interface surface per layer are listed below:

C Reactor

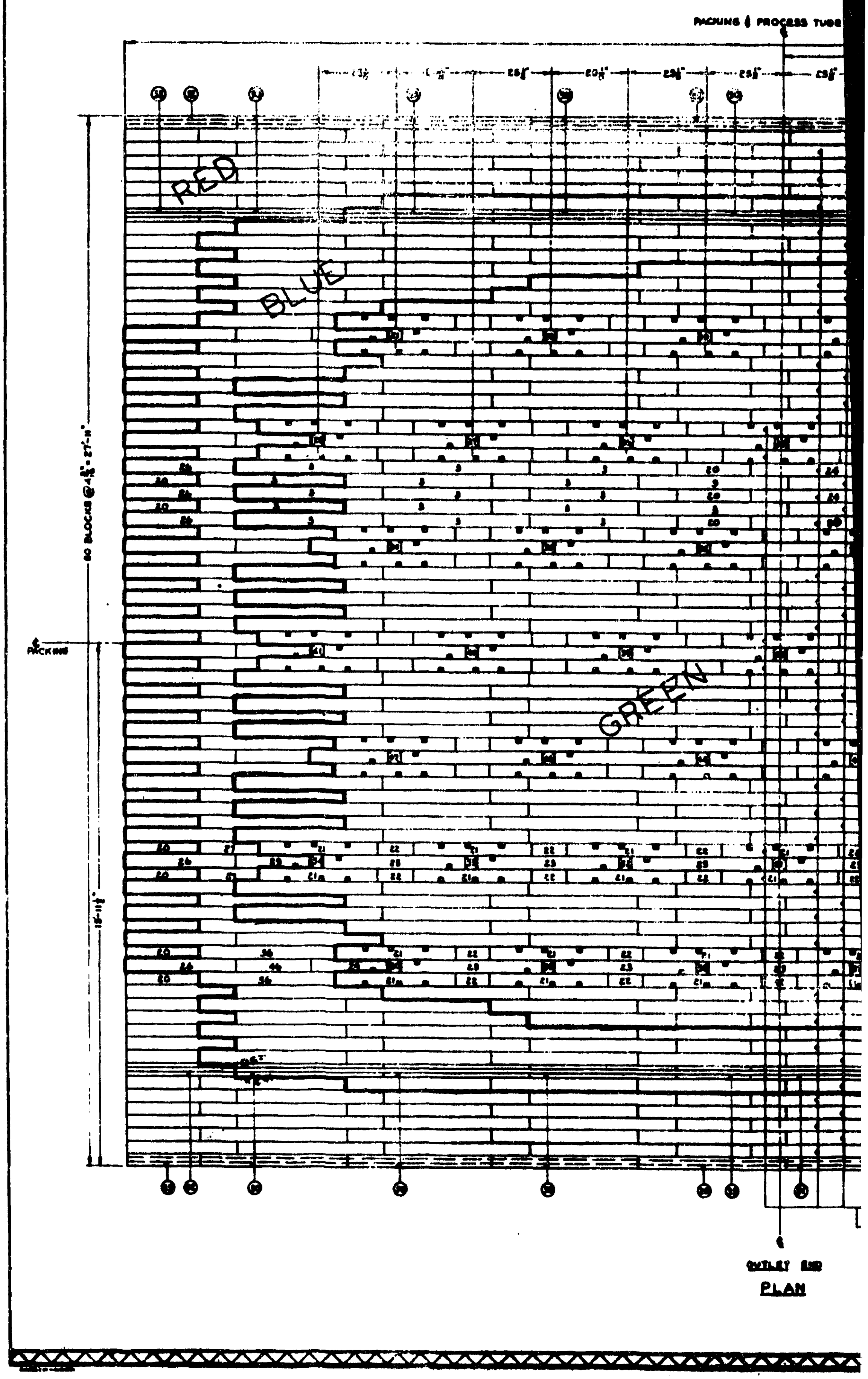
Top Thermal Shield	2.2 lb./in.^{2}
Reflector or Filler Layers	.250 lb./in.^{2}/layer
Natural Loaded Tube Layers	.327 lb./in.^{2}/layer
Enriched Loaded Tube Layers	.319 lb./in.^{2}/layer
Overbore Loaded Tube Layers	.413 lb./in.^{2}/layer
Tube Layer Graphite Only	.233 lb./in.^{2}/layer

K Reactor

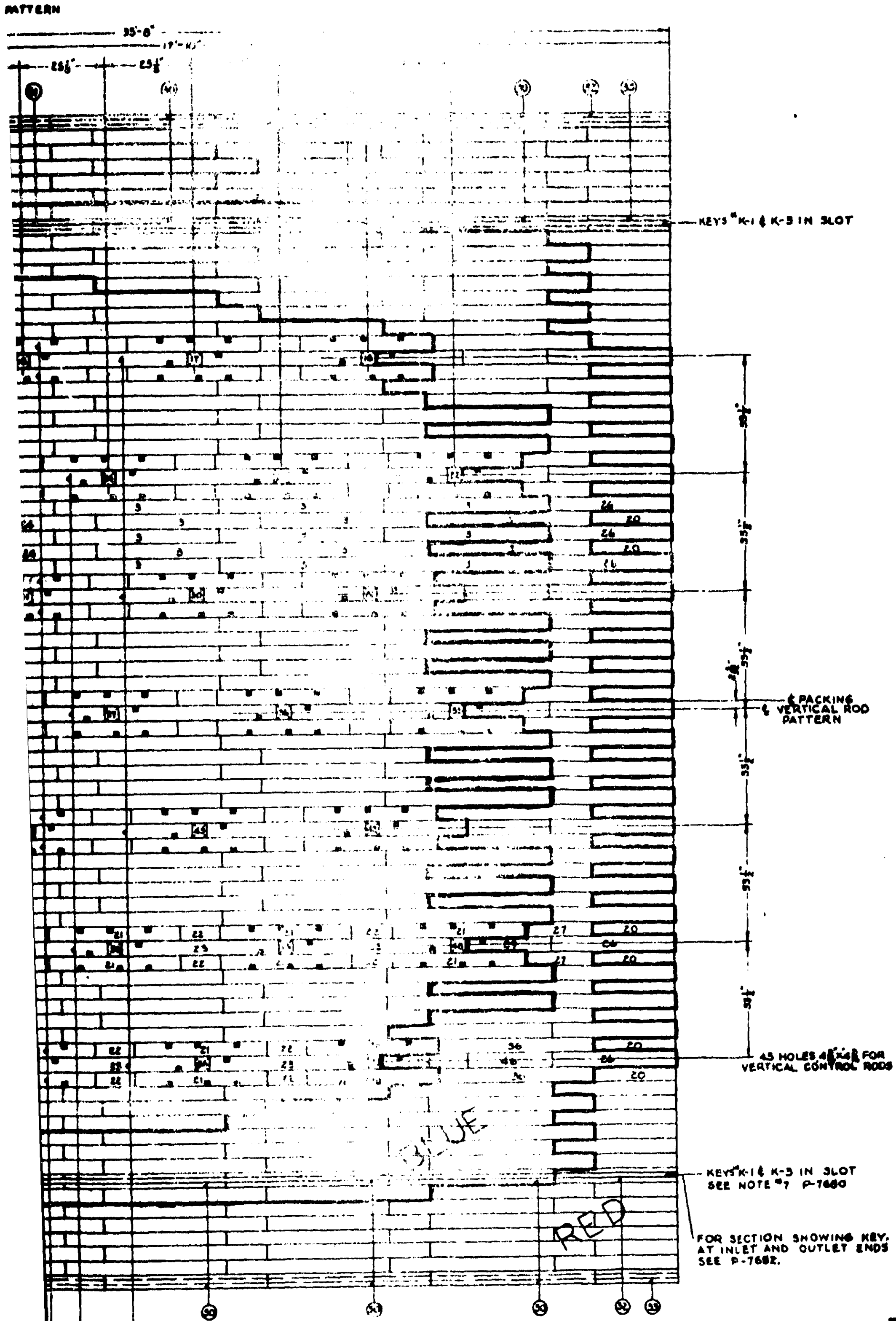
Top Thermal Shield	2.62 lb./in.^{2}
Reflector or Filler Layers	.223 lb./in.^{2} layer
Natural Loaded Tube Layers	.302 lb./in.^{2} layer
Enriched Loaded Tube Layers	.296 lb./in.^{2} layer
Tube layer Graphite Only	.174 lb./in.^{2} layer

In order to use these numbers to calculate the loading at a particular point in the stack, the nature of the layers above the point in question must be known. If it is a point in the side reflector, for instance, the loading would be, for C Reactor 2.2 lb./in.^{2} + .250 x the number of layers down from the top of the stack to the point in question. If the point is in the center of the stack, then the contribution of each different type of layer must be taken into account down to the layer in question.

[redacted]



INLET END
PACKING ℄ PROCESS TUBE
RED
BLUE
GREEN
℄ PACKING
OUTLET END
PLAN



MATERIAL FOR ONE LAYER

RED	BLUE	GREEN		BLK NO.	DESCRIPTION	REFERENCE	[illegible]
36	[illegible]	100		3	4⅜ x 4⅜ x 48	SKETCH "D" P-7691	[illegible]
81	4	22		20	x 36	[illegible]	107
		90		21	x 30⅜	C P-7692	[illegible]
		76		22	x 11⅜	D P-7691	76
		38		23	x 46⅜	A P-7692	[illegible]
10	8	37		24	x 44	D P-7691	56
26	50			26	x 36	D	76
	12			27	x 12⅜	D	12
	10	4		29	x 25⅜	A P-7692	[illegible]
15	11			30	x 48	A P-7691	[illegible]
2	2			31	x 44	A	4
4				32	x 36	A	4
5	1			33	x 24	A	6
	16			34	x 44	E	16
	8			46	x 25⅜	E	8
217	[illegible]	[illegible]				TOTAL	[illegible]
		AL		[illegible]	1½" SQUARE	SKETCH A P-7690	[illegible]
		AL		[illegible]	1½" SQUARE	C	[illegible]

DECLASSIFIED

APPROVED FOR CONSTRUCTION

AS BUILT

NOTES
1. BLOCK NUMBERS AS SHOWN DIRECTLY APPLIED TO A ROW OF BLOCKS ARE TYPICAL FOR ALL SIMILAR ROWS [illegible]
2. FOR TOLERANCES [illegible] GENERAL INFORMATION SEE P-7680
3. FOR KEYING [illegible] SEE P-7658
4. ALL KEYS [illegible] MATERIAL

[redacted] This document contains restricted data as defined in the Atomic Energy Act of 1954.

P-7680 PACKING BLK. LAYERS & GEN. ASSEMBLY
REFERENCE DRAWINGS

[redacted]

M 1 CHECKED FOR "AS BUILT" PROJECT COMPLETE. [illegible]
REVISIONS

SCALE:
DRAWN C J FAMS DATE 5-28-51
CHECKED [illegible] DATE 6-14-51
ENGINEERING REQUISITION NO. 105-C-1-4380
PROJECT NO. C-431-8
APPROVALS

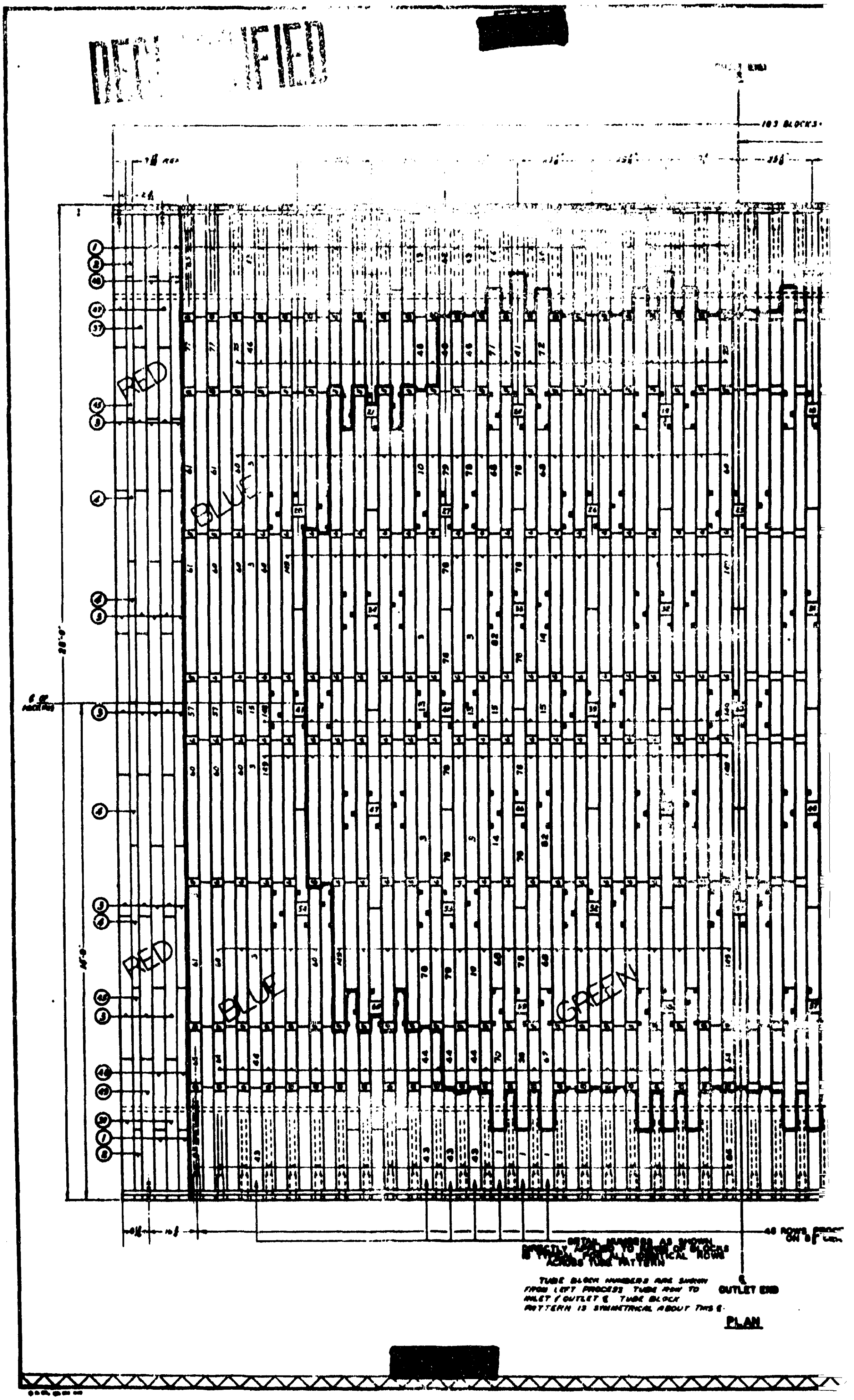
U. S. ATOMIC ENERGY COMMISSION
HANFORD WORKS
1601 GENERAL ELECTRIC

PACKING BLOCK LAYERS
ARRANGEMENT PLAN
LAYERS #36, 38, 42, 44, 50, 54, 56, 62, 66 & 68

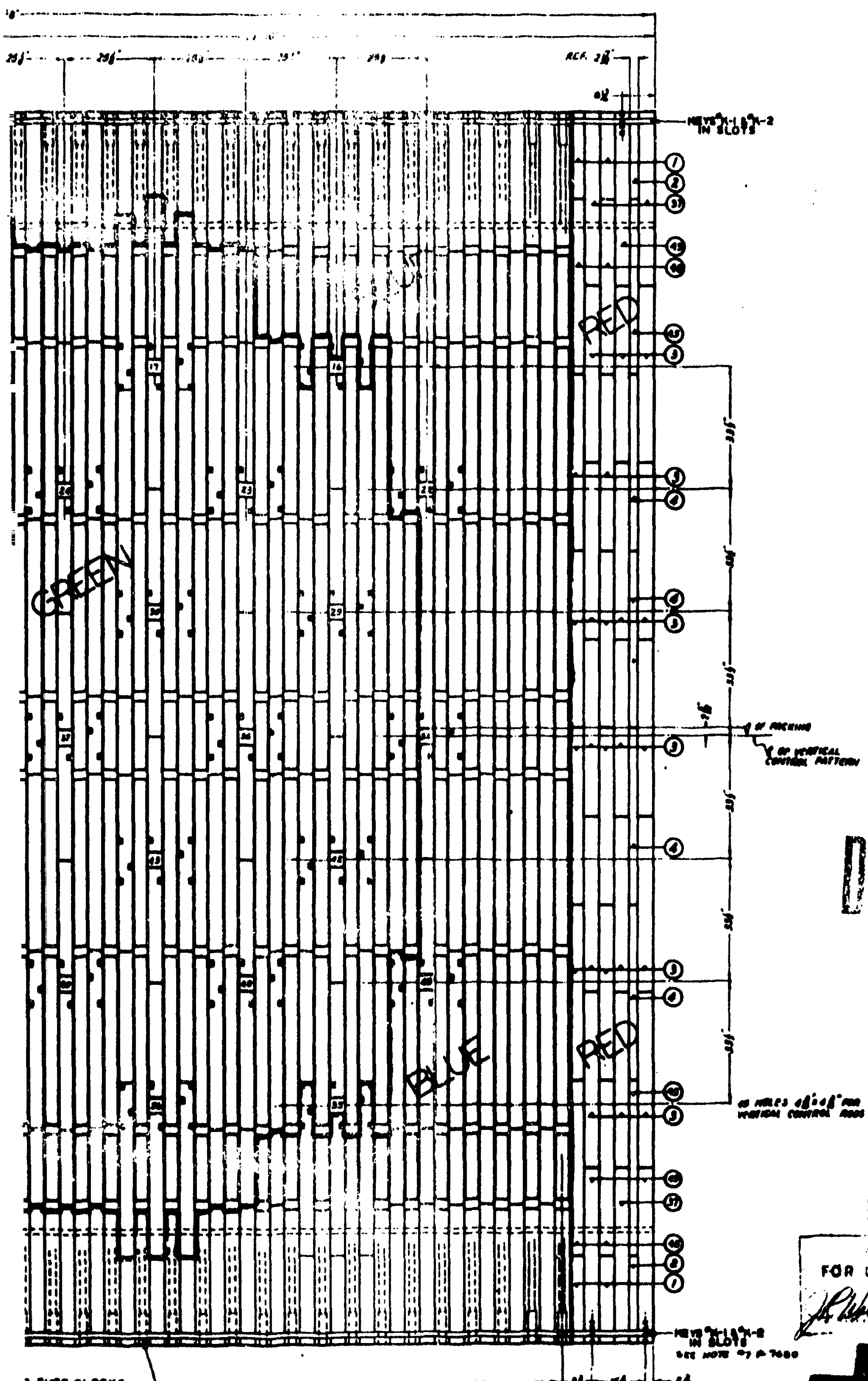
BLDG. NO. 105-C DWG. NO. P-7734

SHEET #46

[redacted]



[redacted]



MATERIAL FOR ONE LAYER

RED	BLUE	GREEN		BLK NO	DESCRIPTION	REFERENCE	QUAN.
8	84			1	4[illegible] x 4[illegible] x 24	SKETCH A, P-7691	92
4				2	x 2[illegible] x 24	B	4
46	20	24		3	x 4[illegible] x 48	C	90
8				4	x 2[illegible] x 48	D	8
		176		6	4[illegible] x 4[illegible] x 4[illegible]	A, P-7695	176
		178		8		x 4[illegible]	B	178
	4	10		10	4[illegible] x 4[illegible] x 48	SKETCH A, P-7693	14
	2	12		13	x 21[illegible]	A	14
		12		14	x 48	A	16
	6	12		15	x 21[illegible]	B, P-7691	18
6				37	x 48	B	6
	2	4		38	x 39[illegible]	A, P-7694	6
	2	4		41	x 43[illegible]	A	6
	44			42	x 38[illegible]	C, P-7691	44
	14	13		44	x 20[illegible]	D	27
4				45	x 2[illegible] x 48	E	4
	14	13		46	x 4[illegible] x 25[illegible]	D	27
8				48	x 48	B	8
6				49	x 48	D	6
	6			57	4[illegible] x 4[illegible] x 18[illegible]	A, P-7695	6
	20	24		60	x 45[illegible]	A	44
	8			61	x 45[illegible]	A	8
	20	24		64	x 18[illegible]	A	44
	8			65	x 18[illegible]	B	8
	18			66	4[illegible] x 4[illegible] x 27[illegible]	B, P-7691	18
	2	4		67	x 47[illegible]	A, P-7692	6
		84		68	x 35[illegible]	B, P-7691	84
	2	4		70	x 47[illegible]	C, P-7692	6
	2	4		71	x 48	A, P-7692	6
	2	4		72	x 48	C, P-7693	6
	18	24		75	4[illegible] x 4[illegible] x 22[illegible]	A, P-7696	42
	8	36		76	4[illegible] x 4[illegible] x 31[illegible]	A, P-7696	44
	4			77	4[illegible] x 4[illegible] x 22[illegible]	A, P-7696	4
	4	10		78	4[illegible] x 4[illegible] x 48	A, P-7698	14
	4	12		79	x 37[illegible]	A, P-7696	16
		12		82	x 48	A, P-7698	12
	92			85	4[illegible] x 4[illegible] x 36[illegible]	C, P-7696	92
	4	36		148	x 18[illegible]	A	40
	6	106		149	x 45[illegible]	A	112
90	376	824				TOTAL	1290
		ALL		151	1[illegible] SQUARE	SKETCH A, P-7690	[illegible]
		ALL		152	1[illegible] SQUARE	B	65'-9"

NOTES

1. SPACING OF HOLES FOR 1[illegible]" ⌀ SUPPORT PINS IN OUTLET END SHOWN. INLET END SIMILAR BUT TO OPPOSITE HAND
2. ALL KEYS & ALL NO. 6 & 8 BLOCKS TO BE GREEN MATERIAL
3. FOR [illegible] DIMENSION, HOLES 16-40 SEE P-7682
4. FOR TOLERANCE & GENERAL INFORMATION SEE P-7680.
5. BLOCKS NO. 8 MUST BE ORIENTED WITH SMALLER DIA. BORE TOWARDS OUTLET END.

DECLASSIFIED

AS BUILT

RESTRICTED DATA

APPROVED FOR CONSTRUCTION 9-5-51

[redacted]

NO.	DESCRIPTION	BY	DATE	APPD.	DATE	APPD.
1	REVISED FOR "AS BUILT" [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

REVISIONS

SCALE:	APPROVALS BY	DEPT.	DATE
DRAWN BY [illegible] 6-6-51	[illegible]	[illegible]	6-23-51
CHECKED BY [illegible]	[illegible]	[illegible]	6-23-51
[illegible] 8-11-51			
[illegible]			
ENG. REP. NO. 105-C-1-4380			
PROJECT NO. C-431-B	[illegible]	[illegible]	[illegible]

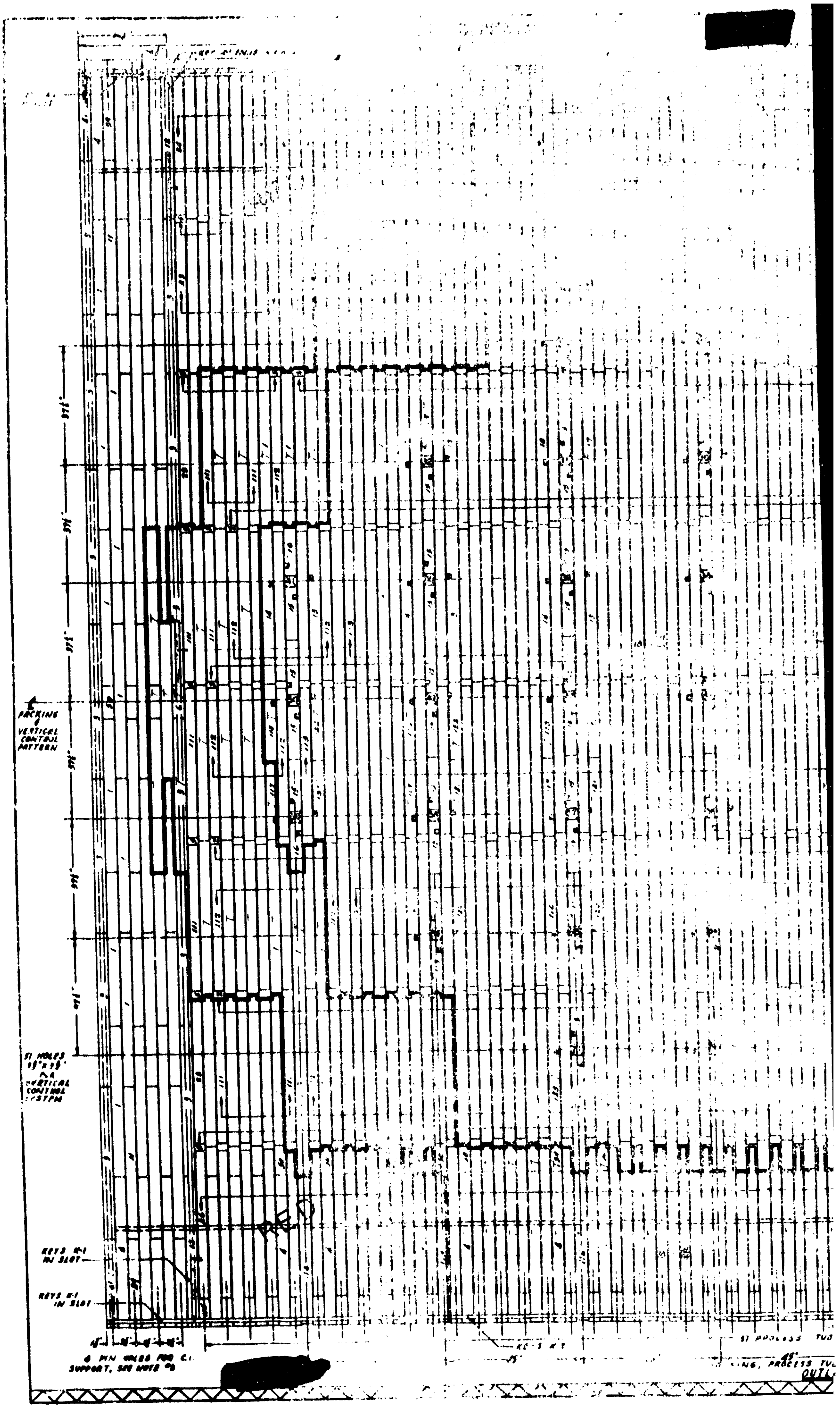
DWG. NO.	TITLE
P-7680	PACKING BLOCK LAYERS GEN. ARRG'T.

REFERENCE DRAWINGS

1601

GENERAL ELECTRIC CO.
HANFORD WORKS
PACKING BLOCK LAYERS
ARRANGEMENT PLAN
LAYER 55

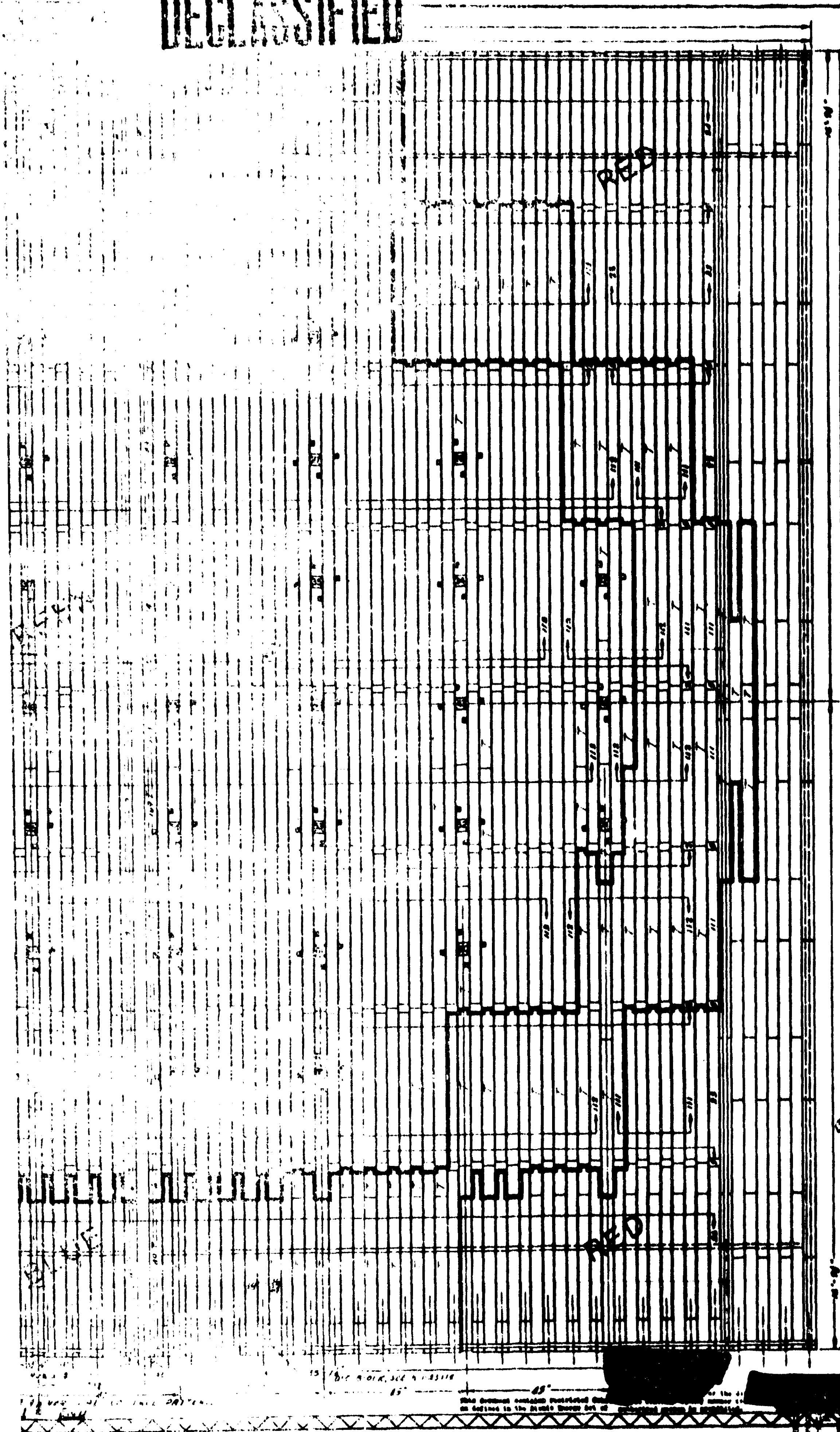
BLDG. NO. 105-C DWG. NO. P-8496



PACKING
VERTICAL CONTROL PATTERN
KEYS K-1 IN SLOT
KEYS K-1 IN SLOT

[redacted]

DECLASSIFIED



MATERIAL LIST

BLOCK NO.	QUANTITY	RED	BLUE	WHITE	GREEN
1	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]				[illegible]
111	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]
[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		
TOTAL	[illegible]	315	260		[illegible]
[illegible]	[illegible]				[illegible]
[illegible]	[illegible]				[illegible]
[illegible]	87				
[illegible]	87				

NOTE:

1. FOR GENERAL INFORMATION & BLOCK DETAILS, SEE H-?-?.
2. BLOCK NUMBERS, AS SHOWN DIRECTLY APPLIED TO A ROW OF BLOCKS ARE TYPICAL FOR ALL SIMILAR ROWS
3. CAST IRON SUPPORT-PIN HOLES, AS DIMENSIONED, ARE TYPICAL FOR ALL FOUR CORNERS.
4. PROCESS TUBE ROW BLOCKS HAVE THEIR NUMBERS INDICATED BY BRACKETS, THUS [bracket] ALL SUCH INCLUDED BLOCKS HAVE THE SAME NUMBERS AS THOSE AT THE BRACKET ENDS
5. ALL KEYS ARE GREEN MATERIAL
6. ALL DIMENSIONS ARE NOMINAL EXCEPT THOSE IN ... WHICH ARE 'AS BUILT'
7. TUBE ROW BLOCKS ARE ALL TS MAT'L EXCEPT DET'S ... WHICH ARE CS MAT'L.
8. ALL BLOCKS MARKED T IN THE BLUE & GREEN ZONES ARE TS MAT'L. THE REMAINING BLOCKS IN THESE ZONES ARE SPEER MAT'L

AS BUILT

CHECKED FOR 'AS BUILT 'KE' PROJECT COMPLETE R8016

REVISIONS

APPROVALS

R 8016

U. S. ATOMIC ENERGY COMMISSION
HANFORD WORKS
GENERAL ELECTRIC

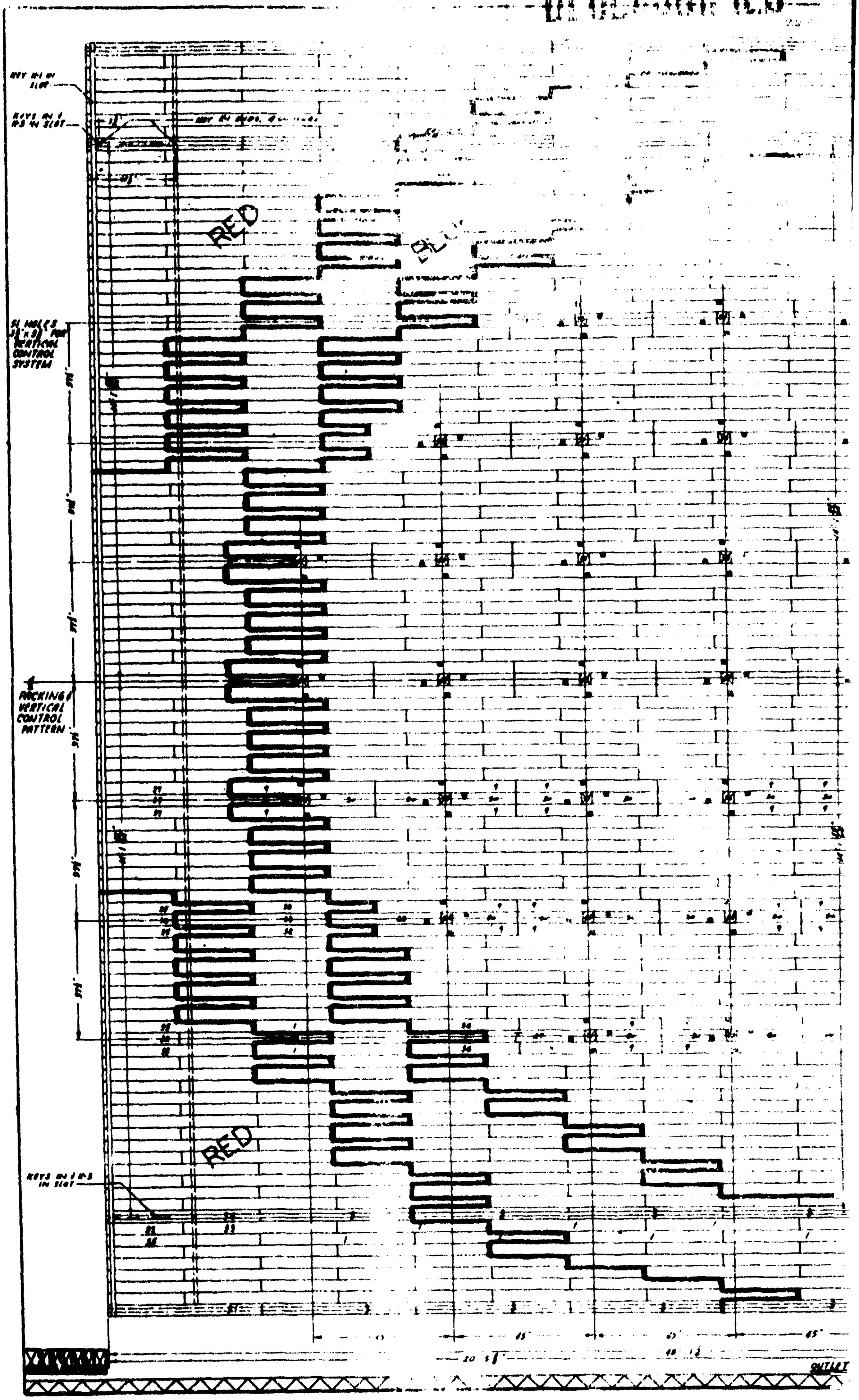
1601

PACKING BLOCK LAYERS
ARRANGEMENT PLAN
LAYER 03

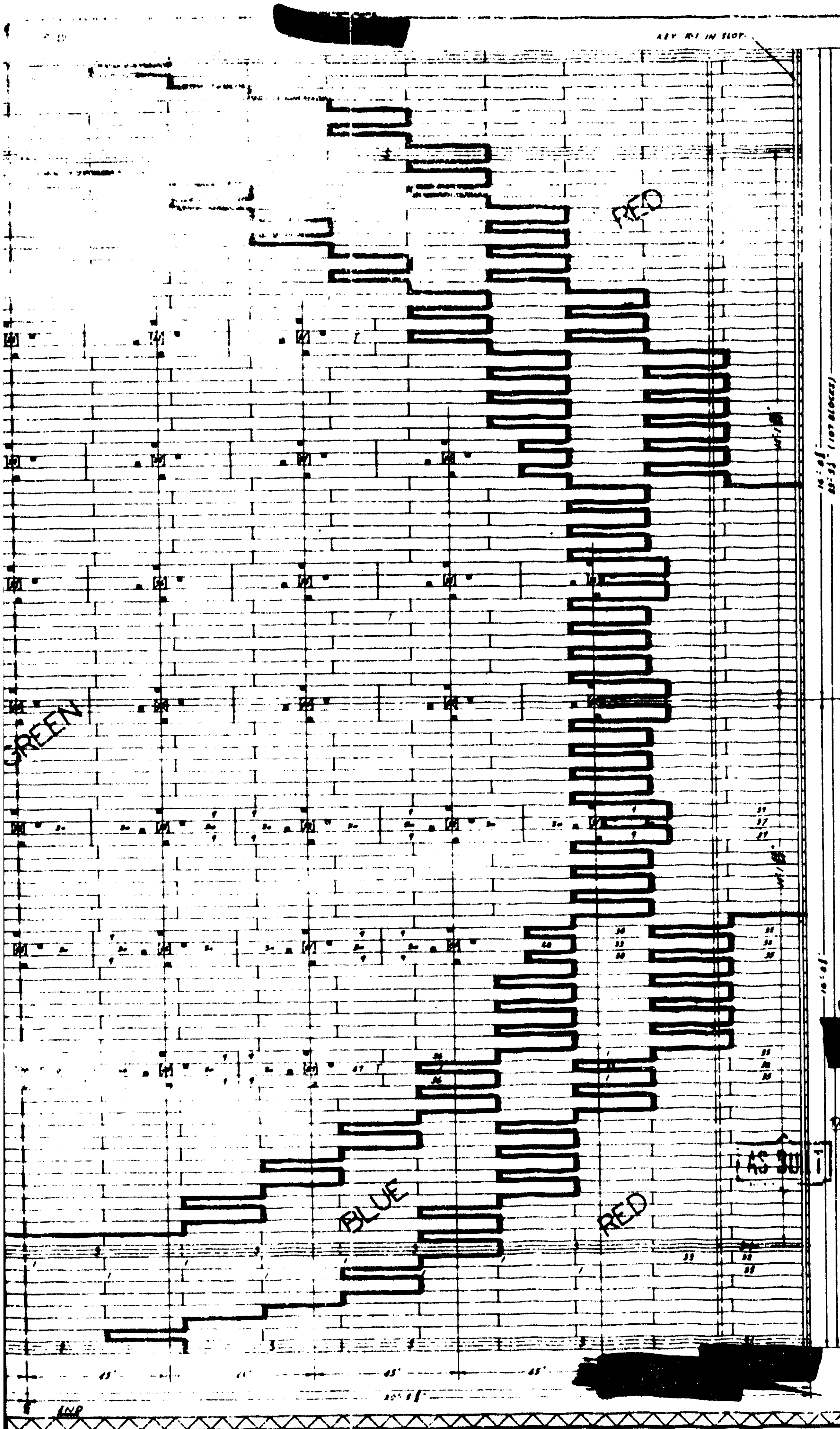
REACTOR FACILITIES

[redacted]

DECLASSIFIED


RED
PACKING / VERTICAL CONTROL PATTERN
RED
OUTLET

[redacted]



[redacted]

MATERIAL LIST

[illegible]

NOTES

1. ALL BLOCKS MARKED 'S' IN THE BLUE ZONE ARE SPEER MAT'L. THE REMAINING BLOCKS IN THIS ZONE ARE TS MAT'L.
2. ALL BLOCKS MARKED 'T' IN THE GREEN ZONE ARE TS MAT'L. THE REMAINING BLOCKS IN THIS ZONE ARE SPEER MAT'L.
3. DIMENSIONS IN 64THS ARE 'AS BUILT.'
4. FOR GENERAL INFORMATION & BLOCK DETAILS, SEE H-1-21410
5. BLOCK NUMBERS, AS SHOWN DIRECTLY APPLIED TO A ROW OF BLOCKS, ARE TYPICAL FOR ALL SIMILAR ROWS
6. ALL DIMENSIONS ARE NOMINAL

ALL KEYS ARE GREEN

[redacted]

REV.	DESCRIPTION			
1	CHECKED FOR 'AS BUILT' AS PROJECT COMPLETE			

REVISIONS

SCALE: NONE "C"

APPROVALS

ENGINEER REQUEST NO. R-8016

PROJECT NO. CA-512-R

U. S. ATOMIC ENERGY COMMISSION
HANFORD WORKS
GENERAL ELECTRIC

1601

PACKING BLOCK LAYERS
ARRANGEMENT PLAN
LAYER 84

PROJECT TITLE: 100-K REACTOR FACILITY

BLDG NO. 105-KE | DWG NO. H-1-21504 KE

DATE FILMED

6/22/94

END

4