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GRAPHITE BURNOUT

INTERIM REPORT

ON IP-25-A (PT-105-532-E)

B. A. RYAN and D. R. de HALAS

MARCH 15, 1960

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INTERIM REPORT ON IP-25-A (PT-105-532-E)

By

B. A. Ryan and D. R. de Halas

Materials Development
Reactor and Fuels Research and Development Operation

March 15, 1960

HANFORD ATOMIC PRODUCTS OPERATION
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GRAPHITE BURNOUT
INTERIM REPORT ON IP-25-A (PT-105-532-E)

INTRODUCTION

Graphite reacts with such gases as CO_2 , O_2 , or water vapor to form gaseous oxides of carbon. In the case of CO_2 -graphite interaction, the reaction rate is not significant until about 550 C. Water oxidizes graphite, very roughly, three times faster than CO_2 .⁽⁸⁾ Air will oxidize graphite appreciably at temperatures below 500 C.

Graphite removal from Hanford reactors is very important, since graphite is used both as a structural support and a moderator for neutrons. Griggs has shown that small graphite samples oxidized to 10 per cent weight loss had only about one-half their original compression strength.⁽¹⁾ Hence, the longevity of the reactors depends to a great extent on maintaining a low graphite oxidation rate.

A means of monitoring the extent of graphite loss, i. e. , the burnout rate, is necessary to establish future reactor operational standards. Presently, weighed samples of reactor grade graphite are placed along the length of an empty process channel in each reactor. Thus, a sample is exposed to the reactor's ambient conditions of power level, moderator temperature, and gas composition. This program was initiated in the vicinity of June, 1953 by Woodley.⁽²⁾

This report presents data on graphite burnout obtained from in-reactor experiments authorized under IP-25-A (PT-105-532-E) from August, 1957⁽³⁾ to January, 1960. Burnout rates are obtained by a direct measurement of the weight loss of control graphite samples exposed to the reactor atmosphere.

SUMMARY AND CONCLUSIONS

Burnout rates of graphite in the reactors are influenced primarily by the oxygen and moisture contents of the reactor gas. Water can cause further attack by depositing impurities on the graphite which will then catalyze oxidation.

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Reactor operation is not restricted by CO₂ oxidation of graphite below approximately 580 C. However, at higher temperatures, CO₂ oxidation can severely limit operation. Small amounts of air are harmful over about 200 C and the effect increases with temperature.

EXPERIMENTAL METHOD

All samples used in this monitoring program were machined from 4-1/4 x 4-1/4 x 50-inch bars of reactor grade graphite. Generally, KC, TSGBF or CSGBF graphite samples were used; however, in some instances CSF and WSF were exposed with the normal samples, and some previously irradiated samples were re-exposed. Except for C and KW-reactors, the samples were not of the same type graphite used in construction of the reactor. All samples were machined cylinders, 4 inches in length and 0.43 inches in diameter. Following weighing on an analytical balance, the samples were inserted into graphite boats. The boats are illustrated in Figure 1. Transverse holes were drilled through the boats to allow free passage of reactor gas.

During reactor shutdown the boats were placed in an empty process channel from which the tube had been removed. They were positioned to obtain front, central, and rear burnout rates. After an exposure of usually four to twelve months, the samples were pushed to the rear by aluminum poles inserted from the front face. At the rear face the samples were retrieved and placed in lead casks; the graphite boats were discarded in the basin. The samples were reweighed after standing a few days in vacuo to remove moisture and allow for radiation decay. The oxidation rate was calculated from the weight change.

The experimental oxidation rates, reported as per cent weight loss per 1000 operating days, are an average of the five samples in each boat. The gas composition was obtained by averaging weekly mass spectrometric data on the reactor atmosphere. In reporting water leak history, Van Stone leaks and leaks several rows and/or columns from the samples were ignored. It was assumed that the water vapor from distant leaks would be swept through

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the reactor before it could reach the samples. However, tube leaks in the immediate vicinity of the samples were considered in evaluating the behavior of the samples.

Only in two experiments were the channels filled with samples from front to rear. These were the first charge in 3066-KE and the fourth charge in 1960-C. In the former the temperature history was unreliable due to faulty thermocouples. However, in 1960-C good temperature readings were available during this experiment. These average temperatures, read from thermocouples placed 4, 10, 15, 20 and 25 feet downstream from the face of the graphite stack in channels 1561 and 2261, are shown in Figure 11. Temperature values from this distribution curve, corresponding to sample positions in the graphite stack, were used to arrive at the Arrhenius plot in Figure 14.

RESULTS AND DISCUSSION

Burnout Profiles

Samples were placed continuously from front to rear in 1960-C fourth charge, 3066-KE first charge and 1880-KW first charge; however the latter charge was lost. The resulting burnout profiles are shown in Figures 2 and 3. Highest burnout rates were observed near the maximum temperature and flux location at the center of the reactor.

Influence of Water Leaks on Rates

Water, used as coolant in the Hanford reactors, can saturate the surrounding graphite in the event of a tube failure. The graphite oxidation rate is appreciable in a moist atmosphere at 550 C and very high if the temperature exceeds 600 C.

The most dramatic example of high graphite burnout rates, apparently resulting from a water reaction, is shown in Figure 6. Samples in channel 3478-D were probably exposed to moisture from nearby leaks in channels 3579, 3479, and 3675 during the period from July, 1955 to April, 1959. There

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are three possible explanations for these extremely high rates: (1) the leaks were not detected quickly or continued for some time before tube replacement, prolonging the samples' exposure to moisture, (2) the samples were located in a hot spot in the reactor and suffered a severe burnout during a relatively short exposure to moisture, or (3) impurities deposited on the graphite during water leakage catalyzed subsequent oxidation of the graphite by air or CO_2 . The latter mechanism will be discussed in detail below and is extremely important because of the lasting effect these impurities can have on graphite oxidation. This catalysis is capable of causing higher oxidation rates than either of the first two mechanisms.

Another striking example is seen in Figure 9, from May, 1955 to April, 1956. Samples in channel 2577-H could have been exposed to moisture from leaks in channels 2787 and 2578 during this period. Both previous to and following this period no H-Reactor leaks were reported, and the samples had very low oxidation rates.

In another case, Figure 8 indicates that F-Reactor was wet continuously from June, 1955 to June, 1956 and from August, 1957 to April, 1958. Experimental samples exposed to dry conditions during the interval between these two periods revealed a substantially lower oxidation rate.

Obviously, it is impossible to place this treatment on a quantitative basis, since there is no independent method of determining the amount of water from a tube leak which actually reaches the experimental samples. It is likely, in some cases, that water never reaches the channel containing the samples even though the leak occurs in an adjacent channel (Refer to Figure 7). On the other hand, in the case of large ruptures, it is possible that water will flood the samples rapidly and lower the temperature to a point where the reaction rate is intermediate. Considerations of this type easily explain the values for oxidation rates in Figures 6 and 8.

Catalysis of Oxidation by Impurities

Impurities deposited on the graphite during water leaks may catalyze the oxidation. Thus, the reaction with the reactor atmosphere may proceed under conditions that otherwise would not contribute significantly to oxidation. The fact that graphite oxidation is catalyzed by impurities is well established. Day has shown that the thermal oxidation is catalyzed by iron, cobalt, nickel, copper, and manganese;⁽⁴⁾ Clark has demonstrated that impurities normally present in graphite and not subjected to gas purification increase the oxidation rate markedly.⁽⁵⁾ These impurities cause local, highly reactive sites which give rise to preferential oxidation, and the resulting oxidized graphite has the appearance of Swiss cheese, as illustrated in Figure 12.

Impurities, either directly from the process water or redistributed by the water from gunbarrels or other components, are believed to have caused extremely severe burnoff during the sixth charge in channel 1960-C. The data from this charge are shown in Table VI. The autoradiographs in Figure 13 indicate the presence of impurities in pits on the samples. Gamma spectroscopy revealed that the source of the activity was Fe^{59} . Scrapings from craters analyzed by emission spectroscopy contained trace to moderate (10-50 ppm) amounts of iron and vanadium. In contrast, scrapings from the non-pitted area on the bottom side of samples contained zero to less than trace (0 - < 10 ppm) amounts of these two elements. (These concentrations compare with < 10 ppm of iron and < 1 ppm of vanadium for typical, "F" grade gas-purified graphite.) The samples were not prepared from a contaminated bar since other samples from the same bar showed normal weight loss during the third charge in 1880-KW. These results are shown in Table XVI.

After the samples were discharged, the channel was inspected with a borescope⁽⁶⁾ and found to contain dark pitted areas, similar to those on the surface of experimental samples. These pits covered about 50 per cent of the channel surface between 6 feet 9 inches and 18 feet 1 inch from the front of the graphite stack. It was further observed that the top of the channel was affected to a greater degree than the sides or bottom; however, no estimate of the depth of crater penetration could be made.

Influence of Air Leakage on Rates

In the fourth 1960-C charge, an experiment in which the graphite temperature was known fairly accurately, an Arrhenius relationship was found between the reaction rate and temperature. The maximum temperature in this experiment was approximately 480 C. Woodley found an Arrhenius relationship at temperatures under 440 C in a similar in-reactor experiment. (7) Both sets of data are shown in Figure 14; they are particularly interesting because below 500 C the thermally induced CO₂-graphite reaction is too slow to detect experimentally. Furthermore, the observed activation energy (30 to 50 Kcal/mole) precludes the possibility of a radiation-induced reaction (generally a few tenths Kcal/mole activation energy). Of the gases likely to be present, only oxygen could have thermally reacted at a rate sufficient to have caused the observed amount of oxidation. The oxygen-graphite reaction has an activation energy of about 40 Kcal/mole. (8)

Radiation-induced reactions with both carbon dioxide and oxygen become important at lower temperatures and may be responsible for the trend of the Arrhenius plot towards zero activation energy at the low temperatures. Both the thermal- and radiation-induced reactions with oxygen are dependent upon the concentration of oxygen in the reactor atmosphere. Therefore, no significance can be attached to the displacement of Woodley's data from that obtained for 1960-C.

Influence of CO₂-He Ratio on Rates

Figure 15 presents a large amount of data on in-reactor oxidation of graphite for reactor atmospheres with various CO₂-He ratios. Most of these data were collected previously by Fox (9) and are the basis for the current Process Standard on graphite temperatures. (10) The rate of thermally-induced CO₂-graphite reaction (5) is plotted in the same figure. It is apparent that most of the in-reactor data fall above this line.

There is no reason to suspect that data from thermally-induced (ex-reactor) oxidation of graphite in pure CO_2 should not apply as well as in pure CO_2 within the reactor. This observation is supported by the following facts:

1. Some data in Figure 15 fall very near the curves for the thermally-induced reaction with CO_2 or CO_2 -He mixtures. Presumably, these points were obtained during periods of low air leakage.
2. In one case, where a very small air leak occurred in a laboratory experiment, the rate was comparable to the in-reactor rates.
3. The radiation-induced reaction was shown (Arrhenius relationship in Figure 14) to be less than a few tenths of one per cent per 1000 days, even under conditions of known high oxygen content.

It has been noted previously that both water and, particularly, air can increase oxidation rates of the graphite moderator. The combination of impurity catalysis from water leaks with air oxidation presents a very effective means of accelerating oxidation. Hence, with normal conditions that occur during reactor operation (below about 600 C), the CO_2 content of the reactor gas apparently has no significant influence on the oxidation rates of the moderator. Oxidation by CO_2 is overshadowed by the other oxidation reactions.

The Process Standard on graphite temperatures, (C-040, September 1, 1959), is based upon limiting the graphite oxidation rate to 2 per cent per 1000 operating days. This specification was derived from Fox's data⁽⁹⁾ as indicated in Figure 15. Because the relationship from Fox's data was apparently based on oxidation in the presence of oxygen, it cannot be correctly interpreted as showing the CO_2 -graphite reaction rate to be 2 per cent per 1000 operating days at 540 C. As indicated by Clark's data, the CO_2 content of the reactor gas will not cause the oxidation rate to exceed 2 per cent per 1000 operating days below a temperature of 580 C.

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If the oxidation rate with CO_2 is assumed to be proportional to the partial pressure of CO_2 (which should be a very good assumption in CO_2 -He mixtures below one atmosphere pressure), then the CO_2 -He ratio required to limit the oxidation to 2 per cent per 1000 operating days at various temperatures can be calculated. This calculation is compared to the current Process Standard in Figure 16.

In summary, the oxygen and water content of the reactor gas can cause excessive oxidation even at low temperatures (down to about 450 C). On the other hand, the CO_2 content of the reactor gas will have no influence on reactor operating limits below about 580 C.

It is important to note, however, that above 580 C the CO_2 does react appreciably with the graphite. A reactor with a graphite temperature of 750 C and a He content of 90 per cent (10 per cent CO_2) could expect oxidation rates of 40 per cent per 1000 operating days due only to the CO_2 -graphite reaction. If there is oxygen present the reaction rate will be higher.

ACKNOWLEDGEMENT

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FIGURE 1

Containers and Samples for Burnout Exposure

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FIGURE 4

Sample Burnout History in 3461-B

FIGURE 5

Sample Burnout History in 1960-C

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FIGURE 6

Sample Burnout History in 3478-D

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FIGURE 7

Sample Burnout History in 2577-DR

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FIGURE 8

Sample Burnout History in 3580-F

FIGURE 9

Sample Burnout History in 2577-H

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FIGURE 10

Sample Burnout History in 4165-H

FIGURE 11

Graphite Temperature in C Reactor

A. Unpurified Graphite - Oxidized 24 Hours in Air.

B. Gas Purified Graphite - Oxidized 24 Hours in Air.

Both Samples Were Made from Identical Coke and Pitch.

*FIGURE 12

Catalyzed Oxidation of Unpurified Graphite

*Taken from Clark⁽⁵⁾

FIGURE 13

Photograph and Autoradiograph of Samples 127-204 and
127-3 after Oxidation in 1960-C

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FIGURE 14

Rate of Graphite Oxidation in Reactor Atmosphere

FIGURE 15

Oxidation of Graphite at Various Temperatures

FIGURE 16

Conditions Leading to a Burnout Rate of 2%/1000 Operating Days

TABLE I

FOURTH CHARGE - B REACTOR - CHANNEL 3461

<u>Boat Number</u>	<u>Sample Number</u>	<u>Distance from Front of Graphite Stack to C of Boat (in feet)</u>	<u>Original Weight of Sample (in grams)</u>	<u>Loss of Weight of Sample (in grams)</u>	<u>% Weight Loss per 1000 Operating Days</u>
1	123-79	4. 27	15. 8163	0. 0022	0. 08
	123-3		15. 7184	0. 0023	0. 09
	123-6		15. 8491	0. 0033	0. 12
	123-7		15. 8057	0. 0050	0. 18
	123-84		15. 9232	0. 0081	0. 29
2	123-19	14. 02	15. 6626	0. 0357	1. 31
	123-78		16. 0759	0. 0613	2. 20
	123-91		15. 6606	0. 0451	1. 66
	123-82		15. 9433	0. 0346	1. 25
	123-90		15. 7206	0. 0219	0. 80
3	123-26	23. 79	15. 6252	0. 0020	0. 08
	123-97		15. 7793	0. 0016	0. 06
	123-18		15. 6480	0. 0016	0. 06
	123-23		15. 6472	0. 0015	0. 06
	123-27		15. 6348	0. 0017	0. 06

All samples were virgin CS-GBF graphite.

Charged - 5/10/57
 Discharged - 12/20/57
 Exposure - 1649 MWD/AT
 Operating Days - 173. 5

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TABLE II

FIFTH CHARGE - B REACTOR - CHANNEL 3461

<u>Boat Number</u>	<u>Sample Number</u>	<u>Distance from Front of Graphite Stack to C of Boat (in feet)</u>	<u>Original Weight of Sample (in grams)</u>	<u>Loss of Weight of Sample (in grams)</u>	<u>% Weight Loss per 1000 Operating Days</u>
1	123-254	4. 27	15. 7124	0. 0017	0. 01
	123-74		15. 7334	0. 0015	0. 01
	123-73		15. 7584	0. 0020	0. 01
	123-150		15. 7072	0. 0019	0. 01
	123-118		15. 7746	0. 0029	0. 02
2	123-232	14. 02	15. 9902	0. 0115	0. 07
	123-152		15. 5918	0. 0110	0. 07
	123-148		15. 7910	0. 0082	0. 05
	123-151		15. 5783	0. 0077	0. 05
	123-153		15. 5859	0. 0064	0. 04
3	123-231	23. 79	15. 5245	0. 0003	0. 00
	123-71		15. 7421	0. 0016	0. 01
	123-75		15. 7489	0. 0018	0. 01
	123-77		15. 6937	0. 0015	0. 01
	123-76		15. 7346	0. 0013	0. 01

All samples were virgin CS-GBF graphite

Charged	-	12/20/57
Discharged	-	3/8/58
Exposure	-	452 MWD/AT
Operating Days	-	59. 8

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TABLE III
SIXTH CHARGE - B REACTOR - CHANNEL 3431

Boat Number	Sample Number	Distance from Front of Graphite Slack to $\bar{C}$ of Boat (in feet)	Original Wt. of Sample (in grams)	Loss of Wt. of Sample (in grams)	% Wt. Loss per 1000 Operating Days	Original Length of Sample, L (in inches)	Change in Length, ΔL (in inches)	% Length Change $\Delta L/L \times 100$
1	128-265		15.1834	0.0110	0.21	4.0023	-0.0005	-0.01
	128-284		15.8207	0.0209	0.39	4.0002	-0.0001	-0.00
	128-30	4.27	15.6848	0.0185	0.35	4.0004	+0.0009	+0.02
	128-236		15.7419	0.0220	0.41	4.0009	+0.0006	+0.02
2	128-111		15.6594	0.0279	0.53	3.9999	+0.0005	+0.01
	128-112		15.6234	0.0738	1.45	3.9992	+0.0013	+0.03
	128-237		15.5828	0.0790	1.50	4.0003	+0.0002	+0.01
	128-233	14.02	15.4897	0.0644	1.23	4.0004	+0.0003	+0.01
3	128-234		15.5292	0.0476	0.90	4.0005	-0.0002	-0.01
	128-33		15.6679	0.0400	0.75	3.9981	+0.0012	+0.03
	128-34		15.6761	0.0390	0.73	4.0006	+0.0009	+0.02
	128-108		15.6594	0.0016	0.03	3.9983	+0.0002	+0.01
3	128-120	23.79	15.5618	0.0011	0.02	4.0012	+0.0012	+0.03
	128-235		15.4855	0.0001	0.00	3.9996	-0.0004	-0.01
	128-35		15.6411	0.0014	0.03	3.9995	+0.0006	+0.02

All samples were virgin KC graphite.

Charged - 3/8/58
Discharged - 5/14/59
Operating Days - 339.3
Exposure - 3298 MWD/AT

TABLE IV

FOURTH CHARGE - C REACTOR - CHANNEL 1960

Boat Number	Sample Number	Distance from Front of Graphite Stack to C of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days	Temperature ° C
1	69-90	1. 19	15. 5349	0. 0076	0. 23	140-160
	107-58		15. 9195	0. 0034	0. 10	
	107-54		15. 9873	0. 0034	0. 10	
	107-131		15. 8366	0. 0028	0. 08	
	107-132		15. 9316	0. 0028	0. 08	
2	69-293	3. 02	15. 6668	0. 0113	0. 34	360-365
	90-268		15. 4059	0. 0072	0. 22	
	90-207		15. 5401	0. 0073	0. 22	
	90-275		15. 3857	0. 0072	0. 22	
	90-267		15. 3805	0. 0059	0. 18	
3	119-59	4. 85	14. 8382	0. 0072	0. 23	385-395
	69-29		15. 4607	0. 0101	0. 30	
	*102-82		15. 4839	0. 0110	0. 33	
	*102-58		15. 3848	0. 0145	0. 44	
	*102-61		15. 3561	0. 0131	0. 40	
4	120-92	6. 69	13. 4706	0. 0064	0. 22	420-425
	69-7		15. 6310	0. 0127	0. 38	
	*97-38		15. 2976	0. 0103	0. 31	
	*97-102		15. 3498	0. 0094	0. 29	
	*102-45		15. 3843	0. 0123	0. 38	
5	120-9	8. 52	13. 4170	0. 0075	0. 26	435-450
	69-18		15. 5725	0. 0133	0. 40	
	107-130		15. 8572	0. 0102	0. 30	
	107-56		15. 9196	0. 0088	0. 26	
	107-57		15. 9277	0. 0090	0. 26	

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TABLE IV (contd.)

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days	Temperature °C
6	120-78	10.35	13.4968	0.0102	0.36	445-455
	69-24		15.3976	0.0154	0.47	
	69-296		15.5667	0.0160	0.48	
	90-242		15.1308	0.0229	0.71	
	69-61		15.7424	0.0155	0.46	
7	120-8	12.19	13.4287	0.0197	0.69	478
	69-44		15.4942	0.0269	0.82	
	*102-140		15.3134	0.0343	1.05	
	*102-23		15.3934	0.0500	1.52	
	*102-65		15.3998	0.0426	1.30	
8	120-15	14.02	13.4362	0.0571	1.99	482-485
	69-50		15.6779	0.0466	1.39	
	*97-41		15.2934	0.0489	1.50	
	*97-114		15.3111	0.0506	1.55	
	102-57		15.3353	0.0545	1.66	
9	120-12	15.85	13.5051	0.0284	0.98	481-484
	119-226		15.2317	0.0629	1.94	
	97-296		15.2558	0.1071	3.29	
	88-121		16.6190	0.0735	2.07	
	96-218		15.0016	0.1415	4.42	
10	120-85	17.69	13.3902	0.0212	0.74	471-477
	*119-89		15.1004	0.0469	1.46	
	*96-80		15.3300	0.0723	2.21	
	*104-253		15.2919	0.2839	8.71	
	*94-86		16.0368	0.2692	7.87	

TABLE IV (contd.)

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ to Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days	Temperature ° C
11	120-4	19.52	13.3133	0.0231	0.82	455-462
	*N-11-111		14.9707	0.0680	2.13	
	*N-11-46		15.0911	0.0658	2.04	
	*N-11-26		14.8969	0.0658	2.07	
	*N-11-32		14.8875	0.0701	2.21	
12	120-5	21.35	13.1700	0.0117	0.42	425-436
	69-58		15.6936	0.0153	0.46	
	*102-116		15.3533	0.0226	0.69	
	*102-24		15.4973	0.0410	1.24	
	*102-101		15.4721	0.0622	1.88	
13	107-55	23.19	13.9514	0.0065	0.22	392-405
	69-26		15.4701	0.0101	0.30	
	*97-45		15.2542	0.0099	0.30	
	*97-100		15.3864	0.0119	0.36	
	*102-35		15.7454	0.0214	0.64	
14	120-80	25.02	13.1928	0.0024	0.08	350-367
	69-53		15.7440	0.0087	0.26	
	*102-8		15.5667	0.0074	0.22	
	*102-80		15.6111	0.0107	0.32	
	*102-54		15.4138	0.0113	0.34	

TABLE IV (contd.)

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ to Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days	Temperature °C
	120-83		13.3353	0.0018	0.06	
	69-39		15.4440	0.0034	0.10	
15	*97-54	26.85	15.2783	0.0029	0.09	
	*97-107		15.3531	0.0034	0.10	265-295
	*102-121		15.3161	0.0040	0.12	

* These samples were previously irradiated.

Charged	-	3/14/55
Discharged	-	1/27/56
Exposure	-	2420 MWD/AT
Operating Days	-	213.3

<u>Bar Number</u>	<u>Graphite Type</u>
69	WSF
88	KCF
90	CSF
94	WSF
96	CSF
97	WSF
102	WSF
104	KC
107	CSF
119	CSF
120	CSF
N-11	TSGBF
H-9	SGBF

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TABLE V

FIFTH CHARGE - C REACTOR - CHANNEL 1960

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days
1	123-21	4. 26	15. 6382	0. 0046	0. 06
	123-20		15. 6463	0. 0053	0. 07
	123-22		15. 9389	0. 0049	0. 07
	123-24		15. 6319	0. 0057	0. 08
	123-25		15. 5931	0. 0074	0. 10
2	123-96	14. 02	15. 7811	0. 0977	1. 32
	123-95		15. 9385	0. 0990	1. 33
	123-94		15. 6983	0. 0932	1. 27
	123-93		15. 6997	0. 0964	1. 31
	123-98		15. 7759	0. 1310	1. 77
3	123-9	23. 79	15. 8777	0. 0037	0. 05
	123-8		15. 8310	0. 0059	0. 08
	123-2		15. 6881	0. 0061	0. 08
	123-1		15. 8611	0. 0062	0. 08
	123-4		15. 7269	0. 0022	0. 03

All samples were virgin CS-GBF graphite.

Charged - 4/4/56
 Discharged - 3/4/58
 Operating Days - 468. 1
 Exposure - 4672 MWD/AT

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TABLE VI

SIXTH CHARGE - C REACTOR - CHANNEL 1960

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Wt. of Sample (in grams)	Loss of Wt. of Sample (in grams)	% Wt. Loss per 1000 Operating Days	Original Length of Sample, L (in inches)	Increase in Length, ΔL (in inches)	% Length Increase $\Delta L / L \times 100$
1	127-201	4. 27	15. 7953	0. 1233	1. 63	3. 9994	+0. 0011	+0. 03
	127-206		15. 9526	0. 0613	0. 72	3. 9987	+0. 0009	+0. 02
	127-5		15. 7931	0. 0925	1. 12	3. 9972	+0. 0010	+0. 03
	127-4		15. 7637	0. 1616	1. 96	3. 9977	+0. 0015	+0. 04
	127-89		15. 8497	0. 1957	2. 34	4. 0011	+0. 0010	+0. 02
2	127-204	14. 02	15. 8100			3. 9993		
	127-3		15. 6927	2. 8781	34. 8	3. 9993	-0. 0184	-0. 46
	127-6							
	127-208		During the discharging operation, boat #2 crumpled because of excessive oxidation, and samples 127-6, 208, 207 were dropped into the basin.					
	127-207							
3	127-203	23. 79	15. 9016	0. 0140	0. 17	3. 9999	+0. 0016	+0. 04
	127-87		15. 8581	0. 0109	0. 13	3. 9992	+0. 0016	+0. 04
	127-205		15. 8960	0. 0086	0. 10	3. 9857	+0. 0010	+0. 03
	127-202		15. 8473	0. 0071	0. 08	3. 9982	+0. 0012	+0. 03
	127-88		15. 7726	0. 0056	0. 08	3. 9997	+0. 0017	+0. 04

All samples were virgin TS-GBF graphite.

Charged - 3/4/58
 Discharged - 1/25/60
 Exposure - 5868 MWD/AT
 Operating Days - 526. 2

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TABLE VII

NINTH CHARGE - D REACTOR - CHANNEL 3478

<u>Boat Number</u>	<u>Sample Number</u>	<u>Distance from Front of Graphite Stack to C of Boat (in feet)</u>	<u>Original Weight of Sample (in grams)</u>	<u>Loss of Weight of Sample (in grams)</u>	<u>% Weight Loss per 1000 Operating Days</u>
1	123-11	4. 27	15. 8349	0. 0062	0. 13
	123-10		15. 8067	0. 0076	0. 16
	123-85		15. 8337	0. 0126	0. 26
	123-86		15. 6846	0. 0251	0. 52
	123-15		15. 9787	0. 0275	0. 56
2	123-88	14. 02	15. 7160	0. 1235	2. 56
	123-12		15. 8393	0. 1129	2. 33
	123-81		15. 8738	0. 1137	2. 34
	123-80		15. 7945	0. 1003	2. 07
	123-14		15. 8428	0. 0455	0. 94
3	123-13	23. 79	15. 8910	0. 0024	0. 05
	123-83		15. 9594	0. 0025	0. 05
	123-89		15. 6854	0. 0030	0. 06
	123-17		15. 6465	0. 0027	0. 06
	123-92		15. 7103	0. 0019	0. 04

All samples were virgin CS-GBF graphite.

Charged	-	11/18/56
Discharged	-	1/24/58
Exposure	-	2805 MWD/AT
Operating Days	-	306. 6

DECLASSIFIED

TABLE VIII

TENTH CHARGE - D REACTOR - CHANNEL 3478

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days
1	123-79	4. 27	15. 8141	0. 0124	0. 22
	123-3		15. 7160	0. 0181	0. 32
	128-48		15. 5354	0. 0159	0. 29
	128-249		15. 4993	0. 0199	0. 36
	128-252		15. 6571	0. 0256	0. 46
2	123-19	14. 02	15. 6268	0. 2893	5. 15
	123-78		16. 0142	0. 2992	5. 20
	128-44		15. 5650	0. 2738	4. 90
	128. 45		15. 5868	0. 2847	5. 09
	128. 249		15. 5280	0. 2199	3. 94
3	123-26	23. 79	15. 6232	0. 0045	0. 08
	123-97		15. 7777	0. 0041	0. 07
	128-251		15. 4874	0. 0036	0. 07
	128-254		15. 7162	0. 0029	0. 05
	128-249		15. 5673	0. 0039	0. 07

123 samples were CS-GBF graphite, previously irradiated in fourth charge, 3461-B;

128 samples were virgin KC graphite.

Charged - 1/24/58
 Discharged - 3/18/59
 Exposure - 3639 MWD/AT
 Operating Days - 359. 2

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TABLE IX

FIFTH CHARGE - DR REACTOR - CHANNEL 2577

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days
1	123-263	4. 27	15. 6896	0. 0014	0. 02
	123-266		15. 7176	0. 0022	0. 03
	123-282		15. 5443	0. 0026	0. 04
	123-288		15. 6410	0. 0032	0. 04
	123-267		15. 7852	0. 0042	0. 06
2	123-284	14. 02	15. 4247	0. 0042	0. 06
	123-281		15. 5816	0. 0041	0. 06
	123-268		15. 8639	0. 0039	0. 05
	123-283		15. 4812	0. 0045	0. 06
	123-264		15. 7717	0. 0043	0. 06
3	123-262	23. 79	15. 7522	0. 0022	0. 03
	123-301		15. 6465	0. 0022	0. 03
	123-298		15. 6709	0. 0016	0. 02
	123-304		15. 6325	0. 0018	0. 03
	123-294		15. 5640	0. 0016	0. 02

All samples were virgin CS-GBF graphite.

Charged	-	6/14/56
Discharged	-	2/10/58
Exposure	-	3937 MWD/AT
Operating Days	-	469. 5

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TABLE X

SIXTH CHARGE - DR REACTOR - CHANNEL 2577

<u>Boat Number</u>	<u>Sample Number</u>	<u>Distance from Front of Graphite Stack to C of Boat (in feet)</u>	<u>Original Weight of Sample (in grams)</u>	<u>Loss of Weight of Sample (in grams)</u>	<u>% Weight Loss per 1000 Operating Days</u>
1	128-240	4.27	15.7230	0.0030	0.06
	128-238		15.6994	0.0033	0.07
	128-239		15.7234	0.0049	0.10
	128-110		15.6376	0.0062	0.12
	128-109		15.6170	0.0084	0.18
2	128-32	14.02	15.6502	0.0075	0.16
	128-125		15.5473	0.0067	0.14
	128-126		15.4597	0.0069	0.15
	128-29		15.6667	0.0070	0.15
3	128-123	23.79	15.5391	0.0016	0.03
	128-121		15.5596	0.0011	0.02
	128-124		15.5888	0.0011	0.02
	128-122		15.5532	0.0004	0.01
	128-106		15.6904	0.0007	0.01

All samples were virgin KC graphite.

Charged	-	2/10/58
Discharged	-	4/1/59
Exposure	-	2960 MWD/AT
Operating Days	-	305.7

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TABLE XI

SEVENTH CHARGE - F REACTOR - CHANNEL 3580

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days
1	123-214	4.27	15.8523	0.0074	0.27
	123-204		15.6983	0.0146	0.54
	123-211		15.7408	0.0266	0.97
	123-207		15.7308	0.0267	0.98
	123-215		15.6217	0.0410	1.51
2	123-233	14.02	16.0734	0.0425	1.52
	123-201		15.8502	0.0250	0.91
	123-202		15.2004	0.0163	0.62
	123-203		15.5973	0.0126	0.47
	123-212		15.7389	0.0102	0.38
3	123-223	23.79	15.8887	0.0016	0.06
	123-226		15.9008	0.0007	0.02
	123-221		15.6549	0.0007	0.02
	123-246		15.6647	0.0014	0.05
	123-237		15.6632	0.0012	0.04

All samples were virgin CS-GBF graphite.

Charged	-	7/16/57
Discharged	-	3/6/58
Exposure	-	1668 MWD/AT
Operating Days	-	173.4

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TABLE XII

EIGHTH CHARGE - F REACTOR - CHANNEL 3580

Boat Number	Sample Number	Distance from Front to Graphite Stack to C_0 of Boat (in feet)	Original Wt. of Sample (in grams)	Loss of Wt. of Sample (in grams)	% Wt. Loss per 1000 Operating Days	Original Length of Sample, L (in inches)	Change in Length, ΔL (in inches)	% Length Change $\Delta L / L \times 100$
1	123-263	4.27	15.6882	0.0137	0.21	4.0036	-0.0032	-0.08
	123-266		15.7154	0.0162	0.25	4.0004	-0.0012	-0.03
	123-86		15.9487	0.0215	0.33	4.0015	+0.0012	+0.03
	123-213		15.8079	0.0311	0.48	4.0016	+0.0003	+0.01
	123-88		15.9321	0.0384	0.59	4.0015	+0.0017	+0.04
2	123-284	14.02	15.4203	0.0345	0.54	4.0012	-0.0009	-0.02
	123-281		15.5777	0.0272	0.43	4.0010	-0.0005	-0.01
	128-9		15.9636	0.0644	0.98	3.9993	+0.0023	+0.06
	128-214		15.9008	0.0477	0.75	4.0021	+0.0013	+0.03
	128-14		15.9220	0.0410	0.63	4.0005	+0.0029	+0.07
3	123-262	23.79	15.7497	0.0045	0.07	4.0011	0.0000	0
	123-301		15.6441	0.0039	0.06	4.0021	+0.0003	+0.01
	128-12		15.9444	0.0027	0.04	4.0007	+0.0015	+0.04
	128-243		15.4783	0.0036	0.06	4.0013	+0.0003	+0.01
	128-210		15.7522	0.0035	0.05	4.0010	+0.0006	+0.01

123 samples were CS-GBF, previously irradiated in fifth charge, 2577-DR; 128 samples were KC graphite.

Charged - 3/6/58
 Discharged - 7/24/59
 Exposure - 4312 MWD/AT
 Operating Days - 410.5

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TABLE XIII

FOURTH CHARGE - H REACTOR - CHANNEL 2577

<u>Boat Number</u>	<u>Sample Number</u>	<u>Distance from Front of Graphite Stack to C of Boat (in feet)</u>	<u>Original Weight of Sample (in grams)</u>	<u>Loss of Weight of Sample (in grams)</u>	<u>% Weight Loss per 1000 Operating Days</u>
1	123-43	4.27	15.8197	0.0079	0.10
	123-42		15.8243	0.0104	0.13
	123-46		15.8330	0.0098	0.12
	123-126		15.8996	0.0098	0.12
	123-122		15.8277	0.0120	0.15
2	123-44	14.02	15.8005	0.0115	0.14
	123-110		15.7838	0.0118	0.15
	123-111		15.7629	0.0103	0.13
	123-47		15.8230	0.0113	0.14
	123-41		15.8125	0.0113	0.14
3	123-120	23.79	15.8230	0.0081	0.10
	123-124		15.8350	0.0060	0.07
	123-125		15.8589	0.0054	0.07
	123-45		15.8135	0.0060	0.07
	123-123		15.7941	0.0045	0.06

All samples were virgin CS-GEF graphite.

Charged - 4/15/56
 Discharged - 5/11/58
 Exposure - 4350 MWD/AT
 Operating Days - 512.0

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TABLE XIV

FIRST CHARGE - KE REACTOR - CHANNEL 3066

<u>Boat Number</u>	<u>Sample Number</u>	<u>Distance from Front of Graphite Stack to C of Boat (in feet)</u>	<u>Original Weight of Sample (in grams)</u>	<u>Loss of Weight of Sample (in grams)</u>	<u>% Weight Loss per 1000 Operating Days</u>
1	123-271	7.79	15.6877	0.0183	0.27
	123-272		15.7841	0.0120	0.18
	123-297		15.6501	0.0109	0.16
	123-275		15.7788	0.0105	0.16
	123-287		15.7480	0.0099	0.15
2	123-277	9.63	15.7427	0.0014	0.17
	123-278		15.7619	0.0119	0.18
	123-273		15.7416	0.0136	0.20
	123-258		15.6667	0.0196	0.29
	123-261		15.6798	0.0190	0.28
3	123-32	11.46	15.6233	0.0311	0.47
	123-108		15.7850	0.0548	0.81
	123-116		15.7495	0.0595	0.88
	123-38		15.7586	0.0768	1.14
	123-274		15.8164	0.0824	1.22
4	123-104	13.29	15.6383	0.0883	1.32
	123-33		15.6184	0.0944	1.41
	123-101		15.6687	0.0851	1.27
	123-100		15.6831	0.0842	1.26
	123-102		15.6867	0.0963	1.44
5	123-29	15.13	15.6746	0.1404	2.09
	123-103		15.6365	0.0862	1.29
	123-115		15.7711	0.0683	1.01
	123-28		15.8588	0.0686	1.01
	123-109		15.7847	0.0738	1.09

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TABLE XIV (contd.)

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days
6	123-34	16.38	15.5926	0.0696	1.04
	123-113		15.7740	0.0578	0.86
	123-99		15.6916	0.0430	0.64
	123-106		15.8034	0.0523	0.77
	123-30		15.6256	0.0399	0.60
7	123-107	18.21	15.8069	0.0319	0.47
	123-105		15.6828	0.0356	0.53
	123-5		15.7887	0.0653	0.97
	123-37		15.7478	0.0509	0.76
	123-40		15.8028	0.0457	0.68
8	123-36	20.04	15.7286	0.0136	0.20
	123-39		15.7891	0.0089	0.13
	123-121		15.8244	0.0062	0.09
	123-117		15.7870	0.0068	0.10
	123-119		15.7697	0.0062	0.09
9	123-144	21.88	15.7760	0.0062	0.09
	123-146		15.8177	0.0049	0.07
	123-35		15.6166	0.0044	0.07
	123-31		15.6384	0.0047	0.07
	123-112		15.7650	0.0041	0.06
10	123-65	23.71	15.6634	0.0019	0.03
	123-141		15.7399	0.0015	0.02
	123-69		15.7280	0.0005	0.01
	123-142		15.7405	0.0009	0.01
	123-147		15.8283	0.0008	0.01

All samples were virgin CS-GBF graphite.

Charged - 8/6/57
 Discharged - 2/6/59
 Exposure - 4049 MWD/AT
 Operating Days - 427.8

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TABLE XV

SECOND CHARGE - KW REACTOR - CHANNEL 1880

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Weight of Sample (in grams)	Loss of Weight of Sample (in grams)	% Weight Loss per 1000 Operating Days
1	123-225	7.46	15.8373	0.0321	1.49
	123-222		15.6961	0.0217	1.01
	123-228		15.9526	0.0140	0.65
	123-243		15.5538	0.0172	0.81
	123-224		15.7377	0.0227	1.06
2	123-241	15.54	15.4734	0.0218	1.04
	123-134		15.7400	0.0296	1.38
	123-235		15.5173	0.0190	0.90
	123.248		15.7051	0.0224	1.05
	123-234		15.5965	0.0237	1.12
3	123-252	23.63	15.7041	0.0123	0.57
	123-252		15.6087	0.0177	0.83
	123-244		15.5564	0.0147	0.69
	123-255		15.6924	0.0115	0.54
	123-227		15.0240	0.0125	0.57

All samples were virgin CS-GBF graphite.

Charged - 9/17/57
 Discharged - 3/12/58
 Exposure - 1215 MWD/AT
 Operating Days - 136.0

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TABLE XVI

THIRD CHARGE - KW REACTOR - CHANNEL 1880

Boat Number	Sample Number	Distance from Front of Graphite Stack to $\bar{C}$ of Boat (in feet)	Original Wt. of Sample (in grams)	Loss of Wt. of Sample (in grams)	% Wt. Loss per 1000 Operating Days	Original Length of Sample, L (in inches)	Increase in Length, ΔL (in inches)	% Length Increase $\Delta L/L \times 100$
1	127-8	7.46	15.8456	0.0179	0.32	4.0020	0.0027	0.07
	127-215		16.0492	0.0123	0.22	4.0011	0.0012	0.03
	127-33		15.9134	0.0120	0.22	4.0018	0.0020	0.05
	127-211		16.0245	0.0091	0.16	4.0012	0.0008	0.02
	127-14		15.9617	0.0095	0.17	4.0004	0.0014	0.04
2	127-213	15.54	16.0705	0.0655	1.17	4.0004	0.0018	0.05
	127-216		15.9906	0.0546	0.98	4.0014	0.0007	0.02
	127-93		15.8133	0.0550	1.00	4.0012	0.0019	0.05
	127-12		15.9502	0.0413	0.74	4.0014	0.0013	0.03
	127-74		15.8943	0.0356	0.64	4.0010	0.0019	0.05
3	127-92	23.63	15.8790	0.0315	0.57	4.0012	0.0018	0.05
	127-118		15.9566	0.0281	0.50	4.0013	0.0007	0.02
	127-95		15.8986	0.0178	0.32	4.0019	0.0013	0.03
	127-97		15.9460	0.0145	0.26	4.0010	0.0014	0.04
	127-210		15.9285	0.0117	0.21	3.9989	0.0014	0.04

All samples were virgin GS-GBF graphite.

Charged - 3/12/58
 Discharged - 5/26/59
 Exposure - 3720 MWD/AT
 Operating Days - 349.1

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HW-61273 REV

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5. Clark, T. J. Gas-Graphite Reactions I, Thermal and Microwave Oxidation of Various Reactor-Grade Graphites, HW-63855. February, 1960.
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9. Fox, J. C. C-Pile Graphite Burnout Experiment, Final Report, PT-105-548-E, HW-45942. August, 1956.
10. Curtiss, D. H. Basis for Graphite Limits, HW-45154. August, 1956.

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