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INTERIM REPORT

PILE GRAPHITE SAMPLING PRODUCTION TESTS

PILE GRAPHITE EXPANSION

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BY

E. P. WAREKOIS AND P. H. REINKER
TECHNICAL DIVISIONS

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INTERIM REPORT ON PILE GRAPHITE SAMPLING
PRODUCTION TESTS
PILE GRAPHITE EXPANSION

by

E. P. Warekois and P. H. Reinker
Pile Engineering Section
Pile Technology Division

October 23, 1950

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INTERIM REPORT ON PILE GRAPHITE SAMPLING PRODUCTION TESTS

Production Test 105-237-P, including Supplements A through E
Production Test 105-276-P, including Supplement A
Production Test 105-288-P, including Supplement A
Production Test 105-329-P
Production Test 105-373-P

and

FINAL REPORT ON

Production Test 105-237-P, including Supplements A through C
Production Test 105-276-P, including Supplement A
Production Test 105-329-P

INTRODUCTION

This report constitutes a summary and discussion of radiation damage to graphite and its effects on pile distortion. The data covered in this report consist of that obtained from some pile motion measurements and tube bowing measurements, but particularly of that information obtained from direct sampling of pile graphite, as outlined in Pile Technology Division Production Tests ⁽¹⁾.

-
- (1) (a) Production Test 105-237-P, Total Stored Energy of Process Tube Blocks, HW-12156, January 14, 1949, P. H. Reinker
(b) Production Test 105-237-P, Supplement A, Stored Energy of Process Tube Blocks after Pile Annealing, HW-13661, June 22, 1949, P. H. Reinker
(c) Production Test 105-237-P, Supplement B, Pile Graphite Sampling, HW-15506, December 27, 1949, E. P. Warekois
(d) Production Test 105-237-P, Supplement C, Pile Graphite Sampling, HW-16072, February 17, 1950, E. P. Warekois
(e) Production Test 105-237-P, Supplement D, Pile Graphite Sampling, HW-17805, May 15, 1950, E. P. Warekois
(f) Production Test 105-237-P, Supplement E, Pile Graphite Sampling, HW-17834, May 18, 1950, E. P. Warekois
(g) Production Test 105-276-P, Graphite Core Samples, HW-14410, September 9, 1949, T. P. Heckman
(h) Production Test 105-276-P, Supplement A, Graphite Core Samples, HW-15273, December 5, 1949, T. P. Heckman
(i) Production Test 105-288-P, H Pile Graphite Sampling, HW-15090, November 14, 1949, P. H. Reinker
(j) Production Test 105-288-P, Supplement A, DR Pile Graphite Sampling, HW-18804, September 11, 1950, P. H. Reinker
(k) Production Test 105-329-P, Filler Block Graphite Samples, HW-17400, March 30, 1950, P. A. Johnson
(l) Production Test 105-373-P, Tube Block Boring at DR Pile, HW-18818, September 12, 1950, P. H. Reinker

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This report summarizes the data accumulated to date, and correlates the effects of operating conditions to radiation damage. The report also indicates the type of information that is needed to permit a better understanding of the need and development of future corrective measures to be applied to the present piles. It also provides a basis for further experimental work necessary to place the conclusions on a firm foundation.

SUMMARY

Direct pile graphite sampling techniques have been developed to obtain valuable information on the status of the graphite in the present piles. Data obtained by laboratory measurements on samples cut from the piles by these sampling techniques provide the basis for the conclusions presented in this report.

The analysis of the data is sufficiently firm to explain the trends of physical expansion of the pile packing with operation, in terms of what is known about the graphite radiation damage phenomenon.

Expansion of the graphite resulting from pile exposure is shown to be primarily dependent upon the temperature of irradiation. The expansion is some inverse function of the exposure temperature and, except over a very short region in the piles where the neutron flux approaches zero, the variation in flux is not the significant factor in graphite expansion and can be almost eliminated from consideration when large temperature differences exist.

Under normal conditions of operation, relatively large temperature differences do exist in the piles. This has led to differential rates of expansion which produced critical expansion regions in both tube block and filler graphite.

The use of carbon dioxide in the pile gas atmosphere has resulted in temperatures sufficiently high in the central zone to effect nuclear annealing of all the graphite in the lattice, including that in the relatively cool bore region. However, even a 100 per cent concentration of carbon dioxide does not increase the temperatures sufficiently high in the fringe zones to stop the expansion, and thus it is these regions which will become the critical regions in both the old and in the new piles.

At the H Pile, the initial 100 per cent carbon dioxide concentration in the pile gas atmosphere has reduced the rate of expansion in the bore regions in the central zone to a greater extent than in the fringe, with the result that the fringe zone is currently expanding at about twice the rate of the central zone. Even if this

maximum expansion continues at the same rate, the undercut tube blocks at the H Pile will accommodate this expansion for at least 13 years of operation under the present conditions. This is not the case at the DR Pile, and fringe zone expansion of the tube blocks may lead to serious packing distortion. One feasible corrective measure was applied, on an experimental basis, to the DR Pile prior to startup. This consisted of oversizing the process tube bores in one potentially critical expansion region.

DETAILS AND DISCUSSION

This section of the report presents in narrative, tabular, and graphical form, the more significant features of the graphite expansion problem as it applies to the physical condition of the piles. The pertinent facts regarding graphite radiation damage and its effects and control in the Hanford Piles were summarized in a recent report⁽²⁾. The present report contains additional and more specific data obtained from the graphite mining program.

If the discussion is restricted to the most important effect of radiation damage - the physical expansion of the graphite - then the following brief outline of the two most significant factors which control this expansion will provide a basis for the data analysis which follows:

A. Temperature Coefficient of Damage

The rate at which graphite damage occurs is very strongly dependent upon the temperature of irradiation. At an exposure temperature of 250°C. or higher, the expansion rate is almost certainly less than 5 per cent of the rate at 25°C., under equivalent neutron flux conditions. The present test facilities have permitted the evaluation of this "temperature coefficient" at only the low and high temperature limits. Experiments are in progress to investigate the entire temperature range. Data obtained from monitoring work on the distortion of the pile packing have shown that a small temperature differential of the order of 25°C., produced by the heating of the cooling water in its passage through the piles, is effective in lowering the overall rate of damage by about 30 per cent.

(2) "Graphite Radiation Damage - Its Effects and Control in the Hanford Piles", HW-16075, A. A. Johnson, W. R. Lewis, P. H. Reinker, February 20, 1950

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The rate of expansion, at least to the first approximation, is a linear function of the fast neutron flux, provided other variables, such as ambient exposure temperature, remain fixed. The physical expansion of the pile packing, from front to rear, should thus follow approximately a cosine function, in line with the flux distribution from front to rear. The analysis to be presented will show that, except over a very short distance in the pile where the flux approaches zero, the variation in flux is not the significant factor in graphite expansion, and can be almost eliminated from consideration when large temperature differences exist.

B. Nuclear or Pile Annealing

Although it is impossible, in the present production piles, to raise the temperature of the graphite to a value high enough to effect any appreciably useful amounts of thermal annealing, results⁽³⁾ have been obtained on a phenomenon of much more theoretical and practical interest, which indicate that the expansion produced by neutron irradiation can also be annealed by neutron irradiation, if the temperature of exposure is raised to values that are operationally practical. A temperature rise during exposure will not only reduce the rate of expansion, but will, if high enough, reverse at a very appreciable rate the damage previously produced at a lower temperature. Other important physical properties such as thermal conductivity⁽³ⁱ⁾, stored energy^(3g), and the crystal expansion^(3h), follow, with minor variations, the recovery of physical expansion^(3b). This, then, is the explanation, as proposed in other memoranda and reports, for the beneficial effects of carbon dioxide, which has principally the effect of producing higher temperatures in the bore region of the tube blocks of the pile, the region in which most of the expansion has occurred.

(3) Technical Activities Reports - Physical Chemistry Group - Pile Technology Division

- (a) January Report, HW-17012, February 27, 1950
- (b) February Report, HW-17373, March 29, 1950
- (c) March Report - HW-17578, April 19, 1950
- (d) April Report - HW-17862, May 22, 1950
- (e) May Report - HW-18163, June 28, 1950
- (f) June Report - HW-18484, August 2, 1950
- (g) July Report - HW-18666, August 23, 1950
- (h) August Report - HW-19037, October 4, 1950
- (i) September Report - HW-19160, October 20, 1950

C. Graphite Mining⁽⁴⁾

Graphite mining operations were initiated early in 1949 to obtain direct information on the status of the graphite in the bore of the tube blocks of the piles; this method consists of scraping the surface of the bore with a cutter and removing the powdered samples for laboratory studies. The value of this technique was considerably enhanced during the last several months by extending the "spot mining" to a complete front to rear mapping of the tube block bore graphite. Additional information has been obtained from solid pieces of graphite removed, with equipment designed by the Mechanical Development Group, from filler blocks, and from core samples representative of the cross section of tube blocks from edge to bore. The nature of the samples, for the most part, permitted only X-ray and stored energy measurements, with any degree of convenience. Fortunately, X-ray data can be correlated with stored energy and physical expansion by appropriate corrections obtained experimentally from laboratory studies, as shown by Figure I. This correlation is based on the test hole data reported in Interim Report No. 9⁽⁵⁾, on data taken on CSF graphite at relatively low exposures, and on some stored energy data on mined graphite; these data indicate that extrapolation to higher exposures is permissible.

D. Tube Bowing Measurements

The best overall distortion measurements of the packing are obtained from tube bowing measurements. With the recent development of the mercury manometer by the Mechanical Development Group, traverses⁽⁶⁾ have been obtained with considerably higher precision, and consequently the data obtained over relatively short periods of time can be analyzed with more confidence.

Figure 2 is a composite representation of typical tube bowing measurements taken at the D Pile, in tube 4674, from July, 1946 to June 1950. These curves show clearly the overall result of the expansion of the individual blocks of the packing, but the curves do not adequately represent the relative graphite damage from front to rear. The curves show that the rate of overall expansion of the

(4) The writers were assisted by H. H. Burton, D. H. Curtiss and L. A. McClaine of the Pile Engineering Section

(5) Interim Report No. 9 - Effects of Pile Irradiation on Graphite - H. A. Baskin, H. A. Fowler, G. P. Kerr, D. H. Curtiss, E. P. Warekois, HW-13117, April 20, 1949

(6) Measurements were taken by P. A. Johnson and J. B. Cole of the Pile Engineering Section

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pile decreased slightly, with increasing exposure, even before the addition of carbon dioxide to the pile atmosphere in February of 1948. This decreased rate was caused by the increase in graphite temperatures as a result of the decrease in the thermal conductivity with exposure. During this period prior to 1948, the distortion became progressively skewed about the centerline; this was caused by the temperature difference between the front and rear regions of the pile resulting from the heating of the cooling water on its passage through the pile. During the period of increasing carbon dioxide concentrations in 1948, 1949, and 1950 (See Tables 7, II, and III) the expansion at the centerline (at 21 feet) decreased, while the point of maximum expansion moved toward the front face. Data taken during the last several months, with the D Pile at 100 per cent carbon dioxide, have indicated a slight annealing even in the critical region of 10 to 12 feet from the inlet side. This is encouraging, but it is too much to hope that continued exposure will not result in continued expansion in the region closer to the front face.

The only available tube bowing measurements ⁽⁶⁾ from the H Pile is included in Figure 2. This represents the overall stock displacement caused by the filler layer and filler block expansion. This type of packing distortion again indicates the influence of the temperature gradients, from front to center, on the relative rates of expansion in the fringe and central portions of the H Pile, even though operation has been entirely with a 100 per cent carbon dioxide atmosphere.

E. Tube Bore Mining

Tube bore mining operations give the state of damage of the graphite along the length of an individual channel. Typical curves obtained at the various piles are given in Figures 3 and 4. An extreme gradient of crystal damage has always been noted at a distance of 3 feet from the edge of the packing, which corresponds to a position opposite the edge of the first metal slug in the column. The influence of the cooling water in raising the temperature of the graphite in the rear zones of the pile is shown by the less sharply defined gradient of damage in this region. The values of total stored energy of the samples from 2486-B, included in Figure 4, also indicate the same type of gradient along the channel. It is reasonable to assume, by comparing the shapes of these curves with those presented in Figure 2, that the present "roller coaster" configuration resulted

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from the annealing of the central graphite by the introduction of carbon dioxide. The data from the F Pile, presented in Table I and Figure 3, show conclusively that this is the case.

Graphite samples removed from the bore of metal process tube position 1973-H, after an accumulated exposure of 587 MD/CT at 100 per cent carbon dioxide concentration, show already the same distribution of crystal damage now present in the older piles. This is shown by Figure 4. Because of the undercut tube blocks, the bowing traverse of 4674-H is the resultant only of filler block and filler layer expansion; thus it can be compared to the crystal damage gradient only in regard to the general distribution of the damaged areas. The higher central graphite temperatures have suppressed the expansion in this region as compared to that in the fringe zones. The overall rate of crystal expansion based on tube data from 1973-H (3.6% /1000/MD/CT) is less than that for the same region in tube 2486-B (4.6% /1000/MD/CT). Even if this maximum rate of expansion continues, the 3 per cent undercut of the tube blocks at the H Pile will accommodate this expansion for at least 13 years under the present operating conditions.

Corrective measures, deduced from this type of experimental data, have been presented in a recent memorandum⁽⁷⁾. Since that time, experimental steps have been taken to demonstrate the feasibility of one measure in preventing expansion in the critical regions of a new pile. Four tube block bores at the DR Pile were oversized⁽⁸⁾ in accordance with the details sketched in Figure 5. All previous data and calculations⁽⁹⁾ indicate⁽¹⁰⁾ that the enlarged gas annulus will result in temperatures sufficiently high to retard the rate of expansion in this critical region. The tubes will be mined at suitable intervals to determine the effects of the enlarged annulus; regular metal columns with the standard nominal bore will be monitored for comparison.

(7) "Pile Graphite Expansion", E. P. Warekois, P. H. Reinker, HW-18453, July 24, 1950

(8) Equipment was designed by W. K. Alexander and D. F. Foley of the Pile Engineering Section

(9) Calculations were made by H. H. Greenfield and M. W. Carbon of the Pile Engineering Section

(10) Refer to Production Test 105-373-P

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F. Test Hole Graphite Samples

Three 4-foot sections of filler layer keyway bars were removed from the front the front side of the A test hole at the D Pile by the Mechanical Development Group. The details of this sample position are included in Figure 6. The gradient of crystal damage, and the thermal conductivity⁽¹¹⁾, of samples taken along the length of the bars is included. The damage, measured by the crystal expansion as well as the reduced conductivity, is a maximum at a point one foot in from the graphite reflector; this point is directly under tube row 95, with tube row 96 representing the outer limit of the side to side metal charge. The fast neutron flux at this point is estimated to be about 25 per cent of the central flux. These data indicate that a critical expansion region also exists at the sides of the piles in the cooler region even in a reduced fast flux region.

G. Location of Damage

All data obtained from the pile graphite sampling program indicate that the rate of damage in the cooler portions of the piles is greater than the rate in the central zones.

The crystal damage, as measured in the A test hole filler layer, throughout the central flattened zone was uniform and of the order of 2 per cent, compared to a maximum expansion of 5 per cent one foot from the fringe of the reflector.

All crystal damage gradients taken along any process tube position, including that at the H Pile, indicate the damage is more extreme in the regions near the faces of the piles. The data from positions 2279 and 2291-D, shown in Figure 4, indicate that damage to the graphite is more extreme in tube position 2291-D, located in a lower flux but low temperature region of the pile. The maximum expansion at approximately the 12-foot point in the process tube bore is 15 per cent for tube 2291-D compared to a 13 per cent expansion in tube 2279-D. The greater degree of damage in the cooler tube, position 2291-D, is also evident from data taken from the cores removed from these two positions, as shown by Figure 7. The damage in process tube positions at the F Pile indicates that the fringe tube 1387, with an accumulated exposure of 2930 MD/CT, is as damaged as the central tube 2675, with an exposure of the order of 3200 MD/CT.

(11) Measurements of thermal conductivity were made by H. A. Baskin of the Pile Engineering Section

H. Annealing Effects

Irradiation at elevated temperatures of the order of $250^{\circ}\text{C}.$, or higher, produces a very apparent reduced rate of damage, probably because of the increased annealing effect.

The central zone filler layer graphite removed from the A test hole, after several years of exposure at ambient pile temperatures, had only 2 per cent crystal expansion; this magnitude of expansion could be obtained during 300 MD/CT of exposure in the same test hole if irradiations were performed at $30^{\circ}\text{C}.$

Position 2286-D had been operated at ambient pile temperatures for about 2 1/2 years following its use as a metal column for an exposure period of about the same length of time; this exposure period was equivalent to that of 2486-B. These data are given in Figure 4. If an initial state of damage is assumed for 2286-D to be that obtained for 2486-B, then the difference between the curves represents the amount of annealing accomplished by allowing 2286-D to run at ambient pile temperatures for 2 1/2 years. This is a conservative estimate, as the 2486-B position was mined when the B Pile gas was 100 per cent carbon dioxide, and thus the central zone damage is probably lower than that of 2286-D prior to its use as a gas tube. Even so, the data show significant annealing effects in the central portion of the pile, but little or no annealing in the cooler regions near the front and rear faces. The low point at the center line for the 2286 position may represent nearly the maximum amount of pile annealing possible at that temperature of exposure.

The gradients of crystal damage along the two core samples removed from the D Pile in May, 1950, are less than the gradient of damage obtained from a core sample removed about 7 months previously. These data are shown in Figure 7. During this period, the increases in carbon dioxide concentration were effective in reducing the gradient of damage along the entire length of the core (from tube block edge to the bore) but no significant annealing was observed for the tube block edge. The higher values for the core removed from 2291 compared to 2279 show again the influence of the lower temperature in the first case, which results in higher damage, although the neutron flux is about 40 per cent lower.

Table II and Figures 4 and 7 summarize most of the data, from the D Pile, which show that the additions of carbon dioxide have raised the tempera-

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tures of the bore graphite to such an extent that significant pile annealing is occurring at this location in the central regions of the pile. The progressive annealing of the tube bore graphite over a period of seven months is shown by the data in Table II. The recovery of 2273 compared to 2282 is of the same magnitude as the recovery of 2279 compared to 2273. A carbon dioxide addition occurred between each of the sampling dates, but the temperature rise itself would not result in any significant thermal annealing. The recovery during the operating periods between the mining of 2273 and 2282 was also indicated by a decrease of total stored energy from 619 to 525 cal./g. and a decrease from 525 to 447 cal./g. during the period between the mining of 2273 and 2279. At the same time, measurements on 2290 and 2291 showed that expansion in this cooler region of the pile was continuing.

Table I and Figure 3 summarize the data from the F Pile. Three tube positions were mined recently, all of which were nominally in the flattened zone, with 1387 lying on about the edge of the zone. Very good agreement of the mining data was obtained, with 1387 showing slightly more damage as it was from the edge of the flattened zone and thus in a slightly cooler region of the pile. The decrease in expansion with carbon dioxide additions at F Pile is shown by the difference between 1884, mined in March of 1949, and the three tubes mined in July of 1950. The bore graphite recovered about 20 per cent during this additional exposure period of more than one year, as a result of the increased carbon dioxide concentrations. This difference cannot be attributed to thermal effects, because the carbon dioxide additions did not raise the bore graphite temperature sufficiently to result in significant thermal annealing.

The data presented in Figure 3A show the effect of nuclear annealing on the 1884-F graphite samples. The mined graphite samples from 1884-F were thermally annealed in a laboratory oven for a period of five days at a temperature of 375°C. The sample mined in March of 1949 annealed to a value that agreed with the crystal spacing measured for the graphite mined in May of 1949, after the period of pile operation at ambient pile temperature. The laboratory thermal anneal had little effect on the previous pile annealed sample. The two samples of 1884-F graphite were then recharged into a test hole operating at about 335°C., which was about 40°C. lower than the thermal annealing temperature, and discharged after periods of irradiation at this lower temper-

ature. The additional pile exposure at 335°C. has produced continued recovery in these samples, as noted by a decrease in both the C_0 crystal spacing and the total stored energy.

CONCLUSIONS

Direct pile graphite sampling has provided valuable information on the status of the graphite in the piles, and has permitted a reasonably firm analysis of the trends in expansion as a result of the various operating variables.

The analysis of this data, though qualitative in many respects, is sufficiently firm to explain the trends of pile graphite expansion with operation, in terms of what is known from laboratory studies.

The analysis shows that graphite expansion is some inverse function of the temperature of irradiation; the relative fast neutron flux can be almost eliminated from consideration if large temperature differences exist. This condition of relatively low flux, but low temperature, exists in the fringe regions of the piles in both filler blocks and tube blocks, and is thus producing critical regions of graphite expansion. The use of carbon dioxide in the pile gas atmospheres has resulted in temperatures sufficiently high to retard, and in some cases anneal, graphite expansion in the central zones of the piles, including the relatively cool bore region of the lattice. However, even a 100 per cent carbon dioxide concentration is not sufficient to stop expansion in the cooler fringe regions of the piles. Data from the H Pile indicate that expansion is occurring, but the design of the pile is such that at the present maximum rate, the tube block expansion can be accommodated for about 13 years, under the present operating conditions, without producing any overall packing distortion. This is not the case at the DR Pile, and fringe zone expansion of the tube blocks may lead to serious packing distortion.

Irradiations at elevated temperatures are effective in producing reduced rates of expansion or in many cases annealing of the previous damage. The overall filler block expansion is very much less than tube block expansion, but even in this graphite the distribution of damage is such that critical regions are being produced in the fringe zones. Process tubes operating at higher temperatures through the use of gas atmospheres or non-metal charges have annealed in the bore of the channel in the central zone, but with little effect on the fringe damage.

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The only feasible curative measure for graphite expansion consists of raising the graphite temperatures, particularly in the outer fringe zones. Several methods have been suggested to accomplish this. One in particular, the over-sizing of the bore diameter, has already been applied experimentally at the DR Pile. The other methods, such as special metal tube loadings to raise the graphite temperatures in the fringe zones, will require considerable investigation to determine the technical and economical feasibility of such techniques.

The nature of the damage to the graphite is such that complete recovery of the original structure probably will never be attained under the present temperature limits of the present piles. Therefore, future graphite piles should be designed to operate at uniformly high temperatures throughout the graphite to prevent or diminish the rate of expansion. Because, in all probability, a non-expanding graphite will not be developed, design considerations should also allow sufficient space to accommodate expansion which cannot be prevented.

E. P. Warekois
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lb

TABLE I
105-F PROCESS TUBE DATA

Process Tube No.	Date Mined	Total Power Output of tube (MW)	Exposure MD/CT MD/CT= (MW)/(8)(1.42)	Type of Sampling	G _A ±0.02	Total Stored Energy cal./g.	Remarks
Start up 2-45 CO ₂ Addition started 12-48 40% on 2-15-49							
3169 F	2-19-49	--	2390*	Point 20' - 22'	7.29	400	* 4-15-45 to 7-20-45 metal charge - exposure 330 MD/CT: 7-20-45 to 2-19-49 poison charge equiv. exp = 2060 MD/CT
1884 F	3-15-49 *	211.35	2400	Point 20' - 22'	7.57	566	* Metal charged pushed - tube remaining empty
1884 F	5-5-49 *	--	2495*	Point 20' - 22'	7.36	466	* 95 MD/CT additional exposure at ambient pile temperature
CO ₂ Increased to 60% 5-15-45 to 6-1-49 CO ₂ Increased to 80% 4-28-50 to 5-12-50							
2584 F	7-12-50	301.29	3423	Complete Traverse 20'-----	7.39	---	---
2675 F	7-12-50	280.81	3190	Complete Traverse 20'-----	7.40	---	One charge during history consisted of ORNL samples and depleted charge(4 slugs)
1387 F	7-19-50	257.88	2930	Complete Traverse 20'-----	7.41	---	---

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TABLE II
105-D PILE GRAPHITE DATA

Process Tube No.	Date Mined	Total Power Output of tube (MW)	Exposure MD/CT MD/CT = (MW)X8(1.42)	Type of Sampling	Co A ± 0.02	Total Stored Energy cal./CM	Remarks
Start up 12-44 Co ₂ Additions started 2-48 40% on 9-48							
3469-D	4-28-49	--	3300*	Point 20' - 22'	7.14	297	3-29-45 to 2-11-47 metal charge exposure = 1540 MD/CT: 2-11-47 to 4-28-49 gas tube equiv. metal exp. = 1760 MD/CT
2292-D	10-26-49	296.78	3370	Point 20' - 22' and Core	7.57 7.12*	6.19**	* Tube Block Edge ** Bore Graphite
Co ₂ Increased to 60% 11-1-49 to 11-15-49							
2273-D	2-8-50	321.55	3653	Point 16'	7.46	525	---
2290-D	2-8-50	265.36	3014	Point 16'	7.47	552	----
Co ₂ Increased to 80% 3-1-50 to 3-15-50 Co ₂ Increased to 100% 5-1-50 to 5-21-50							

TABLE II (Cont'd)
105-D FILE GRAPHITE DATA

Process Tube No.	Date Mined	Total Power Output of tube (MW)	Exposure MD/CT (MW)(8)(1.42)	Type of Sampling	Co o A ± 0.02	Total Stored Energy cal./CM	Remarks
2279-D	5-24-50	340.89	3873	Traverse to "A" T. H. and Core	7.36 7.15*	447**	* Tube Block Edge ** Bore Graphite
2291-D	5-24-50	251.12	2853	Traverse to "A" T. H. and Core	7.57* 7.45**	---	* Bore Graphite o core end = 7.72 A ** Tube block edge
2286-D	6-14-50	183.80	2088 3288	Complete Traverse 20'-----	7.09	---	12-17-44 to 2-16-48 metal charge ex- posure 2088 MD/CT 2-16-48 to 6-14-50 gas tube equiv. metal exp. = 1200 MD/CT
"A" Hole Filler Layer	7-50 8-50	--	--	Filler Layer Keyway	6.82*	--	* Central zone See Figure 6 for complete traverse

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TABLE III
105-B PROCESS TUBE DATA

Process Tube No.	Date Mined	Total Power Output of tube (MW)	Exposure MD/CT MD/CT = (MW)(8)(1.42)	Type of Sampling	Co o A ±0.02	Total Stored Energy cal./CM	Remarks
Start up 9-44 Co ₂ Additions started 1-49 100% on 2-50							
2486-B	4-19-40	187.34	2128	Complete Traverse 8' 10' 13' 15 1/2 21 26 1/2 32'	-- 6.70 6.73 7.29* 7.34 7.26 7.25 7.30 7.01	-- 47 350 448 461 446 454 77	*Diffraction tracing indicated sample mixture by two distinct maxima

105-H PROCESS TUBE DATA

Start up 9-49
Co₂ Concentration 100%

2577-H	1-5-50	4	45.4*	Point 20' - 22'	6.70	34	* 9-49 to 11-22-49 metal charge exp. = 45.4 - empty (tubeless) to 1-5-50 *Comparison value from 2575-H metal tube
2577-H	9-6-50	--	580 *	Complete Traverse	6.70	--	
1973-H	9-6-50	51.59	587	Complete Traverse 12' 21' 30'	6.85 6.78 6.79

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Figure 2... Vertical Deflection of
Process Tubes 4674 Da H

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Figure 3... Crystal Expansions in the Bore of Process Tubes
F Pile

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Figure 4..... Crystal Expansions in the Bore of Process Tubes B- D- H Pile

91-D (5-24-50)

82-D (10-26-49) St. E. 619 cal/gm

90-D (2-8-50) " 552 "

73-D (2-8-50) " 525 "

279-D (5-24-50) " 447 "

Figure 5--

Process Tubes 2580 2581 2680 2681 at DR Pile
Oversized, as sketched, previous to Start Up.
Refer to Production Test 105-373 P.

Figure 6- Radiation Damage Along 'A' Test Hole at D Pile

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Figure 7--
Crystal Expansion in Process Tube Blocks

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