BNWL-237

56.

HIGH TEMPERATURE RADIATION DAMAGE TO GRAPHITE

J. F. Doar
J. T. Meers
H. H. Yoshikawa

Dun for 60008 763

DEC 8 1966

DEC 12 1966

L. J. Rhee 525541101N

May 1966

BATTELLE-NORTHWEST

BATTELLE MEMORIAL INSTITUTE / PACIFIC NORTHWEST LABORATORY

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/ FOR THE U. S. ATOMIC ENERGY COMMISSION

HIGH TEMPERATURE RADIATION DAMAGE TO GRAPHITE

Part II

RADIATION DAMAGE IN GRAPHITE

J. T. Meers

J. F. Doar

H. H. Yoshikawa

FIRST UNRESTRICTED
DISTRIBUTION MADE

JUN 21 1969

FOREWORD

This report, which is Part II of a two-part summary, presents the post-irradiation evaluation of several sets of graphite samples which were prepared by the Carbon Products Division of Union Carbide Corporation and submitted to the Hanford Atomic Products Operation for irradiation testing. Part I covers the period from April 1, 1960 to June 30, 1962 and contains a description of the samples and the preliminary evaluation of the materials selected for irradiation. Part II covers the contract period April 1, 1960 to June 30, 1962 and also contains the data for measurements through June 1, 1965.

The work described herein was supported in part by the Carbon Products Division of Union Carbide Corporation and in part by the United States Atomic Energy Commission under Contract No. AT-(45-1)-1603.

ABSTRACT

All of the post irradiation test data through June 1, 1965 for the samples described in Part I of this report are tabulated by sample set. From this mass of data, selected cases of interest have been chosen for discussion of each of the properties which were measured. Lengths and coefficients of thermal expansion were determined by Battelle-Northwest Laboratory, formerly Hanford Atomic Products Operation; the remainder of the properties discussed were measured by the Research Laboratory staff of the Carbon Products Division of Union Carbide Corporation.

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. POST-IRRADIATION RESULTS	1
A. X-ray Results.	1
B. Susceptibility.	3
C. Length Changes	4
1. Filler Particle Size	4
2. Carbon Black Filler	4
3. Impregnant Carbon	5
4. Density	5
5. Anisotropy	8
D. Coefficient of Thermal Expansion	8
E. Sonic Modulus Measurements	8
F. Electrical Resistivity and Thermal Conductivity	11
G. Electron Microscopy	13
III. CONCLUSIONS	15
IV. ACKNOWLEDGMENTS	16
REFERENCES.	17
APPENDIX	18
A. Post-Irradiation Data	
ERRATA.	55

FIGURE CAPTIONS

<u>FIGURE</u>		<u>PAGE</u>
1	X-ray Spacing of Damaged Madagascar Flake, ZTA, and Anthracite.	2
2	Radiation Damaged Single Crystals and CEP Cubes. Susceptibility Trace vs. Radiation Level.	3
3	Length Changes in the Conventional Graphite, Lampblacks, and Impregnation-Binder Series.	6
4	Length Changes in the Controlled Density and ZT 4130 Series.	7
5	Coefficient of Thermal Expansion of the Lampblacks, the ZTA's and the Controlled Density Series.	9
6	Changes in the Sonic Moduli of Various Sample Sets.	10
7	Electrical Resistivity and Thermal Conductivity.	12
8	Effect of Pulse-Annealing on the Resistivity of a Damaged ZTA Sample.	13
9	Electron Photomicrograph of a 338 MWD/AT Madagascar Flake.	14

TABLE CAPTIONS

<u>TABLE</u>		<u>PAGE</u>
I	Madagascar Flake Graphite	19
II	Susceptibility Cubes and Single Crystals	19
III	Continental Coke Series	20
IV	Anthracite Series (With Grain)	21
V	1400°C Lampblack	22
VI	3000°C Lampblack (With Grain)	23
VII	3000°C Lampblack (Across Grain)	24
VIII	3000°C Lampblack--Parma CTE Measurements	25
IX	3500°C Lampblack after 2234 MWD/AT (With Grain)	26
X	ZTA Series	27
XI	ZT 4130 Series	28
XII	Conventional Graphite Series. Particle Size $\leq 0.016''$	29
XIII	Conventional Graphite Series. Particle Size $\leq 0.035''$	30
XIV	Conventional Graphite Series. Particle Size $\leq 0.055''$	31
XV	Controlled Orientation Series (Across Grain)	32
XVI	Controlled Orientation Series (With Grain)	33
XVII	Controlled Density Series. B.D. ~ 1.87 g/cc	34
XVIII	Controlled Density Series. B.D. ~ 1.97 g/cc	35
XIX	Controlled Density Series. B.D. ~ 2.05 g/cc	36
XX	Controlled Density Series. B.D. 2.10 g/cc	37
XXI	High Temperature Controlled Density Series after 2234 MWD/AT	38
XXII	Impregnation-Binder Series after 1715 MWD/AT	39

TABLE CAPTIONS

<u>TABLE</u>		<u>PAGE</u>
XXIII	Laboratory Impregnation Series after 1715 MWD/AT.	39
XXIV	Superfine Series after 2234 MWD/AT	40
XXV	Synthetic Coke-Pitch Series after 1715 MWD/AT	41
XXVI	Isotropic R-Series--Average Values	42
XXVII	Hot Worked Graphite-Z T 4130, Z, and Z T Series, 3351 Through 6133 MWD/AT _k	43
XXVIII	Z Series--Across Grain, 3351 Through 4270 MWD/AT _k	44
XXIX	Z T Series--With Grain, 4665 Through 5584 MWD/AT _k	44
XXX	3500°C Lampblack (With Grain) After 3013 MWD/AT _k	45
XXXI	LB Series--3000°C Lampblack With Grain	46
XXXII	1400°C Lampblack, 6233 Through 10, 645 MWD/AT _k	47
XXXIII	Controlled Orientation Series	48
XXXIV	Conventional Particle Size Series	49
XXXV	Laboratory Impregnation and Particle Size, All Flour Mix Series A, B, and C, Length and Changes After 3013 MWD/AT _k	50
XXXVI	Impregnation Binder Series	51
XXXVII	High Temperature Controlled Density	53
XXXVIII	Superfine Series	54

I. INTRODUCTION

The general problem associated with the use of graphite in nuclear applications has been that of radiation growth, either positive or negative, which occurs whenever graphite is exposed to a fast neutron flux. It was to this general problem that the program was addressed when formulated in 1959. At that time, there were only a few experiments in which the behavior of graphite exposed at high temperatures to fast neutrons had been studied. The materials exposed in the first experiments were conventional moderator graphites, but the materials selected for this program represented a rather wide range of anisotropy and crystallinity.⁽¹⁾

The pre- and post-irradiation measurement of the samples was a cooperative effort between the Carbon Products Division of Union Carbide Corporation and Hanford Atomic Products Operation (now Battelle Memorial Institute, Pacific Northwest Laboratory). Hanford was primarily concerned with the measurement of dimensional changes, and the Carbon Products Division made measurements of electrical resistivity, thermal conductivity and sonic moduli. In several cases, other measurements were made to supplement this work. In the discussion of results, only representative cases are presented; however, a complete set of data is tabulated in the appendix.

This report is the second and final part of the summary report; post-irradiation results are included for the several sample sets described in Part I.

II. POST-IRRADIATION RESULTS

A. X-ray Results

For low irradiation temperatures, the change in the c spacing of the crystallites of graphite is large and relatively easy to follow by X-ray measurement. As the temperature of irradiation is increased, simultaneous annealing of displaced atoms occurs, and the changes in the crystallites are more difficult to follow. For coke-base graphite, the within-sample variation of the crystallite spacings is so large that, for comparisons to be meaningful, exactly the same part of the sample should be measured before and after irradiation. The alternative to this procedure is to use a material which has a very uniform structure.

For this reason, ground, annealed Madagascar flake graphite was chosen for X-ray measurements. In addition to the Madagascar flake, graphites from two other series (ZT 4130 and Anthracite) were examined for changes in the c spacings. The results are given in Figure 1. The unirradiated c spacings for each of these samples was equal to the single crystal value, but the c spacing of the anthracite sample changed rapidly with irradiation and is large compared with the corresponding change in the ZT 4130 c spacing. The change in the ZT 4130 at 5000 MWD/AT exposure is approximately that which one would obtain from a linear extrapolation of the c spacing changes of the Madagascar flakes.

There is a small but consistent difference between the micronized flake; the micronized-annealed flake, and the whole-annealed flake; the radiation induced change in spacing being largest for the initially most disordered, nonannealed sample. For these low levels, the change in spacing is a linear function of dose, and no saturation effects were observed.*

Figure 1

X-ray Spacings of Damaged Madagascar Flake, ZTA, and Anthracite

N-4495

* Recent X-ray measurements of the c spacing of all of the Madagascar flake specimens after irradiations ranging to 3500 MWD/AT indicate that the c spacing saturates at a value of $c_0/2 = 3.3568 \pm 0.0006$ Å for exposures near 1500 MWD/AT. This value represents a net expansion of 0.084 per cent, about equal to the per cent irradiation growth of the well oriented across-grain samples of manufactured graphite for this program.

** In these irradiations, $1 \text{ MWD/AT} \sim 1.2 \times 10^{17} \text{ n/cm}^2 \text{ E} > 0.18 \text{ Mev}$.

B. Susceptibility

The diamagnetic susceptibilities of graphites having extremes of crystallinity were measured using a Faraday balance which had been calibrated by using high purity gold and silver.

The susceptibility results for several low exposures are given in Figure 2.

Figure 2

Radiation Damaged Single Crystals and CEP Cubes
Susceptibility Trace vs. Radiation Level

N-8060

The CEP graphite is a carbon black base graphite which in the unirradiated state has an average crystallite size of approximately 150 Å. The susceptibility of this material is compared with Canadian natural lump graphite (CNG) and with both natural and synthetic single crystals. A major decrease in the susceptibilities of CEP graphite and the single crystals occurs during the first 300 MWD/AT of exposure. The low absolute value of the CNG control (-20.8 emu/g) is not believed to be a typical unirradiated value. The susceptibility of the irradiated CNG compares very favorably with the values for irradiated crystals.

An interesting extension of this work, provided additional exposures could be obtained, would be a study of susceptibility vs. annealing, since it may be possible to estimate the relative magnitudes of the reversible and irreversible damage caused by neutron bombardment.

C. Length Changes

From an applications point of view, the dimensional changes induced in graphite by radiation are the most crucial. Among the several sample sets prepared for irradiation, a number of variables were isolated so that the effect of each upon dimensional stability could be observed.

1. Filler Particle Size

It was expected that the ways in which filler particle size affect dimensional stability would be through orientation (larger particles form a more isotropic graphite) and intra-particle porosity. The dependence of the across-grain length changes upon particle size was slight for conventional extruded graphite. The with-grain direction of the coarsest grain graphite, however, shrinks several per cent less than that of the fine grain samples. (See Figures 3a and 3b).

2. Carbon Black Filler

Carbon black filler produces a near isotropic body; and, in contrast to coke fillers, it is made up of turbostratic highly strained crystallites arranged so that the particles are approximately spherical in shape. The irradiation-induced changes in the carbon black samples have been discussed by Yoshikawa.⁽²⁾ The dimensional changes for samples having heat treatment temperatures of 1400, 3000, and 3500°C are given in Figure 3c. By comparing the per cent length

change of these materials with the data given in Figures 3a and 3b, one may observe the relative stability of "graphitizing" vs. "nongraphitizing" carbon. This comparison illustrates the extremes for polycrystalline carbon: the coke filler used in the conventional graphite represents the most highly graphitic grade commercially available; the carbon black is among those carbons which are least susceptible to ordering by either thermal or mechanical means or combinations of both.

3. Impregnant Carbon

Aside from the possible degrees of crystallinity, the effects of impregnant carbon upon the conventional graphite depend upon its physical location within the matrix (inter or intra locations) and its interaction with the matrix. For the latter concept, the impregnant which bridges or coats a pore will be effective; in other locations, however, it may shrink away from the pore wall and thus not interact with the original matrix. The irradiation shrinkage of graphite as a function of the quantity of impregnant carbon is shown in Figure 3d. For these graphites, the quantity of impregnant carbon does not appear critical until additions of approximately 10 per cent are achieved, at which point a distinct increase in shrinkage of the matrix takes place.

4. Density

The samples prepared with density as a variable have one complicating feature: as the highest densities are approached, anisotropy becomes a variable also. In Figure 4, the samples all have a degree of compaction which results in increased control by the graphite crystallite. In 4a, the development of high anisotropy occurs at a density of about 2.0 g/cm³. Thus, in Figures 4a and 4b, for the highest density samples, the shrinkage behavior is similar to that of pyrolytic graphite.

The data shown in Figures 4c and 4d are for the ZT 4130 samples described in Part I of this report. They were included in the irradiation program as an immediately available example of a new type of graphite. Although the sample-to-sample variation of this experimental material was rather large, the trend is obviously intermediate between conventional graphites and the even more highly oriented high-density controlled density samples.

Figure 3

Length Changes in the Conventional Graphite,
Lampblacks, and Impregnation-Binder Series

N-7684

N-7685

N-7686

N-7687

Figure 4

Length Changes in the Controlled Density and ZT 4130 Series

N-7682

N-7683

5. Anisotropy

Over the range of anisotropies covered by the controlled orientation samples (Transverse to Longitudinal ratios of 0.78 to 6.18), there is very little dependence of the shrinkage on the degree of anisotropy. If one examines the full spectrum of orientation ratios involved in this program, however, he will note a definite dependence on the anisotropy at both the high and low extremes; for example, in Figure 4a, the increasing density produces a corresponding increase in the anisotropy.

D. Coefficient of Thermal Expansion

The thermal expansion for the temperature range 25 to 425°C before and after irradiation was measured on certain samples by Battelle Northwest Laboratories. Some typical results are shown in Figure 5. Here, again, the increase in the coefficient of thermal expansion (CTE) tends to saturate above a certain neutron dose. A possible exception is the highly anisotropic (and variable) with-grain ZT series samples, which were unique in that they all experienced an initial decrease in CTE before showing the characteristic increase. There is some difference in the irradiation level at which the 1400 and the 3000°C lampblack samples reach saturation, the behavior being similar to that found in the contraction rate.⁽³⁾ It should be noted that the magnitude of the increase in the CTE of the 1400°C lampblack is equal to that in all of the coke-base graphites except the controlled density samples and the ZT mentioned above, and the magnitude of the change in the 3000°C lampblack is about equal to that of the controlled density and the other ZT samples.

E. Sonic Modulus Measurements

As mentioned in Part I of this report, measurements of the sonic moduli of the damaged samples were begun when it became apparent that the changes in electrical properties were saturating at a relatively low exposure. Unfortunately, the changes in moduli also appear to have leveled off in most of the samples after an exposure of about 1000 MWD/AT. Typical examples are shown in Figures 6a and 6c. The 50 to 70 per cent increase in sonic moduli at saturation is about one-half as large as the corresponding increase in samples irradiated at 350°C, which,

Figure 5

Coefficient of Thermal Expansion of the Lampblacks,
the ZTA's, and the Controlled Density Series

Figure 6

Changes in the Sonic Moduli of Various Sample Sets

in turn, is about half the increase noted for room temperature irradiation.⁽³⁾ In the case of the very highly anisotropic ZT series, however, the modulus did not reach a saturation value. The magnitude of this increase appears to be somewhat higher than that of the other graphites, but there were no pre-irradiation data for these particular samples. The only measurements available were those made on other samples taken from the same source material. The variation of the average change in all the moduli for the controlled density samples is plotted as a function of density in Figure 6d.

F. Electrical Resistivity and Thermal Conductivity

Electrical resistivity and thermal conductivity were determined on all of the irradiated samples using the standard techniques previously described.⁽¹⁾ Typical results are presented in Figure 7. For most of the samples, the changes in both tend toward a maximum and saturate after about 1000 MWD/AT (See Figures 7a, 7c, and 7d). In the case of the very highly anisotropic ZTA samples, the change is still continuing at an exposure of 5584 MWD/AT (Figure 7b). The magnitude of the change is much greater than in any of the other sample sets. Figures 7e and 7f indicate that there is little effect on the degradation of electrical and thermal conductivities due to either orientation or density over the range of those values involved in the controlled orientation and controlled density series, respectively.

The relative effects of neutron irradiation on the electrical and thermal conductivities are about equal for the well-graphitized samples, as can be seen by the small changes in the product $k\rho$ in Figures 7a, 7c, 7e, and 7f. The resistivity of the lampblack base graphite, on the other hand, experiences a smaller net effect because of neutron bombardment than does the thermal conductivity. This result is expected on the basis that the change in resistivity is inversely proportional to the unirradiated value, whereas the change in thermal conductivity is relatively insensitive to the original value.

Figure 7

Electrical Resistivity and Thermal Conductivity

While measuring the temperature dependence of the thermal conductivity and electrical resistivity of irradiated ZTA and lampblack samples, some in situ pulse annealing was carried out by exposing and measuring the samples at successively higher temperatures. ⁽⁴⁾ One such measurement of the resistivity of a sample of ZTA graphite is shown in Figure 8. As might be expected from the electron microscope studies of damaged flakes, the annealable portion of the damage reflected in the resistivity is almost completely removed by heating to 1600°K, and no further observable annealing takes place above that temperature. ⁽⁵⁾

Figure 8

Effect of Pulse-Annealing on the Resistivity of a Damaged ZTA Sample

N-1660

G. Electron Microscopy

Techniques described in Volume I of this report were used to examine several of the irradiated Madagascar flakes by means of the electron microscope. The preparation of the irradiated flakes by the same procedure as the unirradiated flakes, however, proved to be much more difficult. The irradiated flakes did not cleave readily into suitably thin platelets.

Figure 9 is an electron micrograph of a typical region in a flake irradiated to 338 MWD/AT, showing artifacts which are the result of neutron damage. Numerous white specks identified as dislocation loops ^(6, 7, 8, 9) having diameters of about 100 Å are evident, and the dislocation lines have a definite pinned appearance at the white specks. In the unirradiated specimens, these line dislocations are long, smooth curves which can be shifted by the thermal stresses induced by the electron beam heating. Such motion of the line dislocations in the irradiated samples could not be induced; the lines were apparently pinned by the dislocation loops.

Figure 9

Electron Photomicrograph of a 338 MWD/AT Madagascar Flake

It was found that the dislocation loops increased in size and that the dislocation contrast improved after the first anneal at 1200°C. Annealing at 1600°C caused a further increase to 1000A, in the loop size. Dislocation contrast was further improved and some slight motion was observed at the edges of the crystallites. A 2000°C anneal removed the visible damage entirely, improved dislocation contrast once again, and allowed nearly normal dislocation motion in a few regions. Finally, complete recovery of the pre-irradiation appearance occurred after the flakes were annealed at 3000°C.

Most of this work was done using flakes from the first two irradiation levels (338 MWD/AT and 622 MWD/AT) because the gross damage to the flakes at higher doses tended to obscure details. It was apparent, however, that dislocations were being pinned, for no motion was observed.

III. CONCLUSIONS

When subjected to fast neutron bombardment, the highly oriented polycrystalline graphites behave in a manner similar to that of annealed pyrolytic graphite. The relatively large crystallites control the behavior of these graphites, and the volume change is small and usually positive. On the other hand, graphites made from carbon black shrink or creep internally under neutron bombardment, and the highly strained amorphous or very poorly crystalline carbon controls the behavior of these graphites.

Graphites which have crystallinity intermediate between these extremes comprise the major portion of the materials which have been used in reactor technology. The reactor graphites are composed largely of crystallites, but a fraction of the mass is highly strained, poorly crystalline material. Therefore, the overall dimensional changes under fast neutron bombardment is dependent upon a combination of the behavior of each of these components.

The results of the present work lead to the conclusion that the degree of crystallinity of the graphite is an important factor in determining its stability when exposed at high temperatures to fast neutron irradiation. Simmons⁽¹⁶⁾ has suggested that at high temperatures the most stable graphites are isotropic and highly crystalline and have a high coefficient of expansion. The criterion of high expansion

coefficient simply establishes that the c-axis expansion of the crystallites controls the bulk expansion of the graphite. In this model the expansion of individual crystallites balances the shrinkage of the carbon which is poorly crystalline and/or highly stressed, thus minimizing dimensional changes.

Economic considerations will control how closely this idealized graphite is approached in practice. For a given set of operating conditions, it is now possible to select raw materials so that a reasonable balance between crystallinity, crystallite orientation and distributed porosity can be achieved in reactor graphites.

ACKNOWLEDGMENT

This report was prepared by J. F. Doar and J. T. Meers; the work was performed by R. Bacon, O. L. Blakslee, J. F. Doar, J. T. Meers, C. W. Nezbeda, D. E. Soule, R. Sprague and G. N. Wrights for the Carbon Products Division and by H. H. Yoshikawa of Battelle Memorial Institute, Pacific Northwest Laboratory.

njr

REFERENCES

1. Meers, J. T., and Doar, J. F., "High Temperature Radiation Damage to Graphite, Part I, Preparation of Graphites for Irradiation", HW80752, Hanford Atomic Products Operation, April 15, 1964.
2. Yoshikawa, H. H., Carbon 1, 201 (February, 1964).
3. Losty, H. H. W., "Radiation Effects on Mechanical Properties", in Nightingale, R. E., Nuclear Graphite, P. 313, Academic Press (1962).
4. Doar, J. F., and Pike, J. N., "Effect of Heat Treatment on the High Temperature Thermal Properties of Baked Carbons and Irradiated Graphites", Proc. 5th Carbon Conference, 2, P. 311, Pergammon Press (1963).
5. Nightingale, R. E., "Annealing Radiation Effects", in Nightingale, R. E., Nuclear Graphite, P. 372, Academic Press (1962).
6. Bacon, R., and Sprague, R., "Direct Observations of Imperfections in Graphite Single Crystals", Proc. 5th Carbon Conference, 1, P. 466, Pergammon Press (1962).
7. Bollman, W., Phil. Mag. 5, 621, 1960.
8. Bollman, W., and Hennig, G. R., Carbon 1, 525, 1964.
9. Reynolds, W. N., and Thrower, P. A., Phil. Mag. 12, 573, 1965.
10. Simmons, J. H. W. "Radiation Damage in Graphite", Pp. 136-162, Pergammon Press (1965).

APPENDIX

TABULATION OF POST-IRRADIATION DATA

TABLE I
Madagascar Flake Graphite

Sample	Exposure (MWD/AT)	c_o (Angstroms)	a_o
Annealed Flake:			
Cap. No. 1	338	6.7108	2.4606
No. 2	622	6.7119	2.4617
No. 3	852	6.7123	2.4622
No. 4	1257	6.7132	2.4606
Micronized Flake:			
Cap. No. 5	338	6.7108	2.4600
No. 6	622	6.7125	2.4610
No. 7	852	6.7130	2.4610
No. 8	1257	6.7145	2.4614
Micronized, Annealed Flake:			
Cap. No. 19	338	6.7112	2.4606
No. 20	622	6.7104	2.4613
No. 21	852	6.7115	2.4614
No. 22	1257	6.7118	2.4604
ZT-4130			
	0	6.708	2.458
	5020	6.722	2.463
Anthracite			
	0	6.708	2.460
	5020	6.746	2.469

TABLE II
Susceptibility Cubes & Single Crystals

Sample	Exposure (MWD/AT)	Susceptibility Trace 10^{-6} emu/gm
Lampblack Cubes	0	-20.9
	338	-14.2
	622	-14.1
	852	-14.1
	1257	-13.6
C. N. G. Cubes	0	-21.5
	338	-20.3
	622	-19.6
	852	-18.9
	1257	-17.7
Synthetic Crystals		
	0	-22.5
SPNH-14	338	-20.4
SPNH-15	622	-19.9
SPNH-16	852	-19.3
SPNH-17	1257	-18.7
Natural Crystals		
	0	-22.5
EPNH-44	338	-20.5
EPNH-45	622	-19.6
EPNH-46	852	-19.7
EPNH-47	1257	-19.1

TABLE III
Continental Coke Series

Sample	Exposure (MWD/AT _k)	Δ L (%)	Δ W (%)	Δ c (%) ^o	Δ a (%) ^o	Δ l (%) ^c	Δ l (%) ^a
2	388	-0.011 -0.006	-0.088		-0.283		-2.5
8	338	-0.022 -0.028	-0.039	-0.282	0.325	-5.8	59.7
1	622	0.021 0.012	-0.066		-0.243		-61.9
11	622	-0.032 -0.023	-0.039	-0.149	-0.081	33.1	-29.4
9	852	-0.009 -0.007	-0.046				
7	852	-0.011 -0.011	-0.025	-0.163	-0.081	18.7	149.2
4	852	0.046 0.028	-0.068	0.164	-0.081	16.8	16.9
12	852	-0.041 -0.039	-0.056				
5	1257	-0.006 0.000	-0.081	-0.163		-11.0	
3	1257	0.001 0.002	-0.072	-0.015	-0.041	-22.0	41.0
10	1257	-0.005 -0.024	-0.082				
6	1257	-0.013 -0.005	-0.069	-0.148	0.000	-11.0	29.0

TABLE IV

Anthracite Series (With Grain)

Sample	Exposure (MWD/AT _k)	ΔL (%)	ΔW (%)	ΔC_D (%)	Δa_o (%) ^o	Δl_c (%) ^c	Δl_a (%) ^a	ΔCTE (%)	ρ_i (10 ⁻⁴ g cm)	$\Delta \rho$ (%)	K_i (cal/sec cm deg)	ΔK (%)	E_F (10 ⁴ lbs/in ²)	E_L (10 ⁴ lbs/in ²)	G (10 ⁴ lbs/in ²)
AN-14	608	0.015	-0.034						30.1	50.5	0.0968	-37.6	1.13	1.22	0.260
AN-15		0.008	-0.046						33.5	53.0	0.1038	-27.6	0.98	1.05	0.237
AN- 3		0.003	-0.030						34.0	54.5	0.0986	-30.1	0.99	1.06	0.248
AN- 4	1378	-0.040	-0.039						31.2	61.6	0.0946	-41.2	1.32	1.41	0.290
AN- 5		-0.023	-0.054						41.7	61.6		0.81		0.86	0.223
AN- 6		-0.028	-0.048						38.1	67.9	0.0876	-36.0	0.97	1.04	0.242
AN- 7	3120	-0.058	-0.069	0.83	0.13	-11.8	-54.1	17.1	41.4	74.6	0.0730	-44.3	0.95	1.00	0.248
AN- 8		-0.068	-0.078	0.58	0.09	-17.2	- 3.1	13.4	33.8	61.0	0.0808	-45.4	1.34	1.34	0.298
AN- 9		-0.078	-0.078	0.73	0.11	-19.1	-14.4	4.2	38.1	74.8	0.0827	-41.8	1.10	1.19	0.267
AN-10	5020	-0.115	-0.074	0.54	0.01	- 3.0	34.0	11.0							
AN-11				0.31	0.04	- 1.0	-27.0								
AN-12		-0.133	-0.083	0.24	0.11	-16.0	-49.0	8.2	36.1	78.7	0.0736	-51.8	1.24	1.32	0.296

TABLE V
1400°C Lampblack

Sample	Orientation	Exposure (MWD/AT _K)	ΔL (%)	ΔW (%)	ΔC _O (%)	ΔI _C (%)	ΔCTE (%)	ΔP (%)	ΔK (%)
CL-1		608	-0.332	-0.044	-0.51	9.0	7.0	-15.0	-40.0
CL-2			-0.322	-0.199	-0.07	8.0		3.0	-71.0
CL-3		1378	-0.642	-0.602	0.00	20.3	18.0	0.72	-31.0
CL-4			-0.662	-0.186	-0.59	-10.9	15.0	-0.57	-35.0
CL-9	With Grain	2234	-1.10	-0.84			13.1		
CL-10			-1.08	-1.20			14.2		
CL-5		3120	-1.18	-0.433			21.4	3.1	-31.4
CL-6			-1.18	-0.789			24.8	6.0	-37.3
CL-7		5020	-1.76	-2.65	0.21	94.0	20.0	22.0	-45.0
CL-8			-1.75	-2.28	0.37	58.0	23.0	17.0	-49.0
AC-1		608	-0.294	-0.271			3.0		
AC-2			-0.298	-0.028					
AC-3		1378	-0.588	-0.750			10.0		
AC-4			-0.651	-0.123					
AC-9	Across Grain	2234	-1.07	-0.673			13.0		
AC-10			-1.07	-0.662			11.5		
AC-5		3120	-1.11	-0.81			18.7		
AC-6			-1.11	-1.21			16.8		
AC-7		5020	-1.68	-2.06	0.47	61.0	17.0		
AC-8			-1.66	-2.00	0.37	48.0	12.0		

TABLE VI

3000°C Lampblack (With Grain)

Sample	Exposure (MWD/AT _g)	ΔL (%)	ΔW (%)	Δc (%) ^o	Δa (%) ^o	Δl (%) ^c	Δl (%) ^a	ΔCTE (%)	ρl (10 ⁻⁴ cm)	Δp (%)	KI (cal/sec cm deg)	ΔK (%)	E_F (10 ⁴ lbs in ²)	E_L G
LB-1	338	-0.074	-0.007					10.1	46.8	6.4				
LB-2	338	-0.067	-0.003					3.6	46.5	8.6	0.0707	-2.3		
L-1	338	-0.068						6.2	46.7	6.1				
LB-3	622	-0.066	-0.012	-0.26	0.041	-3.3	-20.0	7.7	47.7	6.5				
LB-4	622	-0.090	-0.006					5.4	47.5	9.5	0.0699	-2.2		
LB-5	622	-0.093	-0.008					1.1	47.3	7.8				
L-4	622	-0.105	-0.011	-0.60	0.000	-23.8	-36.4	6.1	47.3	9.5	0.0595	-17.1	1.87	
LB-6	852	-0.116	-0.005					5.9	46.8	8.3				
LB-7	852	-0.117	-0.003					1.6	48.8	6.8	0.0406	-40.2		
LB-8	1257	-0.129	-0.007	0.06	-0.081	-8.0	7.9	8.0	46.6	6.9	0.0513	-27.8	1.94	
L-6	1257	-0.127	-0.015					11.0	46.8	8.3	0.0513	-28.6	1.98	
LB-1	1664	-0.138	-0.018	-0.25	0.041	4.0	-13.0	10.0	48.5	7.8	0.0428	-38.0	1.87	
LB-2	1664	-0.172	-0.016					9.6	47.9	8.9	0.0566	-19.7	1.98	1.99 0.805
L-1	1652	-0.222	-0.053					3.0	47.1	10.1	0.0602	-16.9	1.90	1.94 0.760
LB-3	1948	-0.223	-0.022					12.2	46.7	6.1	0.0437	-38.0	1.87	0.762
LB-4	1948	-0.229	-0.051	0.27	-0.028	0.7	7.7	4.7	48.3	7.8	0.0669	-3.3	1.95	1.96 0.785
L-4	1936	-0.212	-0.056					2.8	47.8	10.1	0.0621	-13.2	1.91	1.93 0.754
LB-5	2178	-0.255	-0.029					4.8	47.0	7.1	0.0538	-23.9	1.88	0.773
LB-6	2178	-0.265	-0.047	0.25	-0.098	-9.3	26.8							
L-6	2166	-0.220	-0.051					9.5	47.1	9.0	0.0643	-10.5	1.91	1.95 0.770
LB-7	2583	-0.287	-0.020					7.6	47.5	3.9	0.0411	-39.5	1.69	0.770
LB-8	2583	-0.245	-0.055	0.40	-0.094	-2.0	56.4	11.1	47.6	9.2	0.0613	-13.7	2.04	2.07 0.826
L-7	2571	-0.275	-0.052					12.2	47.7	10.4	0.0629	-12.4	2.04	2.05 0.801
		-0.272	-0.051											
		-0.266	-0.051											
		-0.262	-0.051											
		-0.258	-0.067	0.28	-0.102	-3.3	25.0	14.6	48.1	6.9	0.0340	-50.7	1.63	0.743

*These samples annealed one hour at 3000°C between first and second exposure.

TABLE VII

3000°C Lamblack (Across Grain)

Sample	Exposure (MWD/AT _K)	ΔL (%)	ΔW (%)	Δc_o (%)	Δa_o (%)	Δi_c (%)	Δl_a (%)	ΔCTE (%)	$(10^{-4} \Omega \text{ cm})$	Δp (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F, G (10^5 lbs/in^2)
L-2	338	-0.075	-0.004	-0.37	-0.081	-16.0	16.8	0.5	50.7	4.8			
L-3	622	-0.120	-0.011	-0.27	-0.041	-1.4	-47.7	2.2	52.0	8.1			
L-5	852	-0.147	-0.008	-0.16	-0.244	-53.8	-10.3	-1.4	52.9	4.1	0.0411	-32.6	
L-8	1257	-0.211	-0.012	-0.32	-0.160	14.0	1.0	5.0	51.5	6.9	0.0436	-32.3	1.83
L-2	1652	-0.179	-0.043	0.35	-0.202	-11.3	46.3	8.5	50.7	4.8	0.0408	-36.3	1.73
L-3	1936		-0.048	0.12	-0.163	19.1	6.8	6.8	52.2	8.5	0.0334	-48.2	1.71
L-5	2166	-0.251	-0.062	0.22	-0.106	-50.0	21.6	4.1	52.3	3.0	0.0368	-39.7	0.807
L-8	2571	-0.314	-0.051	0.12	-0.126	-0.7	136.0	11.8	51.8	7.5	0.0324	-49.7	1.81
													0.790

TABLE VIII

3000°C Lampblack--Parma CTE Measurements

Sample	Orientation	Exposure (MWD/AT _K)	Mean CTE to 400°C (10 ⁻⁶ /°C)	Sample	Exposure (MWD/AT _K)	Mean CTE to 400°C (10 ⁻⁶ /°C)
CTE-1	With Grain	338	4.44	M-1	338	4.95
CTE-4		622	4.92			
CTE-6		852	4.97	M-2	622	4.95
CTE-7		1257	4.65	M-3	622	4.60
CTE-1		1652	5.05			
CTE-4		1936	4.75	M-4	852	5.24
CTE-6		2166	4.67	M-5	852	4.94
CTE-7	Across Grain	2571	5.45			
				M-6	1257	4.82
CTE-2		338	4.47	M-7	1257	4.87
CTE-3		622	5.14			
CTE-5		852	4.97	M-1	1652	4.92
CTE-2		1652	5.15			
CTE-3		1936	4.99	M-2	1936	4.91
CTE-5		2166	4.95	M-3	1936	4.81
				M-6	2571	4.63
				M-7	2571	5.01
Orientation Unknown						

TABLE IX

3500°C Lampblack after 2234 MWD/AT (With Grain)

Sample	ΔL (%)		ΔW (%)	ΔCTE (%)
	End # 1	End # 2		
LHT-1	-0.42	-0.42	-0.040	
LHT-2	-0.42	-0.42	-0.035	
LHT-3	-0.41	-0.41	-0.026	
LHT-4	-0.42	-0.42	-0.029	
LHT-5	-0.42	-0.42	-0.031	
LHT-6	-0.41	-0.41	-0.025	
LHT-7	-0.41	-0.43	-0.035	12.1
LHT-8	-0.43	-0.43	-0.025	9.1
Average:	-0.42		-0.031	10.6

TABLE X
ZTA Series

Sample	Orientation	Exposure (MWD/AT)	ΔL (%)	ΔW (%)	ΔC_o (%)	Δa_o (%)	Δa_c (%)	Δa (%)	ΔCTE (%)	ΔP (10 ⁻⁴ cm)	ΔP (%)	K (Cal/sec cm deg)	ΔK (%)	E_F (10 ⁶ lb _s / in ²)	$\bar{E}_u$ G
ZT-1	With Grain	338	-0.008	-0.007	0.000	-0.081	-9.9	-36.8	-15.2	14.2	299	0.313	-64.1		
ZT-2			-0.006	-0.011	-0.015	-0.041	-25.8	-4.5	-14.1	11.2	310				
ZT-3		622	-0.013	-0.004	-0.030	0.041	-5.7	-31.4	-46.7	11.3	314	0.370	-67.5		
ZT-4			-0.006	-0.054	-0.119	-0.081	-25.7	-42.4	-77.2	15.7	276	0.213	-71.2		
ZT-5		852	-0.012	-0.003	-0.060	-0.041	-37.9	-24.9	-6.8	13.6	298	0.239	-73.6	3.92	
ZT-6			-0.011	-0.005	-0.061	-0.041	-27.8	36.5	-5.4	16.7	279	0.191	-73.0	2.98	
ZT-7		1257	-0.034	-0.013	0.280	0.081	-13.0	15.0	-0.6	17.2	308	0.168	-77.2	3.08	
ZT-8			-0.039	-0.010	0.150	-0.081	-7.0	13.0	-21.0	13.0	332	0.224	-78.3	5.15	
ZT-1		1652	-0.026	-0.026	0.089	-0.065	-9.3	-29.6	-16.0	15.2	326	0.224	-74.3	3.87	1.20
ZT-2			-0.027	-0.027	-0.074	-0.041	-29.8	1.2	3.1	12.2	337	0.248	-78.3	5.40	1.44
ZT-3		1936	-0.038	-0.024	0.045	-0.024	1.8	2.8	-12.0	12.3	352	0.250	-78.1	5.84	1.45
ZT-4			-0.026	-0.029	0.045	-0.012	-23.9	-6.0	-63.9	16.9	302	0.186	-74.9	3.20	1.11
ZT-5		2166	-0.033	-0.024	-0.030	-0.049	-21.4	-37.8	1.9	15.0	338	0.197	-78.2	4.37	1.28
ZT-6			-0.029	-0.027	-0.015	-0.073	-28.9	15.1	-3.2	17.3	292	0.165	-76.6	3.07	1.08
ZT-7		2571	-0.051	-0.036	0.164	-0.065	-25.6	-13.8	7.3	20.2	380	0.161	-78.1	3.24	1.13
ZT-8			-0.055	-0.031	0.060	-0.142	-8.9	-6.3	-6.9	13.3	341	0.218	-78.9	5.60	1.40
Z-7	Across Grain	388	0.015	-0.034					25.7	68.5				1.25	1.16
Z-1		622	0.000	-0.018					26.5	71.4		0.175	-12.5	1.25	1.20
Z-2			0.000	-0.014					26.3	74.5		0.163	-20.9	1.26	1.21
Z-3		852	0.012	-0.024					27.3	77.0		0.156	-22.4	1.24	1.23
Z-4			0.007	-0.012					27.9	76.4		0.180	-8.2	1.25	1.22
Z-5		1257	-0.022	-0.021					28.9	92.1		0.168	-18.4	1.38	1.34
Z-6			-0.015	-0.025					28.3	81.8		0.177	-11.1	1.36	1.30
														0.880	0.880

TABLE XI
ZT 4130 Series

Sample	Exposure (MWD/AT _k)	ΔL (%)	ΔW (%)	ΔCTE (%)	ρ_i ($10^{-4} \Omega \text{ cm}$)	$\Delta \rho$ (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F (10^4)	E_L lbs/in ²	G in ²
1A 6A	608	0.007 0.011	-0.033 -0.019	4.0	29.7 27.6	80.0 81.5	0.160 0.133	-14.9 -34.8	1.25 1.24	1.09 1.14	0.791 0.817
2A 7A	1378	-0.012 0.011	-0.037 -0.022	11.0	31.2 30.3	96.9 91.9	0.112 0.103	-42.9 -47.7	1.18 1.27	1.20 1.26	0.821 0.685
5A 10A	2234	0.049 0.007	-0.019 -0.045								
3A 8A	3120	0.014 -0.005	-0.032 -0.053	15.2	31.3 31.9	102.6 105.0	0.116 0.089	-42.3 -55.1	1.33 1.27	1.35 1.31	0.919 0.868
4A 9A	5020	0.045 0.027	-0.038 -0.041	13.0	34.7 31.1	103.2 106.2	0.119 0.083	-34.2 -59.6	1.46 1.42	1.31 1.41	0.922 0.928
1W 6W	608	0.008 0.009	-0.017 -0.027	6.0	15.4 14.9	99.7 84.0	0.232 0.214	-42.4 -44.1	2.93 2.92	2.83 2.71	1.01 1.00
2W 7W	1378	-0.019 -0.023	-0.025 -0.027	21.0	17.0 17.1	129.2 110.9	0.165 0.178	-60.5 -53.4	3.04 3.21	3.08 3.21	1.02 1.06
5W 10W	2234	-0.012 -0.032	-0.030 -0.031	0.6 8.2							
3W 8W	3120	-0.035 -0.055	-0.040 -0.043	21.6	17.2 18.0	116.0 125.0	0.199 0.156	-48.9 -59.8	3.23 3.24	3.27 3.27	1.09 1.05
4W 9W	5020	-0.093 -0.073	-0.058	12.0	17.2 16.2	119.1 114.9	0.143	-38.4	3.44 3.27	3.40 3.56	1.13 1.16

TABLE XII
Conventional Graphite Series, Particle Size $\leq 0.016''$

Sample	Exposure (MWD/AT ₁)	ΔL (%)	ΔW (%)	Δc (%) ^o	Δa (%) ^p	Δl (%) ^f	Δl (%) ^a	ρ_i (10 ⁻⁴ deg cm)	$\Delta \rho$ (%)	Ki (cal/sec. cm deg)	ΔK (%)	E_F (10 ⁴ bs/in ²)	ΔE_F (%)	E_L (10 ⁴ bs/in ²)	C
11	1326	0.000	-0.023	0.10		25.0		27.8	129	0.130	-49.0	0.837	40.9	0.910	0.456
12	1326	-0.003	-0.017	0.27		-10.8		30.0	142	0.120	-50.9	0.655	67.5	0.645	0.431
15	2234	-0.008	-0.001	-0.020											
16	2234	0.000	-0.025												
17	2234	0.005	-0.018												
18	2234	-0.002	-0.020												
13	2639	-0.013	-0.023	-0.22		-3.3		29.5	137	0.127	-49.0	0.879	56.1	0.856	0.460
14	2639	-0.006	-0.020	-0.22		-6.9	-29.4	30.0	154	0.144	-45.1	0.884	61.3	0.886	0.457
		-0.016													
		-0.007													
113	1326	-0.012	-0.027	0.48	0.08	11.6	-35.5	19.6	143	0.176	-54.1	1.71	46.1	1.73	0.611
114	1326	-0.014	-0.027	0.59	0.16	-8.8	-54.8	18.6	134	0.172	-55.9	1.76	47.9	1.81	0.615
117	2234	-0.018	-0.026												
		-0.012													
		-0.030													
118	2234	-0.026	-0.028												
119	2234	-0.026	-0.029												
		-0.020													
		-0.024													
120	2234	-0.022	-0.034												
		-0.027													
115	2639	-0.030	-0.038	-0.36	0.00	16.3	-37.5	21.0	160	0.155	-59.6	1.79	52.9	1.84	0.630
		-0.046													
116	2639	-0.029	-0.023	-0.06	-0.13	-23.8	-42.8	19.9	150			1.86	52.6	1.90	0.640
		-0.028													

Conventional Graphite Series. Particle Size $\approx 0.035''$

[illegible]

TABLE XIV

Conventional Graphite Series. Particle Size $\leq 0.055''$

Sample	Exposure (MWD/ATK)	ΔL (%)	ΔW (%)	ΔC_o (%)	Δa_o (%)	ΔL_c (%)	ΔL_a (%)	ρ_i ($10^{-4} \Omega \text{ cm}$)	$\Delta \rho$ (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F (10^4 lbs/in^2)	ΔE_F (%)	E_L (10^4 lbs/in^2)	G
51	1326	-0.002	-0.025	0.42		4.2		26.8	148.2	0.135	-54.7	0.950	46.6	0.980	0.487
52	1326	0.005	-0.021	0.34		-11.2		25.3	138.8		-49.3	0.960	40.8	0.965	0.484
55	2234	0.008	-0.024												
56	2234	0.003	-0.024												
57	2234	0.004	-0.023												
58	2234	0.001	-0.030												
53	2639	0.013	-0.026	-0.10		-9.1		28.3	163.6	0.132	-54.3	1.020	52.0	1.012	0.511
54	2639	0.009	-0.012					29.6	170.1	0.124	-56.2	0.947	49.6	0.950	0.487
		-0.008	-0.024												
		-0.004													
		-0.007													
513	1326	-0.004	-0.022	0.39	0.09	-4.1	-41.6	19.7	153.3	0.176	-55.8	1.61	42.5	1.65	0.579
514	1326	-0.006	-0.025	0.62	0.13	-32.0	-30.4	19.3	141.2		-56.0	1.59	45.2	1.61	0.570
517	2234	-0.007	-0.025							0.171					
		-0.008													
518	2234	-0.013	-0.026												
519	2234	-0.012	-0.020												
		0.000	-0.020												
520	2234	-0.008	-0.029												
		-0.001													
515	2639	-0.010	-0.020	-0.49	-0.01	27.1	-51.7	20.9	171.3	0.155	-61.5	1.62	49.3	1.69	0.591
		-0.017													
516	2639	-0.019	-0.019	-0.15	0.00	33.8	-70.6	20.8	166.2	0.171	-57.0	1.65	47.3	1.69	0.584
		-0.020													
		-0.023													

TABLE XV

Controlled Orientation Series (Across Grain)

Sample	T/L Ratio	Exposure (MWD/AT)	ΔL (%)	ΔW (%)	ΔC (%) ^O	ΔI (%) ^C	ρ_1 ($10^{-4} \Omega \text{ cm}$)	$\Delta \rho$ (%)	K_t (Cal/sec cm deg)	ΔK (%)	E_F (10^6 lbs/in^2)	ΔE_F (%) ^F	E_L (10^6 lbs/in^2)	G
1A1	0.78	1326	-0.001 0.004	-0.030	0.12	-3.9	26.1	129	0.133	-51.1	1.15	43.6	1.16	0.529
1A2		1326	0.007 -0.005	-0.025	0.18	20.0	26.2	135	0.139	-50.0	1.12	45.5	1.19	0.522
1A3		2639	-0.007 -0.016	-0.021	-0.09	-19.4	28.0	141	0.126	-52.8	1.17	48.2	1.18	0.517
1A4		2639	-0.010 -0.007	-0.029	-0.21	6.1	28.7	143	0.137	-47.8	1.14	51.9	1.14	0.508
2A1	2.39	1326	0.005 0.023	-0.029	0.22	-2.8	36.2	125	0.104	-46.1	0.676	38.8	0.738	0.395
2A2		1326	0.023 0.008	-0.040	0.19	9.5	31.5	120	0.119	-45.0	0.770	42.0	0.781	0.427
2A3		2639	-0.008 -0.006	-0.034	-0.21	28.2	35.5	151	0.102	-53.6	0.808	51.0	0.807	0.427
2A4		2639	-0.008 -0.011	-0.026	-0.16	-16.4	34.9	132	0.106	-48.6	0.799	49.6	0.801	0.413
3A1	6.18	1326	0.005 0.005	-0.031	0.00	12.8	37.0	120	0.101	-45.4	0.621	46.5	0.647	0.407
3A2		1326	0.003 0.012	-0.023	0.18	20.2	34.7	128	0.103	-49.5	0.744	48.7	0.761	0.431
3A3		2639	-0.013 0.010	-0.027	-0.10	-22.2	38.0	132	0.099	-47.6	0.682	50.9	0.696	0.407
3A4		2639	-0.003 -0.002	-0.061	-0.03	2.2	37.7	142	0.101	-49.2	0.744	53.1	0.742	0.405

TABLE XVI

Controlled Orientation Series (With Grain)

Sample	T/L Ratio	Exposure (MWD/AT)	ΔL (%)	ΔW (%)	Δc_o (%)	Δa_o (%)	Δl_c (%)	Δl_a (%)	ρ_i ($10^{-4} \Omega \text{ cm}$)	$\Delta \rho$ (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F (10^6 lbs/in^2)	ΔE_F (%)	E_L (10^6 lbs/in^2)	G
1C1	0.78	1326	0.010 0.010 0.003	-0.028	0.61	0.14	-41.0	-1.8	28.7	124	0.106	-54.9	0.940	43.5	0.998	0.505
1C2		1326	-0.003	-0.027	-0.15	0.12	-15.8	-57.8	28.7	128	0.117	-52.4	0.952	43.2	0.978	0.510
1C3		2639	-0.004 -0.005 -0.006	-0.022	-0.36	-0.05	33.1	-56.3	31.4	145	0.115	-52.5	0.986	50.5	0.998	0.495
1C4		2639	-0.005 -0.006 -0.009	-0.029	-0.07	0.02	35.0	-56.6	31.0	137	0.111	-53.4	0.975	50.3	0.981	0.505
2C1	2.39	1326	0.008 0.007 -0.006	-0.035	0.62	0.20	-16.0	-52.4	23.6	128	0.147	-51.0	1.24	57.0	1.32	0.461
2C2		1326	-0.001	-0.030	0.58	0.14	-3.4	-13.6	25.4	144	0.136	-54.4	1.20	46.1	1.25	0.460
2C3		2639	-0.011 -0.011 -0.009	-0.034	0.00	-0.09	-34.9	-62.4	25.4	154	0.132	-57.4	1.34	66.9	1.37	0.482
2C4		2639	-0.001	-0.030	-0.04	-0.11	27.3	-55.3	25.3	152	0.136	-56.1	1.35	64.9	1.33	0.442
3C1	6.18	1326	-0.005 -0.001 -0.005	-0.029	0.10	0.09	-2.7	-49.8	20.3	146	0.176	-53.2	1.90	42.9	2.04	0.554
3C2		1326	-0.006 -0.013 -0.017	-0.029	0.51	0.16	6.3	-22.3	19.6	135	0.165	-55.6	1.90	42.9	2.04	0.545
3C3		2639	-0.015 -0.015 -0.013	-0.023	-0.19	0.06	-6.9	-63.6	21.0	160	0.167	-56.5	1.99	47.4	2.04	0.622
3C4		2639	-0.013	-0.027	-0.03	-0.04	34.6	-56.4	21.3	155	0.150	-59.5	1.95	51.2	2.00	0.545

TABLE XVII

Controlled Density Series. B. D. ~ 1.87 g/cc

Sample	B. D. (g/cc)	Exposure (MWDAT _K)	ΔL (%)	ΔW (%)	ΔCTE (%)	ρ_i (10^{-4} g/cm)	$\Delta \rho$ (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F (10^6 lbs/in ²)	ΔE_F (%)	E_L (10^6 lbs/in ²)	ΔE_L (%)	G (10^6 lbs/in ²)	ΔG (%)
D-1-6	1.859	2234	0.006	-0.021											
D-1-7	1.845	2234	0.006	-0.020											
D-1-8	1.815	2234	0.006	-0.024											
D-1-1	1.868	2234	0.004	-0.025	2.7										
D-1-2	1.829	2234	-0.001	-0.019	3.8										
D-1-4	1.839	2639	0.001	-0.018											
D-1-5	1.814	2639	-0.008	-0.020											
			-0.006	-0.020											
			0.005												
D-1-26	1.876	2234	0.048	-0.032											
D-1-27	1.897	2234	0.049	-0.037											
D-1-28	1.900	2234	0.050	-0.031											
D-1-21	1.880	2234	0.046	-0.020	10.1										
D-1-22	1.895	2234	0.085	-0.013	7.9										
D-1-23	1.864	2639	0.086	-0.021											
D-1-24	1.897	2639	0.045	-0.019											
			0.019	-0.019											
			0.050	-0.019											
D-1-25	1.900	2639	0.051	-0.022		52.3	111	0.0581	-53.5	0.551	53.5	0.545	56.2	0.407	53.5
			0.031	-0.022											
			0.046												

TABLE XVIII

Controlled Density Series. B. D. ~ 1.97 g/cc

Sample	B. D. (g/cc)	Exposure (MWD/AT _k)	ΔL (%)	ΔW (%)	ΔCTE (%)	ρ_i (10^{-4} Ω cm)	$\Delta \rho$ (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F (10^6 lbs/in ²)	ΔE_F (%)	E_L (10^6 lbs/in ²)	ΔE_L (%)	E_G (10^6 lbs/in ²)	ΔG (%)
D-2-1	1.956	2234	0.008	-0.019	0.6										
D-2-2	1.944	2234	0.004	-0.015	3.4										
D-2-3	1.968	2234	0.007	-0.024											
D-2-4	1.980	2234	0.004	-0.018											
D-2-10	1.961	2234	0.001	-0.016											
D-2-11	1.947	2234	0.003	-0.019											
D-2-12	1.947	2234	0.004	-0.023											
D-2-5	1.975	2639	0.006	-0.016		17.9	158	0.187	-58.0	2.47	54.1	2.56	55.1	0.719	54.6
D-2-6	1.942	2639	0.005	-0.018		18.4	140	0.183	-54.9	2.06	47.6	2.11	51.9	0.616	52.1
D-2-7	1.953	2639	0.006	-0.019		17.3	145	0.187	-57.4	2.33	49.1	2.39	54.2	0.674	51.1
D-2-8	1.964	2639	0.010	-0.018		18.7	154	0.179	-57.5	2.31	49.3	2.36	53.2	0.693	50.6
D-2-9	1.960	2639	0.009	-0.015		16.3	144	0.192	-58.6	2.42	48.3	2.44	52.2	0.686	49.5
			0.012												
			0.014												
			-0.006												
D-2-21	1.958	2234	0.068	-0.022	7.6										
D-2-22	1.950	2234	0.064	-0.011	9.0										
D-2-23	1.970	2234	0.065	-0.018	9.4										
D-2-24	1.960	2234	0.062	-0.019											
D-2-30	1.960	2234	0.067	-0.017											
D-2-31	1.968	2234	0.051	-0.023											
D-2-32	1.950	2234	0.051	-0.018											
D-2-25	1.961	2639	0.061	-0.014		42.8	121	0.0907	-43.3	0.700	45.8	0.706	54.8	0.518	50.6
D-2-26	1.943	2639	0.065	-0.022		45.3	124	0.0825	-46.4	0.607	43.5	0.625	54.3	0.467	49.2
D-2-27	1.952	2639	0.062	-0.023		46.4	124	0.0820	-45.3	0.631	43.	0.646	54.5	0.475	56.3
D-2-28	1.962	2639	0.047	-0.017		39.1	106								
D-2-29	1.971	2639	0.044	-0.021		41.3	114	0.0830	-48.5	0.681	43.4	0.694	54.9	0.519	47.9
			0.045												
			0.040												
			0.050												
			0.050												

TABLE XIX

Controlled Density Series. B.D. ~ 2.05 g/cc

Sample	B. D. (g/cc)	Exposure (MWD/ATK)	ΔL (%)	ΔW (%)	ΔCTE (%)	ρ_i (10^{-4} g/cm)	$\Delta\rho$ (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F (10^6 lbs/in 2)	ΔE_F (%)	E_L (10^6 lbs/in 2)	ΔE_L (%)	G (10^6 lbs/in 2)	ΔG (%)
D-3-1	2.054	2234	-0.009	-0.021	6.4										
			-0.012												
D-3-2	2.058	2234	-0.012	-0.019	5.5										
			-0.013												
D-3-3	2.061	2234	-0.014	-0.029	7.3										
			-0.011												
D-3-9	2.046	2234	-0.008	-0.020											
			-0.007												
D-3-10	2.048	2234	-0.007	-0.017											
			-0.007												
D-3-11	2.045	2234	-0.007	-0.025											
			-0.007												
D-3-4	2.050	2639	-0.026	-0.013		15.5	164	0.202	-61.9	3.43	55.1	3.54	54.6	0.903	56.2
			-0.022												
D-3-5	2.048	2639	-0.031	-0.012		13.7	126	0.219	-57.1	3.52	56.5	3.64	55.5	0.888	54.7
			-0.021												
D-3-6	2.055	2639	-0.022	-0.014		14.2	159	0.224	-60.4	3.95	51.9	4.01	53.0	0.900	55.7
			-0.019												
D-3-7	2.040	2639	-0.027	-0.011		14.6	164	0.218	-61.1	3.54	54.6	3.62	55.4	0.922	55.5
			-0.025												
D-3-8	2.048	2639	-0.023	-0.011		13.3	134	0.233	-57.2	3.76	54.7	3.81	53.6	0.916	54.7
			-0.028												
D-3-21	2.053	2234	0.082	-0.040	4.4										
			0.087												
D-3-22	2.045	2234	0.086	-0.032	1.7										
			0.079												
D-3-23	2.054	2234	0.085	-0.029	5.2										
			0.086												
D-3-29	2.054	2234	0.065	-0.031											
			0.067												
D-3-30	2.052	2234	0.055	-0.036											
			0.056												
D-3-31	2.056	2234	0.071	-0.034											
			0.070												
D-3-24	2.050	2639	0.051	-0.014		43.6	97	0.0731	-47.7	0.841	59.0	0.824	58.1	0.641	57.1
			0.038												
D-3-25	2.040	2639	0.011	-0.013		37.8	116	0.0820	-53.6	0.926	60.5	0.910	55.0	0.622	51.0
			0.024												
D-3-26	2.048	2639	0.043	-0.012		39.6	98	0.0702	-54.7	0.862	60.0	0.843	55.3	0.609	48.1
			0.036												
D-3-27	2.040	2639	0.051	-0.013		47.6	113	0.0664	-51.9	0.818	57.0	0.807	57.3	0.621	56.5
			0.048												
D-3-28	2.044	2639	0.037	-0.013		41.8	96	0.0730	-50.0	0.861	61.0	0.848	55.9	0.628	57.0
			0.061												

TABLE XX
Controlled Density Series. B.D. 2.10g/cc

Sample	B.D. (g/cc)	Exposure (MWD/AT ₁)	ΔL (%)	ΔW (%)	ΔCTE (%)	π (10 ⁻⁴ cm)	$\Delta \rho$ (%)	Ki (cal/sec cm deg)	ΔK (%)	E_F (10 ⁹ lbs/in ²)	ΔE_F (%)	E_L (10 ⁶ lbs/in ²)	ΔE_L (%)	G (10 ⁶ lbs/in ²)	ΔG (%)
D-4-1	2.12	2234	-0.020	-0.023	13.3										
D-4-2	2.09	2234	-0.017	-0.016	-2.3										
D-4-6	2.10	2234	-0.021	-0.021											
D-4-7	2.10	2234	-0.016	-0.012											
D-4-8	2.12	2234	-0.016	-0.013											
D-4-3	2.10	2639	-0.017	-0.011											
D-4-4	2.10	2639	-0.032	-0.011											
D-4-5	2.10	2639	-0.027	-0.012		10.6	169	0.300	-61.9	6.50	56.6	6.57	57.9	1.167	63.6
			-0.030												
			-0.037												
			-0.034												
D-4-21	2.09	2234	0.082	-0.015	7.7										
D-4-22	2.10	2234	0.085	-0.028	4.1										
D-4-26	2.10	2234	0.086	-0.015											
D-4-27	2.10	2234	0.078	-0.025											
D-4-28	2.10	2234	0.077	-0.029											
D-4-23	2.10	2639	0.077	-0.011											
D-4-24	2.10	2639	0.065	-0.009											
D-4-25	2.10	2639	0.059	-0.010		53.6	109	0.0624	-48.5	0.797	60.4	0.796	65.1	0.705	61.7
			0.066												
			0.059												
			0.063												

TABLE XXI

High Temperature Controlled Density Series after 2234 MWD/AT

Sample	B. D. (g/cc)	ΔL (%)	ΔW (%)	ΔCTE (%)
D-5-2	2.092	-0.039	-0.035	
		-0.038		
D-5-3	2.092	-0.034	-0.028	
		-0.033		
D-5-4	2.100	-0.048	-0.017	
		-0.048		
D-5-5	2.093	-0.046	-0.052	
		-0.045		
D-5-6	2.088	-0.048	-0.023	1.6
		-0.047		
D-5-7	2.090	-0.042	-0.016	9.7
		-0.040		
D-5-21	2.089	0.070	-0.036	
		0.070		
D-5-22	2.089	0.073	-0.019	
		0.073		
D-5-23	2.095	0.046	-0.025	
		0.046		
D-5-24	2.098	0.051	-0.022	
		0.053		
D-5-25	2.097	0.055	-0.058	5.9
		0.058		
D-5-26	2.092	0.092	-0.020	7.3
		0.097		

TABLE XXII

Impregnation-Binder Series after 1715 MWD/AT

Across Grain			Impregnant Carbon ~14.5 W/o			With Grain		
Sample	ΔL (%)	ΔW (%)				Sample	ΔL (%)	ΔW (%)
I-3-1	-0.076	-0.033				I-3-21	-0.055	-0.026
I-3-2	-0.075	-0.036				I-3-22	-0.070	-0.018
I-3-3	-0.076	-0.028				I-3-23	-0.058	-0.019
I-3-4	-0.072					I-3-24	-0.065	-0.021
I-3-5	-0.072	-0.033				I-3-25	-0.067	-0.025
I-3-6	-0.072	-0.035				I-3-26	-0.072	-0.021
I-3-7	-0.075	-0.037				I-3-27	-0.063	-0.024
I-3-8	-0.074	-0.034				I-3-28	-0.065	-0.018
<u>Impregnant Carbon ~ 11 W/o</u>								
I-4-1	-0.046	-0.029				I-4-21	-0.037	-0.043
I-4-2	-0.045	-0.047				I-4-22	-0.031	-0.045
I-4-3	-0.044	-0.030				I-4-23	-0.029	-0.023
I-4-4	-0.047	-0.042				I-4-24	-0.027	-0.031
I-4-5	-0.046	-0.028				I-4-25	-0.030	-0.017
I-4-6	-0.043	-0.032				I-4-26	-0.033	-0.036
I-4-7	-0.046	-0.025				I-4-27	-0.038	-0.020
I-4-8	-0.045	-0.025				I-4-28	-0.035	-0.038
<u>Impregnant Carbon = 0 W/o</u>								
Conv. Graphite							-0.020	
All Flour Mx-0.004								

TABLE XXIII

Laboratory Impregnation Series after 1715 MWD/AT

Sample	Impregnant (w/o)	ΔL (%)	ΔW (%)	Sample	Impregnant (w/o)	ΔL (%)	ΔW (%)	Sample	Impregnant (w/o)	ΔL (%)	ΔW (%)
	0	-0.020			0	-0.014			0	-0.010	
A-1	3.6	-0.014	-0.016	B-1	2.8	-0.012	-0.024	C-1	3.0	-0.012	-0.028
A-2	3.4	-0.011	-0.018	B-2	2.9	-0.016	-0.013	C-2	2.7	-0.008	-0.020
A-3	3.3	-0.009	-0.014	B-3	3.1	-0.011	-0.016	C-3	3.1	-0.008	-0.012
A-4	3.9	-0.010	-0.015	B-4	3.8	-0.011	-0.020	C-4	3.2	-0.007	-0.016
A-11	9.0	-0.005	-0.014	B-11	7.1	-0.003	-0.020	C-11	6.1	-0.003	-0.018
A-12	7.5	-0.004	-0.014	B-12	7.0	-0.007	-0.017	C-12	6.1	-0.002	-0.018
A-13	7.6	0.000	-0.023	B-13	6.6	-0.004	-0.011	C-13	6.1	0.006	-0.016
A-14	7.6	0.000	-0.013	B-14	7.3	-0.001	-0.015	C-14	6.1	-0.001	-0.013
A-21	9.4	-0.023	-0.017	B-21	9.6	-0.031	-0.014	C-21	8.4	-0.019	-0.015
A-22	9.9	-0.026	-0.017	B-22	8.9	-0.026	-0.030	C-22	8.7	-0.019	-0.017
A-23	10.8	-0.023	-0.013	B-24	9.6	-0.030	-0.016	C-23	8.2	-0.016	-0.019
A-24	9.5	-0.021	-0.022	B-25	9.5	-0.028	-0.030	C-24	8.5	-0.016	-0.017

TABLE XXIV
Superfine Series after 2234 MWD/AT

Sample	ΔL (1%)	ΔW (1%)	ΔCTE (1%)
SFL-1	-0.075	-0.022	
	-0.076		
SFL-2	-0.085	-0.029	
	-0.083		
SFL-3	-0.068	-0.028	
	-0.067		
SFL-4	-0.080	-0.019	
	-0.080		
SFL-5	-0.074	-0.020	
	-0.074		
SFL-6	-0.074	-0.019	
	-0.073		
SFL-7	-0.076	-0.018	23.1
	-0.074		
SFL-8	-0.080	-0.013	20.3
	-0.077		
Average	-0.076	-0.021	21.7

TABLE XXV

Synthetic Coke-Pitch Series after 1715 MWD/AT

Sample	ΔL (%)	ΔW (%)	Δc (%) ^o	Δl (%) ^c
38-1	0.003 0.004	-0.045	-0.55	5.2
38-2	0.002 0.002	-0.044	-0.55	9.8
39-1	0.000 0.001	-0.047	-0.75	56.6
39-2	0.004 0.005	-0.050	-0.53	79.6
41-1	- 0.005 - 0.005	-0.042	-0.34	-11.6
41-2	- 0.002 - 0.004	-0.042	-0.58	12.2
46-1	0.000 0.001	-0.049	-0.49	9.0
46-2	0.000 0.001	-0.056	-0.37	13.7
AVERAGE:	0.000	-0.047	-0.52	21.8

TABLE XXVI

Isotropic R-Series--Average Values

Sample Identification	Orientation	Dose (MWD/AT)	ΔL (%)	ΔWt (%)	ΔCTE (%)	ΔE_F (%)	ΔE_L (%)	ΔG (%)
R-12 through R-14	Across Grain	~ 1500	----	----	----	+49.2	+49.0	+47.8
R-49 through R-51	With Grain "A"	~ 1500	----	----	----	+48.6	+49.0	+47.6
R-90 through R-92	With Grain "B"	~ 1500	----	----	----	+49.6	+49.0	+47.5
R-1 through R-7	Across Grain	2175	-0.049	-0.024	+ 8.5	+55.0	+54.7	+53.4
R-40 through R-45	With Grain "A"	2175	-0.053	-0.027	+ 7.9	+54.7	+55.4	+53.8
R-81 through R-86	With Grain "B"	2175	-0.053	-0.025	+10.0	+56.9	+57.0	+54.4

TABLE XXVII

Hot Worked Graphite-ZT 4130, Z, and ZT Series,
3351 Through 6133 MWD/AT_k

Sample	Mwd/AT _k	L/inches	%ΔL	%ΔW	%Δ CTE
ZT4130-1A	3621	4.2	+0.033	-0.065	
ZT4130-6A	3621	1.8	-0.038	-0.057	+14.6
Average %Δ and Std. Dev.			-0.003 ± 0.050 -0.061 ± 0.006		
ZT4130-6W	3621	2.1	-0.073	-0.052	
ZT4130-1W	3621	2.5	-0.069	-0.049	+24.6
Average %Δ and Std. Dev.			-0.071 ± 0.003 -0.051 ± 0.002		
ZT4130-2A	4391	3.0	+0.024	-0.111	
ZT4130-7A	4391	1.8	+0.054	-0.084	+17.0
Average %Δ and Std. Dev.			+0.039 ± 0.021 -0.098 ± 0.019		
ZT4130-7W	4391	2.1	-0.119	-0.090	
ZT4130-2W	4391	2.5	-0.085	-0.088	+20.7
Average %Δ and Std. Dev.			-0.102 ± 0.024 -0.089 ± 0.001		
ZT4130-3A	6133	4.2	+0.064	-0.083	
ZT4130-8A	6133	1.8	+0.032	-0.097	+17.6
Average %Δ and Std. Dev.			+0.048 ± 0.023 -0.090 ± 0.010		
ZT4130-3W	6133	2.5	-0.124	-0.090	+30.2
ZT4130-8W	6133	2.1	-0.160	-0.077	
Average %Δ and Std. Dev.			-0.142 ± 0.025 -0.083 ± 0.009		

The ZT4130 samples marked "A" indicates, against the grain, and "W" with the grain.
Width of samples 1/4 inch x 1/4 inch by 1.8 to 4.1 inches in length.

TABLE XXVIII

Z Series--Across Grain
3351 Through 4270 MWD/AT_k

Sample	Mwd/At _k	%ΔL	%ΔW
Z-7	3351	+0.055	-0.110
Z-1	3675	Broken	-----
Z-2	3675	Broken	-----
Z-3	3865	+0.054	-0.069
Z-4	3865	+0.054	-0.067
Average %Δ (Z-3, Z-4) and Std. Dev.		+0.054 ± 0.000	-0.068 ± 0.001
Z-5	4270	-0.020	-0.077
Z-6	4270	-0.035	-0.072
Average %Δ (Z-5, Z-6) and Std. Dev.		-0.028 ± 0.011	-0.075 ± 0.004

Sample size 1/4 x 1/4 x 4 inches.

TABLE XXIX

ZT Series--With Grain
4665 Through 5584 MWD/AT_k

Sample	Mwd/At _k	%ΔL	%ΔW	%ΔCTE
ZT-1	4665	-0.096	-0.060	- 1.4
ZT-2	4665	-0.097	-0.052	+25.0
Average %Δ and Std. Dev.		-0.097 ± 0.001	-0.056 ± 0.004	+11.8 ± 1.8
ZT-3	4949	-0.110	-0.051	+ 8.0
ZT-4	4949	-0.098	-0.057	+ 4.4
Average %Δ and Std. Dev.		-0.104 ± 0.008	-0.054 ± 0.003	+6.2 ± 2.5
ZT-5	5179	-0.107	-0.051	+12.6
ZT-6	5179	-0.103	-0.061	0.0
Average %Δ and Std. Dev.		-0.105 ± 0.002	-0.056 ± 0.007	+6.3 ± 8.9
ZT-7	5584	-0.126	-0.072	+14.6
ZT-8	5584	-0.164	-0.056	+27.7
Average %Δ and Std. Dev.		-0.145 ± 0.026	-0.064 ± 0.011	+21.2 ± 9.3

Sample lengths of the ZT series is 2.0 inches.

TABLE XXX
3500°C Lampblack (With Grain)
After 3013 MWD/AT_k

Sample	%Δ L	%Δ W	%Δ CTE
*LHT-10	-0.446	-0.011	+ 9.41
*LHT-11	-0.427	-0.009	+ 9.98
*LHT-12	-0.453	-0.010	+10.40
*LHT-13	-0.452	-0.010	+11.96
LHT-14	-0.448		
LHT-15	-0.449		
LHT-16	-0.448		
LHT-17	-0.449		
*Flat ends			
Average %Δ and Std. Dev.			
LHT-10 through LHT-13 (flat ends)			
	-0.445 ± 0.012	-0.010 ± 0.001	+10.44 ± 1.09
LHT-14 through LHT-17 (round ends)			
	-0.449 ± 0.001		
LHT-10 through LHT-17 (round and flat ends)			
	-0.447 ± 0.008		

TABLE XXXI

LB Series--3000°C Lampblack With Grain
4677 Through 5596 MWD/AT_k

Sample	Mwd/At _k	%ΔL	%ΔW	%ΔCTE
LB-1	4677	-0.439	-0.075	+13.7
LB-3	4961	-0.424	-0.090	+ 9.3
Sample LB-2 was baked 3000°C by NCC after each irradiation of 338 and 1664 Mwd/At _k .				
LB-2	4677	-0.499	-0.032	+ 6.2
Sample LB-4, the same as LB-2, except irradiations of 622 and 1948 Mwd/At _k .				
LB-4	4961	-0.470	-0.068	+ 8.1
Sample LB-6, the same as LB-2, except irradiations of 852 and 2178 Mwd/At _k .				
LB-6	5191	-0.561	-0.034	+10.2
Sample LB-8 was baked at 3000°C only after the second irradiation of 2533 Mwd/At _k .				
LB-8	5596	-0.532	-0.064	+13.4

TABLE XXXII

1400°C Lampblack, 6233 Through 10, 645 MWD/AT_k

Sample	Mwd/At _k	%ΔL	%ΔW	%ΔCTE
AC-1 (Against Grain)	6233	-2.11	-2.02	+19.7
AC-2	6233	-2.05	-0.67	+15.9
Average %Δ and Std. Dev.		-2.08 ± 0.04	-1.35 ± 0.95	+17.8 ± 2.6
AC-3	7003	-2.29	-3.76	-----
*AC-4	7003	-----	-1.27	
Average %Δ and Std. Dev.			-2.52 ± 1.76	
AC-5	8745	-2.63	-3.20	+23.5
AC-6	8745	-2.59	-4.35	+26.2
Average %Δ and Std. Dev.		-2.61 ± 0.002	-3.78 ± 0.81	+24.9 ± 1.9
AC-7	10645	-2.86	-5.18	+24.9
AC-8	10645	-2.87	-----	+20.0
Average %Δ and Std. Dev.		-2.87 ± 0.01		
CL-1 (With Grain)	6233	-2.16	-1.35**	+19.1
CL-2	6233	-2.20	-3.12	+26.8
Average %Δ and Std. Dev.		-2.18 ± 0.03	-2.19 ± 1.32	+23.0 ± 5.5
CL-3	7003	-2.47	-3.95	+30.4
CL-4	7003	-2.41	-1.78	+20.3
Average %Δ and Std. Dev.		-2.44 ± 0.03	-2.87 ± 1.53	+25.4 ± 7.0
CL-5	8745	-2.67	-1.98	+24.9
CL-6	8745	-2.74	-3.03	+25.5
Average %Δ and Std. Dev.		-2.70 ± 0.05	-2.51 ± 1.46	+25.2 ± 0.4
CL-7	10645	-3.10	-6.78	+33.4
CL-8	10645	-3.10	-6.14	+34.7
Average %Δ and Std. Dev.		-3.10 ± 0.00	-6.46 ± 0.45	+34.1 ± 0.9

*End of sample cut off prior to last charge, weight change recorded only.

**Excessive weight losses were noted.

The average length of all AC series samples approximately 2.7 inches.

TABLE XXXIII

Controlled Orientation Series
After 4339 MWD/AT_k

T/L Ratio 0.78--Across Grain

Sample	%Δ L	%Δ W
T/L Ratio 0.78 - Across Grain		
*1A1	-----	-----
1A2	-0.037	-0.129
T/L Ratio 0.78 - With Grain		
1C1	-0.029	-0.151
1C2	-0.031	-----
Average %Δ and Std. Dev.		-0.030 ± 0.001
T/L Ratio 2.39 - Across Grain		
2A2	-0.009	0.112
T/L Ratio 2.39 - With Grain		
2C1	-0.027	-0.153
2C2	-0.036	-0.140
Average %Δ and Std. Dev.		-0.032 ± 0.006
T/L Ratio 6.18 - Across Grain		
3A1	-0.013	-0.126
T/L Ratio 6.18 - With Grain		
3C1	-0.045	-0.087
3C2	-0.043	-----
Average % Δ Std. Dev.		-0.044 ± 0.001
*For some unknown reason, this sample read 30-50 R/hr and will be discarded.		

TABLE XXXIV
Conventional Particle Size Series
After 4339 MWD/AT_k

Sample	%Δ L	%Δ W
Particle Size < 0.016 - Across Grain		
11	-0.031	-0.082
12	-0.029	-0.078
Average %Δ and Std. Dev.		-0.030 ± 0.001 -0.080 ± 0.003
Particle Size < 0.016 - With Grain		
113	-0.061	-0.116
*114	-----	-----
Particle Size < 0.035 - Across Grain		
31	-0.001	-0.091
32	-0.032	-0.090
Average %Δ and Std. Dev.		-0.017 ± 0.021 -0.091 ± 0.001
Particle Size < 0.035 - With Grain		
313	-0.060	-0.087
314	-0.048	-0.090
Average %Δ and Std. Dev.		-0.054 ± 0.008 -0.089 ± 0.002
Particle Size < 0.055 - Across Grain		
51	-0.024	-0.082
52	-0.019	-0.083
Average %Δ and Std. Dev.		-0.022 ± 0.004 -0.083 ± 0.001
Particle Size < 0.055 - With Grain		
513	-0.046	-0.081
514	-0.047	-0.077
Average %Δ and Std. Dev.		-0.047 ± 0.001 -0.079 ± 0.003

*Sample discarded for the same reason as Sample 1A1, Page 7.

TABLE XXXV

Laboratory Impregnation and Particle Size, All Flour Mix
Series A, B, and C, Length and Changes After 3013 MWD/AT_k

Sample	%Δ L	%Δ W
A- 5	-0.032	-0.023
A- 6	-0.034	-0.018
A- 7	-0.035	-0.021
A- 8	-0.036	-0.022
Average %Δ and Std. Dev.	-0.034 ± 0.002	-0.021 ± 0.002
A-15	-0.022	-0.020
A-16	-0.024	-0.018
A-17	-0.025	-0.015
A-19	-0.023	-0.012
Average %Δ and Std. Dev.	-0.024 ± 0.001	-0.016 ± 0.003
A-25	-0.048	-0.015
A-26	-0.054	-0.021
A-27	-0.050	-0.017
A-28	-0.051	-0.021
Average %Δ and Std. Dev.	-0.051 ± 0.003	-0.019 ± 0.003
B- 6	-0.036	-0.013
B- 7	-0.043	-0.015
B- 8	-0.039	-0.011
Average %Δ and Std. Dev.	-0.039 ± 0.004	-0.013 ± 0.002
B-15	-0.032	-0.013
B-16	-0.030	-0.013
B-17	-0.030	-0.009
B-18	-0.028	-0.012
Average %Δ and Std. Dev.	-0.030 ± 0.002	-0.012 ± 0.002
B-26	-0.062	-0.015
B-27	-0.051	-0.015
B-29	-0.068	-0.010
Average %Δ and Std. Dev.	-0.060 ± 0.009	-0.013 ± 0.003
C- 5	-0.029	-0.010
C- 6	-0.029	-0.017
C- 7	-0.027	-0.012
C- 8	-0.028	-0.013
Average %Δ and Std. Dev.	-0.028 ± 0.001	-0.013 ± 0.003
C-15	-0.020	-0.007
C-16	-0.023	-0.013
C-17	-0.017	-0.009
C-18	-0.026	-0.012
Average %Δ and Std. Dev.	-0.022 ± 0.004	-0.010 ± 0.003
C-25	-0.039	-0.021
C-26	-0.042	-0.014
C-27	-0.045	-0.017
C-28	-0.043	-0.021
Average %Δ and Std. Dev.	-0.042 ± 0.002	-0.018 ± 0.003

Set A - Maximum particle size 0.016 inch.

Set B - Maximum particle size 0.030 inch.

Set C - Maximum particle size 0.060 inch.

All samples numbered 1 through 10 have one impregnation with pitch. Samples 11 through 20 have one impregnation with a nongraphitizing impregnant. Samples 21 through 30 have two impregnations with nongraphitizing impregnants.

TABLE XXXVI
Impregnation Binder Series
After 3013 MWD/AT

11.8 w/o Impregnant Carbon - Across Grain			
Sample	%ΔL	%ΔW	%ΔCTE
*I-1-29	-0.060	-0.007	+10.6
*I-1-30	-0.060	-0.009	+ 6.3
I-1-31	-0.060		
I-1-32	-0.059		
*Flat Ends			
Average %Δ and Std. Dev.			
I-1-29 and I-1-30 (flat ends)	-0.060 ± 0.000	-0.008 ± 0.001	+ 8.5 ± 3.0
I-1-31 and I-1-32 (round ends)	-0.060 ± 0.001		
I-1-29 through I-1-32	-0.060 ± 0.000		
11.8 w/o Impregnant Carbon - With Grain			
*I-1-9	-0.069	-0.008	+ 3.6
*I-1-10	-0.077	-0.005	+ 4.7
I-1-11	-0.076		
I-1-12	-0.071		
*Flat ends			
Average %Δ and Std. Dev.			
I-1-9 and I-1-10 (flat ends)	-0.073 ± 0.006	-0.007 ± 0.002	+ 4.2 ± 0.8
I-1-11 and I-1-12 (round ends)	-0.074 ± 0.004		
I-1-9 through I-1-12	-0.073 ± 0.004		
*I-2-29	-0.053	-0.005	+ 0.7
*I-2-30	-0.053	-0.002	+ 8.7
I-2-31	-0.051		
I-2-31A	-0.043		
I-2-32	-0.057		
*Flat ends			
Note: Sample length of I-2-31 is 2.3 inches and I-2-31A is 1.2 inches.			
Average %Δ and Std. Dev.			
I-2-29 and I-2-30 (flat ends)	-0.053 ± 0.000	-0.004 ± 0.002	+ 2.0 ± 3.1
I-2-31 through I-2-32 (round ends)	-0.050 ± 0.006		
I-2-29 through I-2-32	-0.051 ± 0.006		
9.9 w/o Impregnant Carbon - With Grain			
*I-2-9	-0.069	-0.004	+ 4.3
*I-2-10	-0.067	-0.004	- 0.3
I-2-11	-0.066		
I-2-12	-0.063		
*Flat ends			
Average %Δ and Std. Dev.			
I-2-9 and I-2-10 (flat ends)	-0.068 ± 0.001	-0.004 ± 0.000	4.7 ± 5.6
I-2-11 and I-2-12 (round ends)	-0.065 ± 0.002		
I-2-9 through I-2-12	-0.066 ± 0.002		

TABLE XXXVI (Cont. d)

14.5 w/o Impregnant Carbon - Across Grain			
Sample	% Δ L	% Δ W	% Δ CTE
*I-3-29	-0.101	-0.016	+11.6
*I-3-30	-0.111	-0.008	+13.4
I-3-31	-0.116		
I-3-32	-0.098		
*Flat ends			
Average % Δ and Std. Dev.			
I-3-29 and I-3-30 (flat ends)	-0.106 $\pm$ 0.007	-0.012 $\pm$ 0.006	+12.5 $\pm$ 1.3
I-3-31 and I-3-32 (round ends)	-0.107 $\pm$ 0.013		
I-3-29 through I-3-32	-0.107 $\pm$ 0.008		
14.5 w/o Impregnant Carbon - With Grain			
*I-3-9	-0.117	-0.008	+ 6.1
*I-3-10	-0.095	-0.008	+ 7.3
I-3-11	-0.115		
I-3-12	-0.118		
*Flat ends			
Average % Δ and Std. Dev.			
I-3-9 and I-3-10 (flat ends)	-0.106 $\pm$ 0.015	-0.008 $\pm$ 0.000	+ 6.7 $\pm$ 0.8
I-3-11 and I-3-12 (round ends)	-0.117 $\pm$ 0.002		
I-3-9 through I-3-12	-0.111 $\pm$ 0.010		
11 w/o Impregnant Carbon - Across Grain			
*I-4-9	-0.070	-0.009	+13.9
*I-4-10	-0.085	-0.008	+12.0
I-4-11	-0.079		
I-4-12	-0.081		
*Flat ends			
Average % Δ and Std. Dev.			
I-4-9 and I-4-10 (flat ends)	-0.078 $\pm$ 0.010	-0.009 $\pm$ 0.001	+12.9 $\pm$ 1.3
I-4-11 and I-4-12 (round ends)	-0.078 $\pm$ 0.004		
I-4-29 through I-4-32	-0.078 $\pm$ 0.006		
11 w/o Impregnant Carbon - With Grain			
*I-4-29	-0.060	-0.014	+ 5.8
*I-4-30	-0.060	-0.010	+16.4
I-4-31	-0.061		
I-4-32	-0.059		
*Flat ends			
Average % Δ and Std. Dev.			
I-4-29 and I-4-30 (flat ends)	-0.060 $\pm$ 0.000	-0.012 $\pm$ 0.003	+11.1 $\pm$ 7.5
I-4-31 and I-4-32 (round ends)	-0.060 $\pm$ 0.001		
I-4-29 through I-4-32	-0.060 $\pm$ 0.000		

TABLE XXXVII

High Temperature Controlled Density
After 3013 MWD/AT_k

<u>Density 2.10 g/cm³ - With Grain</u>			
Sample	%Δ L	%Δ W	%Δ CTE
*D-5-8	-0.055	-0.005	+7.7
*D-5-9	-0.055	-0.006	+9.4
D-5-10	-0.073		
D-5-11	-0.068		
D-5-12	-0.055		
Average %Δ and Std. Dev.			
D-5-8 and D-5-9 (flat ends)	-0.055 ± 0.000	-0.006 ± 0.001	+7.7
D-5-10 through D-5-12 (round ends)	-0.065 ± 0.009		+9.4
D-5-8 through D-5-12	-0.061 ± 0.009		
<u>Density 2.10 g/cm³ - Across Grain</u>			
*D-5-28	+0.068	-----	+6.2
*D-5-29	+0.099	-----	+6.0
D-5-30	+0.081		
D-5-31	+0.107		
D-5-32	+0.089		
Average %Δ and Std. Dev.			
*flat ends			
D-5-28 and D-5-29 (flat ends)	+0.084 ± 0.021	-----	+6.1 ± 0.1
D-5-30 through D-5-32 (round ends)	+0.092 ± 0.013		
D-5-28 through D-5-32	+0.089 ± 0.015		
The approximate lengths of samples D-5-28 through D-5-32 is 2.8 inches.			
These samples were baked to as near 3600°C as possible and were cut from the companion stock from which samples D-4-1 through D-4-1 and D-4-21 through D-4-28 were cut.			

TABLE XXXVIII

Superfine Series

Sample Identification	Exposure (MWD/AT)	Avg. ΔL (%)	Avg. ΔWt (%)	Avg. ΔCTE (%)	Avg. ΔE (%)	Avg. ΔE (%)
SFL-1 through 8	2234	-0.076	-0.021	+21.7	-----	-----
SFL-10 through 13	3013	-0.091	-0.011	+19.2	+70.2	+76.4

ERRATA

The correct title of the table on Page 48 of Appendix A in Part I of this report is "Table XL. R Series, With Grain 'B' Samples." The correct title of the table on Page 60 of the same appendix is "Table XXVIII. High Temperature Controlled Density Series, B. D. ~ 2.10 g/cc."

INTERNAL DISTRIBUTION

Copy Number

1	F. W. Albaugh
2	T. W. Ambrose
3	J. H. Cox
4	D. R. de Halas
5	J. W. Helm
6	J. L. Jackson
7	L. D. Johnson
8	S. S. Jones
9	W. C. Morgan
10	R. E. Nightingale
11	E. M. Woodruff
12-55	H. H. Yoshikawa
56-60	Extra
61	Technical Information Files
62-63	Technical Publications

EXTERNAL DISTRIBUTION (Special)

Number of Copies

3	Atomic Energy Commission, Washington Division of Reactor Development Attn: R. E. Pahler J. M. Simmons I. F. Zartman
2	General Atomic Division Attn: R. B. Duffield G. B. Engle
1	Great Lakes Carbon Company P. O. Box 637 Niagara Falls, New York Attn: Bruce Bailey
1	Oak Ridge Operations Office Attn: D. F. Cope
5	Richland Operations Office Attn: L. R. Lucas L. F. Perkins R. L. Plum R. K. Sharp Technical Information Library
1	Speer Carbon Company Research and Development Laboratories Packard Road & 47th Street Niagara Falls, New York
26	Union Carbide Corporation, Cleveland Parma Research Center Attn: J. F. Doar (13) J. T. Meers (13)

EXTERNAL DISTRIBUTION (Special)(contd)

Number of Copies

1	Union Carbide Corporation (ORNL-Y-12) Attn: F. L. Carlsen
1	Wright Air Development Division Wright-Patterson AFB, Ohio Attn: R. H. Wilson (Major)