

**DRAGON PROJECT USE ONLY**

Part I

O.E.C.D. HIGH TEMPERATURE REACTOR PROJECT  
DRAGON



**Dragon Project Report**

**DIMENSIONAL CHANGES OF GRAPHITE SPECIMENS  
IRRADIATED IN DRAGON FUEL ELEMENT 700**

by  
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November, 1967

Dimensional Changes of Graphite Specimens Irradiated  
in Dragon Fuel Element 700 (Parts I and II)

Since this report was written the results of the graphite damage calibration experiment carried out in the High Flux Reactor (H.F.R.) Petten have shown that the previously assumed nickel dose equivalence between H.F.R. and Dragon was incorrect and that the correct relationship is as follows:

$$10^{20} \text{ n cm}^{-2} \text{ Ni dose Dragon} = 1.7 \times 10^{20} \text{ n cm}^{-2} \text{ Ni dose H.F.R. Petten} = \\ 1.7 \times 10^{20} \text{ n cm}^{-2} \text{ Ni dose Dido}$$

Dragon Ni doses are used in the report.

In the report, graphite specimen temperatures in Dragon have been derived from the shrinkage behaviour of Pechiney G5 graphite (Ref. No.60) which has been well characterised at 600, 900 and 1200°C in H.F.R. Petten. An alteration in the Ni dose equivalence therefore has the consequence of altering the axial temperature profile derived for Dragon fuel spines. For example, the curve shown in Fig.8, Part I must be reduced by 100°C on this account, and this correction applies to all Dragon spine graphite temperatures quoted in both Parts I and II of the report. It is to be noted that this correction brings the derived curve (Fig. 6 Part I) into much better agreement with the thermocouple readings.

M. R. Everett

20th March 1968

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IRRADIATED IN DRAGON FUEL ELEMENT 700

PART I

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ABSTRACT

Fuel element 700 was the first of the four elements in the First Metallurgical Series to be removed from the Dragon core, having received a fast neutron dose of  $\sim 3 \times 10^{20}$  n cm<sup>-2</sup>. The changes in physical properties of the graphite specimens, contained in the spines of this element, were measured and correlated with the available and derived data on temperature and neutron dose.

CONTENTS

	<u>PAGE NO.</u>
1. INTRODUCTION	5
2. PRE-IRRADIATION DATA	6
2.1 Graphites	6
2.2 Specimens	7
2.3 Flux Monitors	7
3. POST-IRRADIATION DATA	20
3.1 Irradiation History	20
3.2 Physical Properties	20
3.2.1 Physical Appearance	20
3.2.2 Activity of the Specimens	21
3.2.3 Dimensional Changes	21
4. INTERPRETATION OF DATA	21
4.1 Derivation of Axial Temperature Profile	21
4.2 Results	23
5. DISCUSSION	23
6. CONCLUSIONS	28
7. REFERENCES	28

LIST OF TABLES

TABLE

1. Position of Ceramic Flux Monitors in Rod 3 of Element 700	8
2. Lengths of Invar Reference Standards	8
3.1 First Series Metallurgical Elements - Element 1 - Rod 1	9
3.2     "     "     "     "     -     "     " - Rod 2	11
3.3     "     "     "     "     -     "     " - Rod 3	13
3.4     "     "     "     "     -     "     " - Rod 4	16
3.5     "     "     "     "     -     "     " - Rod 5	18

TABLEPAGE NO.

4.	Typical Physical Properties and Summary of Irradiation Shrinkages, for the Range of Graphites Irradiated in Fuel Element 700	24
5.	Details and Dimensional Changes of Pyrolytic Graphite Samples (Ex Winfrith)	26
6.	Details and Dimensional Changes of Pyrolytic Graphite Samples (Ex R.M.L. Culcheth)	27

LIST OF ILLUSTRATIONSFIGURE

- Graphite Specimens and Containers
- Irradiation History of Fuel Element 700
- Shrinkage of Graphite No. 1 vs. Height in Reactor Core
- Shrinkage of PGA Graphite vs. Height in Reactor Core
- Shrinkage of G5 Graphite vs. Height in Reactor Core with Petten Data Superimposed
- Log Shrinkage of G5 // Graphite vs.  $\frac{10^4}{T^{\circ}K}$  for a Range of Neutron Doses
- Log Shrinkage of G5  $\perp$  Graphite vs.  $\frac{10^4}{T^{\circ}K}$  for a Range of Neutron Doses
- Temperature and Dose Curves vs. Height in Reactor Core for Fuel Element 700
- Log Shrinkage of PGA, G5 and HX30 Graphite vs.  $\frac{10^4}{T^{\circ}K}$
- Log Shrinkages of Graphites in Rod 1 vs.  $\frac{10^4}{T^{\circ}K}$
- Log Shrinkage of Graphites in Rod 2 vs.  $\frac{10^4}{T^{\circ}K}$
- Log Shrinkage of Graphites in Rod 2 vs.  $\frac{10^4}{T^{\circ}K}$
- Log Shrinkage of Graphites in Rod 3 vs.  $\frac{10^4}{T^{\circ}K}$
- Log Shrinkage of Graphites in Rod 4 vs.  $\frac{10^4}{T^{\circ}K}$

FIGURE

15. Log Shrinkage of Graphites in Rod 5 vs.  $\frac{10^4}{T^{\circ}K}$
16. Axial Temperature Profiles in Fuel Element
17. Physical Properties of PGA Graphite Ex Fuel Element 700
18. Physical Properties of G5 Graphite Ex Fuel Element 700
19. Physical Properties of HX30 Graphite Ex Fuel Element 700
20. Physical Properties of Graphite No. 1 Ex Fuel Element 700
21. Physical Properties of Graphite 5 Ex Fuel Element 700
22. Physical Properties of Graphite 6 Ex Fuel Element 700
23. Physical Properties of Graphite 7 Ex Fuel Element 700
24. Physical Properties of Graphite No. 16 Ex Fuel Element 700
25. Physical Properties of Graphite No. 17 Ex Fuel Element 700

# DIMENSIONAL CHANGES OF GRAPHITE SPECIMENS

## IRRADIATED IN DRAGON FUEL ELEMENT 700

### PART I

by

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#### 1. INTRODUCTION

The objective of the Dragon graphite irradiation programme is to study the behaviour of a wide range of graphites, when irradiated under conditions existing in an HTGCR. This requires that the graphites should be tested at temperatures ranging from 600°C to 1400°C, whilst being subject to neutron doses of up to  $3 \times 10^{22}$  nvt (Dido Ni dose).

Work on a range of graphites, either of direct interest to the Dragon experiment or to a proposed power reactor, is being carried out, by Blackstone [1] in the HFR at Petten. Specimens in these experiments have received doses of up to  $5 \times 10^{21}$  n cm<sup>-2</sup>.

Some graphites have been irradiated in the Dragon Reactor in the two uprated elements, which were in the core for a fifty day period during the 10 MW run (November, 1965 to January, 1966). The pre-irradiation details of these two elements have been described by Voice [2, 3] and the irradiation results have been analysed by Graham [4].

This report gives details relevant to the graphite specimens irradiated in the first element (No. 700) of the "Metallurgical Series", which was irradiated from May to August, 1966 under 20 MW conditions and received a fast neutron dose of approximately  $3 \times 10^{20}$  nvt (Ni dose Dragon). The remaining seven elements of the "Metallurgical Series", will be removed from the core at intervals such that each will be subjected to an increasingly higher dose.

Further examination of the results, on a more theoretical basis, is being carried out [5] in a separate series of reports.

Graphites very rarely have bulk physical properties which are perfectly isotropic, because, during the manufacturing process, the graphite crystals tend to take up some degree of preferred orientation, depending on the material used and the mode of formation, whether "extruded" or "pressed". If the graphite is "extruded", it will be found that a major proportion of the crystallites are aligned in such a way that the basal planes are parallel to the direction of extrusion. Consequently this is often called the "parallel" direction (i.e., this is the major direction of alignment of the crystallites). There are two perpendicular ( $\perp$ ) directions in an extruded graphite, both of which are normal to the extrusion direction. Now, for a pressed graphite the

crystallites take up positions such that the basal planes are perpendicular to the direction of pressing and give two "parallel" (//) directions. The "perpendicular" ( $\perp$ ) crystallite direction of a pressed graphite, is, therefore, parallel to the direction of forming.

Then, if // and  $\perp$  refer only to the orientation of the crystals, it can be said that:

- (a) an extruded graphite has one "parallel" and two "perpendicular" directions, and
- (b) a pressed graphite has one "perpendicular" and two "parallel" directions.

The above definitions of "parallel" and "perpendicular" are those which are used in this report.

## 2. PRE-IRRADIATION DATA

### 2.1 Graphites

The following graphites were studied in this experiment:

- (a) graphites of direct interest to the Dragon Reactor,
- (b) nuclear grade fine grain graphites already in production,
- (c) experimental graphites supplied by the manufacturers and
- (d) a few samples of pyrocarbon.

The graphites contained in Rod 2 were supplied by RMI, Culcheth, Similarly, a number of American graphites, supplied by Battelle Northwest Laboratory, USA, were irradiated in Rod 3. Other materials irradiated, were several Gilsonite based graphites and some isotropic or near-isotropic graphites, of British or Continental manufacture.

So that direct comparisons could be made between the damage induced in the graphites by the Dragon Reactor and that caused by other reactors, the graphites HX30, PGA and P echiney G5 were included in most of the rods to act in part as reference samples. Details of these graphites are as follows:

HX30 This is an experimental graphite developed by AERE, Harwell so as to have a fine grained texture and a controlled pore size. Some of the fuel tubes, in the Dragon Second Charge, have been made from this material.

PGA British Pile Grade A material manufactured by British Achesons Electrodes Limited and Anglo Great Lakes, the former being singly impregnated with pitch and the latter doubly impregnated. (BAEL material was irradiated in fuel element 700).

## G5

A fine grained Pechiney graphite, which has been doubly impregnated with pitch and which contains no carbon black. Some fuel tubes in the second Dragon core have been made from G5 graphite.

## Graphite 34

This a fine grained, pressed graphite, of high strength, manufactured by Carbone Lorraine. It has been used for the top blocks of the Dragon fuel elements.

## 2.2 Specimens

The graphites were machined into cylindrical specimens of nominal length 2.625 in except for those of graphite numbers 26 (// and ⊥); 13 (⊥) and 2 (⊥) which had to be manufactured to a nominal length of 1.750 in because of shortage of material. The diameters of all specimens were 0.22 in. Illustrations of these specimens, together with the graphite spine-container can be found in Fig. 1.

Accurate measurements (i.e., to 0.0001 in) were made on every specimen at 20°C by rotating the specimen in a transducer comparator jig and noting the maximum and minimum readings. These are recorded in Table 3. Details of the apparatus can be found in [2]. The jig was "zeroed" against standard lengths of invar (measured to within ±0.00001 in) the actual lengths of which can be found in Table 2.

The pyrocarbon could not be machined into cylindrical specimens because of its laminar structure, and therefore was cut into bars of square cross section, the lengths being approximately 1.75 in. Actual length measurements were made using the same comparator apparatus as for the graphite specimens. However, because of the difficulty in manufacture, all the major length measurements, corresponded to the "a-axis" direction of the material. Consequently, measurements in the "b and c-axis" directions had to be made, using a micrometer gauge.

## 2.3 Flux Monitors

The flux distribution throughout the element was measured by irradiating pairs of Ni and Co ceramic monitors [2] in alternate containers of Rod 3 (see Table 1). Every monitor was encapsulated in a separate silica envelope and then each pair of Ni and Co monitors was wrapped in niobium foil. The end cap of each spine container contained a diametrically drilled hole into which the monitors were placed.

The reactions used in the monitors are:

Ni-58 (n,p) Co-58 - to measure the fast neutron flux.

Co-59 (n,γ) Co-60 - to measure the thermal flux and to provide a correction for the loss of Co-58 in the reaction Co-58 (n,γ) Co-59, which has an appreciable cross section.

Table 1 Position of Ceramic Flux Monitors in Rod 3 of Element 700	
Monitor Type and Reference Number	Position above Datum* inches
Ni-113 Co-133	61.00
Ni-131 Co-139	48.25
Ni-119 Co-103	35.51
Ni-127 Co-123	22.76
Ni-139 Co-111	10.10

\*The datum level is the basal plane of the fuel in the core

Table 2 Lengths of Invar Reference Standards	
Standard	Length (20°C) in
a	2.62489
c	2.62470
d	2.61482
e	2.60977
b	1.75025
f	1.75050
g	1.74465

Table 3.1  
First Series Metallurgical Elements - Element 1 - Rod 1  
Fuel Element 700 - Position 1/2

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths						Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-400 °C) x 10 <sup>-6</sup> °C <sup>-1</sup>		Electrical Resistivity mΩ cm		Young's Modulus 10 <sup>5</sup> psi		Total Length and Weight of Container Plus Contents
					Pre-Irradiation			Post-Irradiation						Pre	Post	Pre	Post	Pre	Post	
1-1																		5.753 in 157.499 g		
1-2																		6.316 in 173.999 g		
1-3																		6.318 in 170.838 g		
1A	21	//	1A1	43.31	-1.0	a	-0.9	-10.7	e	-10.0	-9.4	-9.6	-0.37			1.30	1.64	1.40	1.84	
	21	⊥	1A2		-1.3	a	-0.8	-9.8	e	-7.0	-7.4	-7.6	-0.29			1.11	1.63			
	3A	⊥	1A3		-1.2	a	-0.8	-9.8	e	-9.2	-8.5	-8.7	-0.33			1.59	1.96			
	3A	//	1A4		-1.6	a	-1.0	-12.5	e	-11.8	-10.9	-11.1	-0.42			1.44	1.77			
	16	//	1A5		+0.7	a	+1.4	-7.3	e	-6.0	-7.6	-7.8	-0.30	4.0	4.69	0.72				
	16	⊥	1A6		-3.3	a	-2.9	-9.8	e	-9.1	-6.3	-6.5	-0.25	4.5	4.80	0.77				
	17	//	1A7		-0.3	a	+0.2	-7.6	e	-7.2	-7.4	-7.6	-0.29	4.40	4.76	0.80	1.30			1.37
	17	⊥	1A8		-1.1	a	-0.7	-6.4	e	-6.1	-5.3	-5.5	-0.21	4.96	5.02	0.38				
	59	//	1A9		-0.1	a	+0.2	-11.3	e	-11.0	-11.2	-11.4	-0.43			0.48	0.85			
	60	//	1A10		-0.8	a	+1.2	-12.4	e	-11.5	-12.9	-13.1	-0.49			1.30	2.10			
	21	//	1A11	40.56	-2.5	a	-1.6	-12.0	e	-11.0	-9.5	-9.7	-0.37			1.30	1.74	1.30	1.43	
	21	⊥	1A12		-2.5	a	+0.2	-11.5	e	-7.4	-8.2	-8.4	-0.32			1.11	1.67			
	3A	⊥	1A13		-1.7	a	-1.3	-10.5	e	-9.9	-8.7	-8.9	-0.34			1.59	1.95			
	3A	//	1A14		-2.1	a	-1.3	-13.4	e	-12.4	-11.2	-11.4	-0.43			1.54	1.82			
	16	//	1A15		-0.5	a	+1.3	-8.6	e	-7.2	-8.3	-8.5	-0.33			0.72	1.24			
	16	⊥	1A16		+0.9	a	+1.1			Broken						0.77	-			
	17	//	1A17		+0.7	a	+1.1	-6.7	e	-6.5	-7.5	-7.7	-0.30	4.40	4.62	0.50				
	17	⊥	1A18		-1.1	a	-0.4	-7.9	e	-7.5	-7.0	-7.2	-0.28			0.88	1.48			
	62	//	1A19		-0.2	a	0.0	-11.0	e	-10.8	-10.8	-20.9	-0.80	1.30	1.29	0.71				
	58	//	1A20																	
					1.759 x 0.258 x 0.255 in 4.145 g		1.507 x 0.276 x 0.250 in		(-14.3 x -6.98 x -1.96%)											
1B	21	//	1B1	36.80	-1.3	a	-0.8	-13.4	e	-13.1	-12.2	-12.4	-0.47			1.00	1.64	1.30	1.45	
	21	⊥	1B2		-1.9	a	+0.7	-12.4	e	-9.7	-9.7	-9.9	-0.38			1.11	1.73			
	3A	⊥	1B3		-1.4	a	-1.2	-12.0	e	-11.9	-10.6	-10.8	-0.41			1.59	1.93			
	3A	//	1B4		-2.0	a	-1.6	-15.0	e	-14.6	-13.0	-13.7	-0.50			1.44	1.84			
	16	//	1B5		-0.2	a	+0.2	-9.6	e	-9.0	-9.3	-9.5	-0.36			0.72	1.27			
	16	⊥	1B6		0.0	a	+0.1	-8.2	e	-7.9	-8.1	-8.3	-0.32			0.77	1.29			
	17	//	1B7		-0.4	a	-0.3	-9.1	e	-9.0	-8.7	-8.3	-0.34	4.40	4.74	0.50	1.60			
	17	⊥	1B8		-0.6	a	-0.4	-8.3	e	-8.0	-7.6	-7.6	-0.30	4.96	4.89	0.88	1.42			
	59	//	1B9		-0.9	a	-0.5	-13.9	e	-13.5	-13.0	-13.2	-0.50	1.3	1.06	0.48	0.99			
	59	⊥	1B10		0.0	a	-0.5	+3.3	e	-7.5	-8.2	-8.4	-0.32	3.2	3.54	0.91	0.88			
	21	//	1B11	34.18	-2.9	a	-1.6	-5.5	d	-4.4	-2.7	-2.8	-0.49			1.00	1.73	1.30	1.88	
	21	⊥	1B12		-0.6	a	+0.1	-10.9	e	-10.3	-10.4	-10.6	-0.40			1.11	1.75			
	3A	⊥	1B13		-2.3	a	-1.9	-12.6	e	-12.4	-10.4	-10.6	-0.40			1.59	1.97			
	3A	//	1B14		-0.6	a	-0.5	-13.4	e	-13.3	-12.8	-13.0	-0.50			1.44	1.78			
	16	//	1B15		0.0	a	+0.2	-10.0	e	-9.7	-9.9	-10.1	-0.39			0.72	1.19			
	16	⊥	1B16		-0.3	a	-0.1	-7.6	e	-7.2	-7.2	-7.4	-0.28			0.77	1.36			
	17	//	1B17		-0.8	a	-0.6	-10.5	e	-10.2	-9.6	-9.8	-0.37	4.40	4.66	0.80	1.35			
	17	⊥	1B18		-1.0	a	-0.7	-8.5	e	-8.2	-7.5	-7.7	-0.29			0.38	1.32			
	60	⊥	1B19		+0.6	a	+0.8	-14.4	e	-14.0	-14.9	-15.1	-0.57			1.68	2.66			
	62	⊥	1B20		-0.1	a	0.0	-6.9	d	-6.7	-6.8	-6.9	-0.54	2.90	2.81	1.20	2.02			
					1.759 x 0.275 x 0.238 in		1.575 x 0.258 x 0.256 in		(-12.9 x -6.2 x +7.6%)											
1C	21	//	1C1	30.55	-0.4	a	+0.3	-13.7	e	-13.3	-13.5	-13.7	-0.52			1.00	1.71	1.40	1.81	
	21	⊥	1C2		-2.3	a	-2.0	-13.3	e	-12.9	-11.0	-11.2	-0.43			1.11	1.70			
	3A	⊥	1C3		-0.7	a	-0.6	-12.4	e	-12.2	-11.7	-11.9	-0.45			1.59	2.03			
	3A	//	1C4		-0.7	a	-0.5	-5.7	d	-5.2	-4.8	-4.9	-0.57			1.44	1.92			
	16	//	1C5		-0.3	a	-0.2	-10.3	e	-9.9	-9.9	-10.1	-0.38	4.0	4.51	0.72	1.37			
	16	⊥	1C6		-0.6	a	+0.4	-9.3	e	-7.4	-8.2	-8.4	-0.32	4.5	4.72	0.77	1.31			
	17	//	1C7		-0.2	a	+0.2	-9.6	e	-9.2	-9.4	-9.6	-0.37	4.40	4.92	0.50	1.62			
	17	⊥	1C8		-0.9	a	-0.4	-9.6	e	-9.0	-8.7	-8.3	-0.36	4.96	4.54	0.38	1.40			
	59	//	1C9		-0.8	a	-0.5	-14.1	e	-13.9	-13.4	-13.5	-0.52	1.3	1.13	0.48	0.99			
	60	//	1C10		+1.0	a	+1.0	-12.0	d	-11.6	-12.8	-22.9	-0.87	2.0	2.06	1.00	1.72			
	21	//	1C11	27.80	-1.3	a	-0.9	-14.5	e	-13.0	-12.6	-12.8	-0.49			1.00	1.71	1.40	2.19	
	21	⊥	1C12		-1.1	a	-0.7	-12.0	e	-11.6	-10.9	-11.1	-0.42			1.11	1.86			
	3A	⊥	1C13		-1.9	a	-1.4	-12.0	e	-11.4	-10.1	-10.3	-0.39			1.59	2.05			
	3A	//	1C14		-1.2	a	-1.0	-15.0	e	-15.0	-13.9	-14.1	-0.54			1.44	1.80			
	16	//	1C15		-0.4	a	0.0	-10.1	e	-9.8	-9.7	-9.9	-0.38	4.0	4.77	0.72	1.26			
	16	⊥	1C16		-1.9	a	-1.2	-10.4	e	-9.2	-8.4	-8.6	-0.33	4.5	5.29	0.77	1.40			
	17	//	1C17		-0.9	a	-0.4	-10.9	e	-10.8	-10.2	-10.4	-0.40			0.90	1.31			
	17	⊥	1C18		-0.5	a	-0.2	-8.9	e	-8.6	-8.4	-8.6	-0.33	4.96	4.98	0.88	1.58			
	62	//	1C19		+0.8	a	+0.9	-12.2	d	-12.1	-13.0	-23.1	-0.88	1.3	1.21	0.71	1.24			
	58	//	1C20																	

Table 3.1 (contd.)

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths						Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-120°C) x 10 <sup>-6</sup> °C <sup>-1</sup>		Electrical Resistivity μΩ cm		Young's Modulus 10 <sup>5</sup> psi		Total Length and Weight of Container Plus Contents
					Pre-Irradiation			Post-Irradiation						Pre-	Post-	Pre-	Post-	Pre-	Post-	
														Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	
5/A/1	Solid Spine of PGM for Small Bore Fuel Compact																	3.154 in		
1D	21	//	1D1	} 20.88	-0.5	a	-0.1	-8.6	o	-8.0	-8.2	-8.4	-0.31			1.00	1.40			
	21	⊥	1D2		-0.7	a	0.0	-9.4	o	-8.4	-8.4	-8.6	-0.34			1.11	1.84			
	34	⊥	1D3		-1.2	a	-0.8	-9.7	o	-9.1	-8.4	-8.6	-0.33			1.59	2.08			
	34	//	1D4		-1.6	a	-1.0	-11.6	o	-11.0	-10.0	-10.2	-0.39			1.44	1.85			
	16	//	1D5		-0.3	a	-0.8	-8.2	c	-7.7	-8.5	-8.7	-0.34	4.0	4.69	0.72	1.35	1.40	1.89	
	16	⊥	1D6		+0.3	a	+0.4	-7.0	o	-6.8	-7.3	-7.5	-0.28	4.5	5.38	0.77	1.40	1.25	1.85	
	17	//	1D7		-0.3	a	-0.3	-7.2	c	-6.6	-6.9	-7.1	-0.27	4.40	4.69	0.80	1.55	1.30	1.62	
	17	⊥	1D8		-0.8	a	-0.5	-6.7	a	-6.5	-6.0	-6.2	-0.24	4.96	5.30	0.88	1.68	1.11	1.34	
	59	//	1D9		-1.3	a	-1.0	-12.8	o	-12.5	-11.5	-11.7	-0.44	1.3	1.03	0.48	1.06	1.93	2.64	
	59	⊥	1D10		-1.0	a	-0.8	-8.0	c	-7.6	-6.9	-7.1	-0.27	3.2	3.20	0.91	1.97	0.88	0.95	
	21	//	1D11	} 18.26	-1.8	a	-1.4	-10.8	o	-10.3	-8.9	-9.1	-0.35			1.00	1.85			
	21	⊥	1D12		-2.4	a	+1.6	-9.6	o	-5.0	-6.9	-7.1	-0.27			1.11	2.01			
	34	⊥	1D13		-1.6	a	-1.3	-9.5	o	-9.2	-7.9	-8.1	-0.31			1.59	2.13			
	34	//	1D14		-2.2	a	-2.0	-13.0	o	-12.6	-10.7	-10.9	-0.42			1.44	1.97			
	16	//	1D15		-0.2	a	-0.2	-7.7	c	-6.8	-7.2	-7.4	-0.28	4.0	4.19	0.72	1.43	1.40	1.83	
	16	⊥	1D16		-2.8	a	-2.6	-8.1	c	-7.9	-5.5	-5.5	-0.21	4.5	5.19	0.77	1.50	1.25	1.79	
	17	//	1D17		-0.5	a	-0.1	-7.0	c	-6.5	-6.4	-6.6	-0.25	4.40	4.82	0.80	1.57	1.30	1.65	
	17	⊥	1D18		-0.8	a	-0.4	-6.4	o	-6.0	-5.6	-5.8	-0.22	4.96	5.25	0.88	1.68	1.11	1.23	
	60	⊥	1D19		+0.9	a	+1.1	-11.2	o	-10.8	-12.0	-12.2	-0.46			1.68	2.59			
	62	⊥	1D20		-0.3	a	0.1	-14.8	o	-14.6	-14.5	-14.7	-0.56	2.90	2.27	1.20	2.06	0.92	1.33	
1E	21	//	1E1	} 14.63	0.0	a	+0.3	-6.0	o	-5.7	-6.0	-6.2	-0.24			1.00	1.73			
	21	⊥	1E2		-1.4	a	+0.4	-5.8	o	-3.4	-4.1	-4.3	-0.16			1.11	2.12			
	34	⊥	1E3		-1.9	a	-1.7	-7.0	o	-6.9	-5.1	-5.3	-0.20			1.59	2.12			
	34	//	1E4		-1.1	a	-0.9	-9.0	c	-8.7	-7.8	-8.0	-0.31			1.44	1.98			
	16	//	1E5		-0.2	a	+0.1	-5.4	o	-5.1	-5.2	-5.4	-0.21	4.0	4.45	0.72	1.38	1.40	1.89	
	16	⊥	1E6		-0.1	a	+0.2	-4.1	c	-3.7	-3.8	-4.0	-0.15	4.5	4.97	0.77	1.45	1.25	1.85	
	17	//	1E7		-0.2	a	+0.2	-6.1	c	-5.6	-5.8	-5.0	-0.23			0.80	1.30			
	17	⊥	1E8		-1.0	a	-0.8	-4.7	c	-4.5	-3.7	-3.9	-0.15	4.96	5.07	0.88	1.69	1.11	1.45	
	59	//	1E9		-0.3	a	0.0	-8.5	o	-8.2	-8.2	-8.4	-0.32	1.3	1.06	0.48	1.00	1.93	2.86	
	60	//	1E10		-0.1	a	+0.1	-7.2	d	-6.9	-7.0	-7.1	-0.65	2.0	1.83	1.00	1.43	1.50	2.82	
	21	//	1E11	} 11.88	-3.3	a	-2.4	-7.6	o	-6.4	-4.2	-4.4	-0.17			1.00	1.81			
	21	⊥	1E12		-2.2	a	-1.8	-5.0	o	-3.6	-2.3	-2.5	-0.10			1.11	1.98			
	34	⊥	1E13		-1.9	a	-1.7	-6.5	o	-6.4	-4.6	-4.8	-0.18			1.59	2.10			
	34	//	1E14		-1.7	a	-1.2	-8.0	o	-7.5	-6.3	-6.5	-0.25			1.44	1.94			
	16	//	1E15		-1.1	a	-0.7	-4.9	o	-4.4	-3.7	-3.9	-0.15			0.72	-			
	16	⊥	1E16		-0.4	a	-0.2	-3.5	o	-3.2	-3.0	-3.2	-0.12	4.5	5.07	0.77	1.43	1.25	1.89	
	17	//	1E17		+0.4	a	+0.8	-3.4	o	-3.0	-3.8	-4.0	-0.15	4.40	4.60	0.80	1.37	1.30	2.05	
	17	⊥	1E18		-0.6	a	-0.2	-3.2	o	-2.9	-2.6	-2.8	-0.11	4.96	5.12	0.88	1.66	1.11	1.52	
	62	//	1E19		-0.2	a	-0.1	-13.5	o	-13.4	-13.3	-13.5	-0.51	1.30	1.38	0.71	1.22	1.95	3.11	
	58	//	1E20																	
					1.758 x 0.296 x 0.255 in			1.550 x 0.271 x 0.249 in			(-11.8 x +5.86 x -2.35)									
					4.109 g															
1F	21	//	1F1	} 8.13	-2.1	a	-0.1	-3.4	o	-2.3	-1.7	-1.9	-0.77			1.00	1.93			
	21	⊥	1F2		-1.8	a	-0.0	-1.5	o	-0.4	0.0	-0.2	-0.01			1.11	2.19			
	34	⊥	1F3		-0.9	a	-0.6	-4.1	o	-4.0	-3.3	-3.5	-0.13			1.59	2.15			
	34	//	1F4		-1.8	a	-1.0	-2.6	o	-2.0	-3.9	-4.1	-0.16			1.44	2.03			
	16	//	1F5		-1.6	a	-1.0	-2.5	o	-2.3	-1.1	-1.3	-0.05	4.0	4.74	0.72	1.40	1.40	1.97	
	16	⊥	1F6		-0.3	a	-0.1	-0.8	o	-0.6	-0.5	-0.7	-0.03	4.5	5.28	0.78	1.49	1.25	1.91	
	17	//	1F7		+0.1	a	+0.2	-1.3	o	-1.0	-1.3	-1.5	-0.06			0.80	1.66			
	17	⊥	1F8		-1.9	a	-0.8	-1.5	o	-1.3	-0.1	-0.3	-0.01			0.88	1.66			
	59	//	1F9		-0.4	a	-0.2	-2.9	o	-2.6	-2.4	-2.6	-0.10	1.3	1.11	0.48	1.05	1.93	2.83	
	59	⊥	1F10		-1.6	a	-1.2	-2.0	o	-1.5	-0.4	-0.6	-0.02	3.2	3.17	0.91	2.03	0.88	0.99	
	21	//	1F11	} 5.51	-4.2	a	-2.8	-5.0	o	-3.9	-0.9	-1.1	-0.04			1.00	1.90			
	21	⊥	1F12		-1.1	a	-0.6	-1.0	o	-0.5	+0.1	-0.1	0.00			1.11	2.02			
	34	⊥	1F13		+0.1	a	+0.4	-3.1	o	-3.0	-3.3	-3.5	-0.13			1.59	2.16			
	34	//	1F14		-1.7	a	-0.9	-5.4	o	-5.0	-3.9	-4.1	-0.16			1.44	1.91			
	16	//	1F15		-1.1	a	-0.3	-2.0	o	-1.3	-0.9	-1.1	-0.04	4.0	4.82	0.72	1.41	1.40	1.88	
	16	⊥	1F16		-0.4	a	-0.2	-0.8	o	-0.6	-0.4	-0.6	-0.02	4.5	5.12	0.77	1.50	1.25	1.74	
	17	//	1F17		-0.1	a	+0.2	-0.7	o	-0.5	-0.7	-0.9	-0.03	4.40	4.44	0.80	1.73	1.30	1.43	
	17	⊥	1F18		-0.8	a	+0.3	-0.7	o	+0.1	-0.1	-0.3	-0.01	4.96	5.18	0.88	1.76	1.11	1.37	
	60	⊥	1F19		+0.7	a	+0.7	-2.4	o	-2.3	-3.0	-3.2	-0.12	3.75	3.99	1.68	2.78	1.18	1.19	
	62	⊥	1F20		-0.5	a	-0.4	-4.1	o	-4.0	-3.6	-3.8	-0.14	2.90	2.92	1.20	2.05	0.92	1.51	
16/A/1	Solid Spine of PGM for Small Bore Fuel Compact																	3.154 in		

Table 3.2  
First Series Metallurgical Elements - Element 1 - Rod 2  
Fuel Element 700 - Position 1/2

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths		Difference in Gage Readings (0.001 in)	Length Change (0.001 in), i.e. Gage Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-90°C) x 10 <sup>-6</sup> °C <sup>-1</sup>		Electrical Resistivity m/Ω cm		Young's Modulus 10 <sup>9</sup> psi		Total Length and Weight of Container Plus Contents		
					Pre-Irradiation	Post-Irradiation				Pre-Irradiation	Post-Irradiation	Pre-Irradiation	Post-Irradiation	Pre-Irradiation	Post-Irradiation			
																	Irradiation	Irradiation
2-1	Solid Spine of PGA																	
2-2	Solid Spine of PGA																	
2-3	Solid Spine of PGA																	
2A	39	//	FTY	43.12	-4.8	a	-4.7	-12.5	o	-12.1	-7.6	-7.8	-0.30				6.376 in 136.097 g	
	39	⊥	FVZ		-7.0	a	-6.8	-13.6	o	-13.4	-6.4	-6.6	-0.25					
	40	//	FIA		-9.1	a	-8.8	-10.5	d	-9.9	-0.3	-10.4	-0.40					
	40	⊥	FVB		-4.0	a	-3.9	-13.3	o	-13.3	-9.5	-9.7	-0.37					
	41	//	FZC		-4.9	a	-4.9	-13.7	o	-13.5	-8.7	-8.9	-0.34					
	41	⊥	GAD		-7.3	a	-6.9	-14.7	o	-14.3	-7.4	-7.6	-0.29					
	42	//	GBE		-5.2	a	-4.8	-7.2	d	-7.0	-2.1	-12.2	-0.46					
	42	⊥	GCP		-5.3	a	-5.1	-14.1	o	-14.0	-8.5	-8.7	-0.33					
	43	//	GUG		-5.5	a	-5.0	-13.4	o	-12.6	-7.8	-8.0	-0.30					
	43	⊥	GWH		-9.0	a	-8.7	-5.7	d	-5.4	-3.8	-13.9	-0.26					
	44	//	GPI		40.50	-2.7	a	-2.7	-15.1	c	-15.0	-12.3	-12.5	-0.48				
	44	⊥	GQE			-2.7	a	-2.6	-13.5	c	-13.3	-10.8	-11.0	-0.42				
	45	//	GHE			-3.1	a	-2.9	-12.2	c	-12.0	-9.1	-9.3	-0.35				
	45	⊥	GIM			-3.2	a	-2.9	-10.6	o	-10.5	-7.5	-7.7	-0.29				
	46	//	GKN			-2.6	a	-1.3	-9.5	o	-8.5	-7.1	-7.3	-0.28				
	46	⊥	GLO			-2.5	a	-1.5	-11.1	o	-10.0	-8.5	-8.7	-0.33				
	47	⊥	GOS			-3.1	a	-2.9	-9.4	d	-9.0	-6.2	-16.3	-0.62				
Cap 21																		
59	//	2A19	-0.5	a		+0.7	-13.2	o	-12.3	-13.3	-13.5	-0.51	1.3	0.99	0.48	0.87	1.93	2.73
59	⊥	2A20	0.0	a		+0.4	-8.0	o	-7.8	-8.1	-8.3	-0.32	3.2	3.32	0.91	1.72	0.88	0.94
2B	39	//	FTY	36.75		-4.7	a	-4.5	-14.5	o	-14.3	-9.8	-10.0	-0.38				6.377 in 135.709 g
	39	⊥	FVV			-4.9	a	-4.6	-13.1	o	-13.0	-8.3	-8.5	-0.32				
	40	//	FVW			-3.7	a	-3.4	-6.5	d	-6.0	-2.7	-12.8	-0.49				
	40	⊥	FZX			-4.0	a	-4.0	-5.7	d	-5.5	-1.6	-11.7	-0.45				
	41	//	FTY			-5.0	a	-4.8	-6.5	d	-6.2	-1.4	-11.5	-0.48				
	41	⊥	FZL			-5.0	a	-4.7	-6.0	d	-5.8	-1.1	-11.2	-0.43				
	42	//	GBA			-5.1	a	-4.7	-9.5	d	-9.0	-4.3	-14.4	-0.55				
	42	⊥	UCB		-5.5	a	-4.7	-8.2	d	-7.8	-2.9	-13.0	-0.50					
	43	//	GDC		-5.2	a	-5.0	-5.5	d	-5.2	-0.2	-10.3	-0.39					
	45	⊥	GED		-4.9	a	-4.5	-13.7	o	-12.0	-7.9	-8.1	-0.31					
	44	//	GFE		34.13	-2.6	a	-2.4	-6.3	d	-6.1	-3.7	-13.8	-0.53				
	44	⊥	GGF			-2.7	a	-2.5	-14.6	o	-14.3	-11.8	-12.0	-0.46				
	45	//	GHC			-2.8	a	-2.6	-13.0	o	-12.9	-10.2	-10.4	-0.40				
	45	⊥	GIH			-3.1	a	-2.7	-12.0	o	-11.5	-8.8	-9.0	-0.34				
	46	//	GKI			0.0	a	+3.0	-8.5	c	-6.5	-9.0	-9.2	-0.30				
	46	⊥	GLX			-0.4	a	+0.3	-10.4	o	-9.6	-10.0	-10.2	-0.39				
	47	⊥	GOM			-3.1	a	-2.8	-11.5	d	-11.3	-8.5	-18.6	-0.71				
Cap 17																		
59	//	2B19	-0.4	a		-0.1	-6.2	d	-5.3	-5.4	-15.5	-0.59			0.48	0.85		
59	⊥	2B20	-0.9	a		-0.3	-10.4	o	-9.5	-9.3	-9.5	-0.36			0.91	1.74		
2C	39	//	FPO	30.37		-4.9	a	-4.8	-6.7	d	-6.4	-1.7	-11.8	-0.45				6.376 in 135.684 g
	39	⊥	FVP			-4.7	a	-4.5	-14.0	o	-13.9	-9.3	-9.5	-0.36				
	40	//	FVR			-4.1	a	-3.9	-8.6	d	-8.0	-4.2	-14.3	-0.55				
	40	⊥	FIZ			-4.0	a	-3.8	-6.3	d	-6.0	-2.2	-12.3	-0.47				
	41	//	FTY			-4.9	a	-4.7	-7.2	d	-7.0	-2.3	-12.4	-0.47				
	41	⊥	FZY			-4.9	a	-4.6	-6.7	d	-6.0	-1.6	-11.7	-0.45				
	42	//	GAF			-4.8	a	-4.6	-10.0	d	-9.5	-5.0	-15.1	-0.58				
	42	⊥	GEX		-5.2	a	-4.9	-8.0	d	-7.8	-2.9	-13.0	-0.50					
	43	//	GCY		-4.8	a	-4.6	-14.5	o	-14.5	-10.0	-10.2	-0.39					
	43	⊥	GDE		-4.9	a	-4.6	-13.3	o	-12.7	-8.3	-8.5	-0.32					
	44	//	GFA		27.75	-2.7	a	-2.5	-7.4	d	-6.9	-4.6	-14.7	-0.56				
	44	⊥	GGB			-2.7	a	-2.5	-14.7	o	-14.4	-11.9	-12.1	-0.46				
	45	//	GHC			-3.6	a	-3.4	-13.8	o	-13.5	-10.1	-10.3	-0.39				
	45	⊥	GID			-2.8	a	-2.7	-11.1	o	-10.6	-8.1	-8.3	-0.32				
	46	//	GKE			-2.5	a	-1.4	-11.2	o	-9.9	-8.7	-8.9	-0.34				
	46	⊥	GLP			-0.8	a	-0.2	-10.5	o	-10.0	-9.7	-9.9	-0.38				
	47	⊥	GDI			-3.1	a	-3.0	-10.4	d	-10.1	-7.2	-17.3	-0.66				
Cap 13																		
59	//	2C19	-1.5	a		-1.1	-10.6	o	-10.2	-9.1	-9.3	-0.35						
59	⊥	2C20	-0.7	a		0.0	-9.4	o	-8.7	-8.7	-8.9	-0.34						

Table 3.2 (contd.)

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths						Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20 to 300°C) $\times 10^{-6} \text{ } ^\circ\text{C}^{-1}$		Electrical Resistivity mΩ cm		Young's Modulus $10^6 \text{ psi}$		Total Length and Weight of Container Plus Contents
					Pre-Irradiation			Post-Irradiation						Pre-	Post-	Pre-	Post-	Pre-	Post-	
														Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	
2D	39	//	FTX	23.99	-4.6	a	-4.5	-13.5	e	-13.3	-8.9	-9.1	-0.35					6.377 in 134.836 g		
	39	⊥	FVL		-5.4	a	-4.9	-12.3	e	-11.9	-7.0	-7.2	-0.27							
	40	//	FWK		-4.0	a	-4.0	-6.1	d	-5.8	-1.9	-12.0	-0.46							
	40	⊥	FLM		-4.0	a	-3.7	-14.2	e	-13.5	-10.0	-10.2	-0.39							
	41	//	FTC		-4.8	a	-4.7	-14.0	e	-13.7	-9.1	-9.3	-0.35							
	41	⊥	FZP		-4.9	a	-4.8	-13.5	e	-13.4	-8.6	-8.8	-0.34							
	42	//	GAR		-4.7	a	-4.6	-7.7	d	-7.5	-3.0	-13.2	-0.50							
	42	⊥	GBS		-5.0	a	-4.7	-15.5	e	-14.9	-10.4	-10.6	-0.40							
	43	//	GOT		-4.7	a	-4.6	-13.0	e	-12.6	-8.2	-8.4	-0.32							
	43	⊥	GDV		-5.0	a	-4.7	-11.5	e	-11.0	-6.6	-6.8	-0.26							
	44	//	GEW		-2.7	a	-2.5	-14.3	e	-14.1	-11.6	-11.8	-0.45							
	44	⊥	GFI		-2.6	a	-2.5	-12.8	e	-12.5	-10.1	-10.3	-0.39							
	45	//	GEY		-2.9	a	-2.6	-11.5	e	-11.6	-8.8	-9.0	-0.34							
	45	⊥	GHE		-3.2	a	-2.9	-10.2	e	-10.0	-7.1	-7.3	-0.28							
46	//	GKA	-1.7	a	-1.2	-8.4	e	-7.5	-6.5	-6.7	-0.26									
46	⊥	GLB	-1.6	a	-1.1	-9.7	e	-8.8	-7.9	-8.1	-0.31									
47	⊥	GQE	-3.2	a	-3.1	-7.0	d	-6.9	-3.8	-13.9	-0.53									
Cap 9																				
59	//		2D19	-1.7	a	-1.6	-14.3	e	-14.0	-12.5	-12.7	-0.48	1.3	0.87	0.46	0.99	1.93	2.93		
59	⊥		2D20	-1.3	a	-1.1	-9.8	e	-9.3	-8.3	-8.5	-0.32	3.2	3.30	0.91	1.92	0.88	0.97		
2E	39	//	FTF	17.61	-4.6	a	-4.6	-11.0	e	-10.9	-6.3	-6.5	-0.25					6.375 in 135.061 g		
	39	⊥	FVC		-5.6	a	-4.9	-10.5	e	-9.5	-4.8	-5.0	-0.19							
	40	//	FWH		-4.0	a	-3.9	-13.1	e	-12.9	-9.1	-9.3	-0.35							
	40	⊥	FVI		-4.1	a	-3.8	-12.6	e	-12.1	-8.4	-8.6	-0.33							
	41	//	FTX		-4.9	a	-4.6	-11.5	e	-11.3	-6.7	-6.9	-0.26							
	41	⊥	FEL		-5.0	a	-4.7	-12.2	e	-11.7	-7.1	-7.3	-0.28							
	42	//	GAR		-5.0	a	-4.8	-14.6	e	-14.3	-9.5	-9.7	-0.37							
	42	⊥	GBO		-5.0	a	-5.0	-13.6	e	-13.3	-8.5	-8.7	-0.33							
	43	//	GDO		-5.0	a	-4.6	-12.0	e	-11.8	-7.1	-7.3	-0.28							
	43	⊥	GDP		-5.2	a	-4.8	-10.7	e	-10.3	-5.5	-5.7	-0.22							
	44	//	GER		-2.6	a	-2.6	-11.7	e	-11.5	-9.0	-9.2	-0.35							
	44	⊥	GFS		-3.2	a	-2.5	-10.5	e	-9.9	-7.4	-7.6	-0.29							
	45	//	GQT		-2.7	a	-2.5	-8.8	e	-8.5	-6.2	-6.4	-0.24							
	45	⊥	GIV		-3.1	a	-2.9	-8.0	e	-7.8	-4.9	-5.1	-0.19							
46	//	GIV	-1.5	a	-0.5	-5.6	e	-4.7	-4.1	-4.3	-0.16									
46	⊥	GKA	-1.8	a	-1.5	-7.1	e	-6.5	-5.2	-5.4	-0.21									
47	⊥	GQA	-3.1	a	-3.0	-13.5	e	-13.5	-10.5	-10.7	-0.41									
Cap 5																				
PGA	//		2E19	-1.2	a	-0.9	-9.7	e	-9.5	-8.6	-8.8	-0.34	1.5	0.94	0.48	1.00	1.93	2.82		
PGA	⊥		2E20	-0.4	a	-0.1	-5.4	e	-5.2	-5.1	-5.3	-0.20	3.2	3.05	0.91	1.72	0.88	1.22		
✓3/4	Solid Spine of PGA for Small Bore Fuel Compact																	3.103 in		
2F	39	//	FTB	8.13	-4.5	a	-4.3	-6.9	e	-6.6	-2.3	-2.5	-0.10					6.385 in 134.693 g		
	39	⊥	FVC		-5.0	a	-4.8	-6.5	e	-6.0	-1.3	-1.5	-0.06							
	40	//	FVD		-4.2	a	-3.9	-9.0	e	-8.5	-4.7	-4.9	-0.19							
	40	⊥	FVE		-4.8	a	-4.5	-7.5	e	-7.3	-2.8	-3.0	-0.11							
	41	//	FTF		-4.9	a	-4.7	-6.9	e	-6.8	-2.0	-2.2	-0.08							
	41	⊥	FZG		-4.8	a	-4.6	-6.5	e	-6.3	-2.3	-2.5	-0.10							
	42	//	GAR		-4.9	a	-4.7	-8.4	e	-8.2	-2.5	-2.7	-0.10							
	42	⊥	GBI		-5.0	a	-4.9	-7.6	e	-7.4	-3.6	-3.8	-0.14							
	43	//	GCK		-4.9	a	-4.6	-7.0	e	-6.5	-2.0	-2.2	-0.08							
	43	⊥	GDL		-4.8	a	-4.6	-6.3	e	-6.0	-1.4	-1.6	-0.06							
	44	//	GEW		-2.7	a	-2.4	Missing												
	44	⊥	GFA		-3.1	a	-2.9	-5.6	e	-5.5	-2.5	-2.7	-0.10							
	45	//	GGO		-3.4	a	-3.3	-4.6	e	-4.5	-2.2	-2.4	-0.09							
	45	⊥	GHS		-3.1	a	-3.0	-3.7	e	-3.5	-0.6	-0.8	-0.03							
46	//	GIR	-4.4	a	-2.0	-3.9	e	-2.7	-0.2	-0.4	-0.02									
46	⊥	GKS	-4.1	a	-1.0	-3.5	e	-2.2	+0.1	-0.1	0.00									
47	⊥	GHW	-3.0	a	-2.9	-7.5	e	-7.5	-4.6	-4.8	-0.18									
Cap 1																				
58	//		2F19	-0.9	a	-0.7	-3.0	e	-2.7	-2.0	-2.2	-0.08	1.3	0.91	0.48	1.08	1.93	2.60		
58	⊥		2F20	-1.2	a	-0.7	-1.7	e	-1.1	-0.5	-0.7	-0.03	3.2	3.36	0.91	2.00	0.88	0.94		
2-0	Solid Spine of PGA																	3.950 in 107.433 g		

Table 3.3  
 First Series Metallurgical Elements - Element 1 - Rod 3  
 Fuel Element 700 - Position 1/2

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths						Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-100°C) x 10 <sup>-6</sup> °C <sup>-1</sup>		Electrical Resistivity μΩ cm		Young's Modulus 10 <sup>6</sup> psi		Total Length and Weight of Container Plus Contents	
					Pre-Irradiation			Post-Irradiation						Pre-	Post-	Pre-	Post-	Pre-	Post-		
														Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation		
5/2/1	Solid Spine of PGA																	2.350 in			
M1-113 Co-133	29	⊥	S61	59.12	+0.9	a	+1.3	-1.1	e	-0.7	-2.0	-2.2	-0.08			1.14	1.47	6.373 in 151.171 g			
	29	//	S157		+1.0	a	+1.3	-2.2	e	-1.9	-3.2	-3.4	-0.13			0.92	1.10				
	29	//	S208		+0.4	a	+0.7	-3.0	e	-2.5	-3.3	-3.5	-0.13			0.92	1.28				
	15	⊥	C59		+0.7	a	+0.9	-2.8	e	-2.5	-3.4	-3.6	-0.14			1.02	1.28				
	15	//	C125		+0.6	a	+1.0	-3.1	e	-2.6	-3.6	-3.8	-0.14			0.88	0.99				
	15	//	C139		+0.3	a	+0.6	-2.9	e	-2.6	-3.2	-3.4	-0.13			0.88	1.02				
	14	//	B164		+0.7	a	+1.2	-3.7	e	-3.0	-4.3	-4.5	-0.17			0.94	1.15				
	14	//	B210		+0.8	a	+1.0	-3.3	e	-3.0	-4.0	-4.2	-0.16			0.94	1.09				
	12	//	D83E		+0.5	a	+1.0	-6.4	e	-5.7	-6.7	-6.9	-0.26			1.44	1.74				
	13	//	K150		+0.3	a	+0.7	-3.5	e	-3.2	-3.8	-4.0	-0.15			0.71	1.06				
	3-1 (H25)	29	⊥		S36	56.50	+0.4	a	+0.5	-2.4	e	-2.3	-2.8	-3.0	-0.11				1.14	1.50	6.373 in 151.171 g
		29	//		S181		+0.5	a	+0.8	-3.7	e	-3.5	-4.3	-4.5	-0.17				0.92	1.37	
		29	//		S212		+0.6	a	+0.8	-3.8	e	-3.6	-4.4	-4.6	-0.18				0.92	1.25	
15		⊥	C30	+0.2	a		+1.0	-3.4	e	-1.9	-3.0	-3.2	-0.12			1.02	1.17				
15		//	C116	+0.6	a		+0.9	-3.6	e	-3.2	-4.2	-4.4	-0.17			0.88	1.13				
15		//	C180	-0.1	a		+0.4	-3.9	e	-3.3	-3.8	-4.0	-0.15			0.88	1.05				
14		//	B104	+0.6	a		+1.0	-5.0	e	-4.5	-5.5	-5.7	-0.22			0.94	1.15				
14		//	B128	+0.3	a		+1.0	-5.3	e	-4.5	-5.6	-5.8	-0.22			0.94	1.24				
12		//	D86H	+1.1	a		+1.3	-7.0	e	-6.8	-8.2	-8.4	-0.32			1.44	1.73				
13		//	K149	+0.5	a		+0.7	-4.5	e	-4.2	-4.9	-5.1	-0.19			0.71	1.05				
3-2 (H26)		29	⊥	S53	52.75		0.0	a	+0.1	-4.7	e	-4.5	-4.7	-4.9	-0.19			1.14	1.53	6.373 in 129.264 g	
		29	//	S153			+0.2	a	+0.4	-7.2	e	-6.6	-7.2	-7.4	-0.28			0.92	1.23		
		29	//	S255			+0.5	a	+0.7	-6.1	e	-6.0	-6.6	-6.8	-0.26			0.92	1.45		
	15	⊥	C27	+0.6		a	+0.2	-5.1	e	-4.3	-4.5	-4.7	-0.18			1.02	1.21				
	15	//	C161	+0.6		a	+1.1	-5.0	e	-4.6	-5.7	-5.9	-0.22			0.88	1.07				
	15	//	G222	+0.2		a	+0.5	-5.7	e	-5.5	-6.0	-6.2	-0.24			0.88	1.04				
	14	//	B147	+0.8		a	+1.2	-7.7	e	-7.3	-8.5	-8.7	-0.33			0.94	1.19				
	14	//	B245	+1.1		a	+1.6	-7.0	e	-6.4	-8.1	-8.3	-0.32			0.94	1.25				
	12	//	D855	+0.5		a	+0.7	-11.0	e	-10.9	-11.5	-11.7	-0.45			1.44	1.78				
	13	//	K113	+0.1		a	+0.3	-6.7	e	-6.5	-6.8	-7.0	-0.27			0.71	1.08				
	3-3 (H27)	29	⊥	S59		50.13	+0.5	a	+0.8	-5.8	e	-5.3	-6.2	-6.4	-0.25			1.14	1.54		6.373 in 129.264 g
		29	//	S189			+0.4	a	+0.8	-7.9	e	-7.6	-8.3	-8.5	-0.32			0.92	1.43		
		29	//	S200			+0.3	a	+0.6	-4.7	e	-4.5	-5.1	-5.3	-0.20			0.92	1.72		
15		⊥	C28	-1.1	a		0.0	-6.3	e	-5.2	-5.1	-5.3	-0.20			1.02	1.24				
15		//	C121	+0.7	a		+1.1	-7.1	e	-6.8	-7.8	-8.0	-0.30			0.88	1.06				
15		//	C158	+0.1	a		+0.6	-6.7	e	-5.8	-6.6	-6.8	-0.26			0.88	1.11				
14		//	B222	+1.1	a		+1.5	-8.1	e	-7.5	-9.1	-9.3	-0.35			0.94	1.21				
14		//	B227	+0.7	a		+1.0	-9.5	e	-9.2	-11.2	-11.4	-0.43			0.94	1.23				
12		//	D852	+0.1	a		+0.2	-11.0	e	-10.9	-11.1	-11.3	-0.43			1.44	1.67				
13		//	K148	+0.4	a		+0.5	-9.5	e	-9.2	-9.8	-10.0	-0.35			0.71	1.13				
M1-131 Co-139		29	//	S98	46.37		+1.0	a	+1.3	-7.2	e	-6.6	-8.1	-8.3	-0.32			0.92	1.45	6.373 in 129.133 g	
		29	//	S150			+0.4	a	+0.9	-11.0	e	-10.2	-11.3	-11.5	-0.44			0.92	1.27		
		29	//	S227			-0.1	a	+0.2	-11.2	e	-10.8	-11.1	-11.3	-0.43			0.92	1.41		
	15	⊥	C22	-1.0		a	+0.1	-7.5	e	-6.6	-6.6	-6.8	-0.26			1.02	1.19				
	15	//	C143	+0.5		a	+0.8	-8.2	e	-7.9	-8.7	-8.9	-0.34			0.88	1.07				
	15	//	C164	+0.8		a	+1.1	-8.0	e	-7.6	-8.8	-9.0	-0.34			0.88	1.10				
	14	//	B244	+0.7		a	+1.5	-10.5	e	-9.5	-11.1	-11.3	-0.43			0.94	1.27				
	14	//	B250	+0.7		a	+1.5	-11.9	e	-10.7	-12.4	-12.6	-0.48			0.94	1.29				
	12	//	D837	0.0		a	+0.3	-13.7	e	-13.5	-13.8	-14.0	-0.55			1.44	1.68				
	13	//	K140	+0.2		a	+0.4	-11.5	e	-11.2	-11.6	-11.8	-0.45			0.71	1.16				
	3-3 (H27)	29	//	S96		43.75	+0.2	a	+1.2	-8.9	e	-7.5	-8.9	-9.1	-0.35			0.92	1.49		6.373 in 129.133 g
		29	//	S116			+0.7	a	+1.1	-12.2	e	-11.6	-12.8	-13.0	-0.50			0.92	1.25		
		29	//	S168			-0.1	a	+0.1	-13.1	e	-12.7	-12.9	-13.1	-0.50			0.92	1.22		
15		⊥	C16	-0.8	a		-0.1	-8.3	e	-7.5	-7.5	-7.7	-0.29			1.02	1.14				
15		//	C151	+0.1	a		+0.5	-9.4	e	-9.0	-9.5	-9.7	-0.37			0.88	1.16				
15		//	C203	+0.9	a		+1.0	-13.8	e	-13.5	-14.5	-14.7	-0.56			0.88	1.22				
14		//	B162	-0.8	a		+0.6	-12.4	e	-12.1	-12.1	-12.3	-0.47			0.94	1.16				
14		//	B209	+0.5	a		+1.5	-13.3	e	-12.0	-13.6	-13.8	-0.53			0.94	1.37				
13		//	K136	+0.2	a		+0.1	-12.5	e	-12.1	-12.5	-12.7	-0.48			0.71	1.15				
12		//	D829	+0.2	a		+0.4	-7.8	e	-7.6	-8.0	-8.1	-0.69			1.44	1.85				

Table 3.3 (contd.)

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths						Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-200°C) $\times 10^{-6} \text{ } ^\circ\text{C}^{-1}$		Electrical Resistivity $\text{m}\Omega \text{ cm}$		Young's Modulus $10^6 \text{ psi}$		Total Length and Weight of Container Plus Contents
					Pre-irradiation			Post-irradiation						Pre-	Post-	Pre-	Post-	Pre-	Post-	
3A (H)	29	⊥	S38	40.00	+0.6	a	+0.8	-9.2	c	-9.0	-9.8	-10.0	-0.38			1.14	1.58	6.375 in 129.95 g		
	29	//	S172		+0.7	a	+1.0	-13.5	c	-13.3	-14.3	-14.5	-0.55			0.92	1.32			
	29	//	S206		+0.3	a	+0.1	-14.1	c	-14.0	-14.1	-14.3	-0.54			0.92	1.34			
	15	⊥	C51		+0.6	a	+1.1	-11.0	c	-10.5	-11.6	-11.8	-0.45			1.02	1.31			
	15	//	C214		+0.1	a	+0.6	-11.1	c	-12.7	-11.3	-11.5	-0.44			0.88	1.03			
	15	//	C221		+0.1	a	+0.6	-12.1	c	-11.3	-11.1	-11.3	-0.43			0.88	1.05			
	14	//	B113		+0.3	a	+0.7	-6.1	d	-5.5	-5.3	-5.4	-0.62			0.94	1.24			
	14	//	B160		0.0	a	+0.2	-6.5	d	-5.2	-6.2	-5.3	-0.62			0.94	1.20			
	12	//	DS25		-0.4	a	+0.2	-7.8	d	-7.5	-7.3	-7.4	-0.66			1.44	1.62			
	13	//	E125		+0.3	a	+0.4	-12.5	c	-12.1	-13.7	-13.9	-0.53			0.71	1.17			
	29	⊥	S29		37.38	0.0	a	+2.1	-10.0	c	-9.8	-10.0	-10.2	-0.39			1.14		1.55	
	29	//	S170			+1.2	a	+1.4	-13.7	c	-13.5	-14.9	-15.1	-0.58			0.92		1.23	
	29	//	S244	+0.3		a	+0.6	-14.8	c	-13.9	-14.8	-15.0	-0.57			0.92	1.21			
	15	⊥	C54	+0.8		a	+1.0	-10.8	c	-12.6	-11.6	-11.8	-0.45			1.02	1.39			
	15	//	C224	+0.3		a	+0.5	-11.3	c	-10.9	-11.6	-11.8	-0.45			0.88	1.02			
	15	//	C243	+0.4		a	+0.5	-10.5	c	-10.3	-10.9	-11.1	-0.42			0.88	1.15			
	14	//	B108	+0.4		a	+0.8	-15.5	c	-14.8	-15.7	-15.9	-0.61			0.94	1.30			
	14	//	B143	+1.0		a	+1.3	-13.5	c	-13.1	-14.5	-14.7	-0.56			0.94	1.23			
12	//	DS19	+0.7	a		+0.8	-7.3	d	-6.9	-7.7	-7.7	-0.69			1.44	1.65				
13	//	E146	+0.4	a	+0.6	-14.8	c	-14.5	-15.1	-15.3	-0.58			0.71	1.17					
3B (H)	29	⊥	S50	35.63	+0.6	a	+0.7	-10.2	c	-10.1	-10.8	-11.0	-0.42			1.14	1.59	6.375 in 129.749 g		
	29	//	S182		+0.6	a	+0.7	-14.5	c	-14.1	-15.0	-15.2	-0.58			0.92	1.47			
	29	//	S183		+0.3	a	+0.6	-14.7	c	-14.5	-15.1	-15.3	-0.58			0.92	1.48			
	15	⊥	C19		+0.4	a	+0.4	-8.9	c	-8.0	-8.6	-8.8	-0.34			1.02	1.29			
	15	//	C202		+0.1	a	+0.3	-10.2	c	-9.9	-10.2	-10.4	-0.39			0.88	1.16			
	15	//	C225		0.0	a	+0.5	-12.1	c	-11.6	-12.1	-12.3	-0.47			0.88	1.11			
	14	//	B140		+0.7	a	+1.3	-5.6	d	-5.4	-6.5	-6.5	-0.63			0.94	1.21			
	14	//	B179		+0.5	a	+1.0	-6.4	d	-5.8	-6.9	-6.9	-0.65			0.94	1.25			
	12	//	DS63		+0.5	a	+0.7	-8.8	d	-8.5	-9.2	-9.3	-0.73			1.44	1.15			
	13	//	E166		+0.4	a	+0.6	-5.5	d	-5.3	-5.9	-6.0	-0.61			0.71	1.20			
	29	//	S82		31.01	+1.1	a	+1.5	-10.7	c	-10.0	-11.6	-11.8	-0.45			0.92		1.52	
	29	//	S104			+0.6	a	+0.9	-15.0	c	-14.6	-15.6	-15.8	-0.60			0.92		1.44	
	29	//	S202	+0.3		a	+0.7	-12.0	c	-11.4	-12.2	-12.4	-0.47			0.92	1.40			
	15	⊥	C41	+0.5		a	+1.1	-13.1	c	-12.5	-13.7	-13.9	-0.53			1.02	1.43			
	15	//	C210	+0.3		a	+0.6	-11.6	c	-11.4	-12.0	-12.2	-0.46			0.88	1.21			
	15	//	C217	+0.1		a	+0.5	-12.0	c	-11.4	-12.0	-12.2	-0.46			0.88	1.07			
	14	//	B111	-0.1		a	+0.4	-6.6	d	-6.0	-6.7	-6.8	-0.64			0.94	1.16			
	14	//	B174	+0.7		a	+1.0	-7.9	d	-7.6	-8.6	-8.6	-0.71			0.94	1.28			
12	//	DS7	+0.2	a		+0.5	-9.8	d	-9.3	-9.9	-10.0	-0.76			1.44	1.79				
13	//	E167	+0.2	a	+0.5	-7.0	d	-6.5	-7.1	-7.2	-0.65			0.71	1.16					
3C (H10)	29	⊥	S24	27.25	+0.6	a	+0.7	-10.4	c	-10.4	-11.1	-11.3	-0.43			1.14	1.60	6.375 in 128.047 g		
	29	//	S176		+0.3	a	+0.5	-6.9	d	-6.2	-6.9	-7.0	-0.61			0.92	1.45			
	29	//	S198		-1.2	a	+0.5	-8.0	d	-7.0	-7.2	-7.3	-0.66			0.92	1.32			
	15	⊥	C80		+0.9	a	+1.1	-13.0	c	-12.7	-12.8	-13.0	-0.50			1.02	1.40			
	15	//	C102		+0.4	a	+0.7	-12.4	c	-12.1	-12.5	-13.0	-0.50			0.88	1.16			
	15	//	C212		+0.2	a	+0.6	-13.2	c	-12.8	-13.4	-13.6	-0.52			0.88	1.05			
	14	//	B173		+0.3	a	+0.6	-7.3	d	-6.8	-7.5	-7.6	-0.67			0.94	1.36			
	14	//	B187		+1.0	a	+1.4	-14.1	c	-13.6	-15.0	-15.2	-0.58			0.94	1.24			
	12	//	DS35		+0.3	a	+0.4	-9.1	d	-9.0	-9.4	-9.5	-0.74			1.44	1.72			
	13	//	E172		+0.4	a	+0.6	-5.9	d	-5.6	-6.2	-6.2	-0.62			0.71	1.22			
	29	⊥	S68		24.63	-0.5	a	+0.7	-8.3	c	-8.0	-8.7	-8.9	-0.34			1.14		1.72	
	29	//	S193			-0.9	a	+0.6	-15.0	c	-14.7	-14.1	-14.3	-0.54			0.92		1.55	
	29	//	S239	-0.9		a	+0.8	-14.5	c	-14.3	-13.6	-13.8	-0.53			0.92	1.43			
	15	⊥	C57	+0.7		a	+1.0	-12.2	c	-12.0	-13.0	-13.2	-0.51			1.02	1.35			
	15	//	C105	-0.1		a	+0.5	-10.9	c	-10.1	-10.7	-10.9	-0.42			0.88	1.14			
	15	//	C124	+0.4		a	+0.6	-11.4	c	-10.5	-11.4	-11.6	-0.44			0.88	1.15			
	14	//	B152	+0.3		a	+1.5	-7.0	d	-5.4	-7.1	-7.2	-0.65			0.94	1.29			
	14	//	B241	+1.0		a	+1.3	-13.0	c	-12.9	-14.1	-14.3	-0.54			0.94	1.30			
13	//	E119	+0.4	a		+1.0	-7.1	d	-6.9	-7.7	-7.7	-0.68			0.71	1.31				
12	//	DS15	-0.1	a	+0.1	-8.2	d	-8.1	-8.1	-8.2	-0.89			1.44	1.82					

Table 3.3 (contd.)

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths					Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-300°C) x 10 <sup>-6</sup> C <sup>-1</sup>		Electrical Resistivity mΩ cm		Young's Modulus 10 <sup>5</sup> psi		Total Length and Weight of Container Plus Contents
					Pre-irradiation		Post-irradiation						Pre-	Post-	Pre-	Post-	Pre-	Post-	
													Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	
HI-127 Co-123	29	//	389	20.88	+0.3	a	+0.6	-6.9	c	-6.1	-7.0	-7.2	-0.27			1.14	1.64	6.373 in 128.608 g	
			3168		+0.2	a	+0.5	-12.0	c	-11.6	-12.2	-12.4	-0.47			0.92	1.33		
			3210		+0.1	a	+0.6	-11.3	c	-10.8	-11.4	-11.6	-0.44			0.92	1.52		
			08		0.0	a	+0.5	-7.6	c	-6.8	-7.5	-7.7	-0.29			1.02	1.27		
			C171		+0.5	a	+0.7	-9.7	c	-9.4	-10.1	-10.3	-0.39			0.88	1.12		
			C213		+0.4	a	+0.9	-9.3	c	-8.8	-9.7	-9.9	-0.35			0.88	1.10		
			B105		+0.4	a	+0.9	-14.3	c	-14.0	-14.8	-15.0	-0.57			0.94	1.45		
			B150		+1.1	a	+1.5	-15.9	c	-15.4	-14.9	-15.1	-0.58			0.94	1.52		
			B618		+0.5	a	+0.5	-14.5	c	-14.4	-14.9	-15.1	-0.58			1.44	1.87		
			E18		+0.3	a	+0.5	-10.7	c	-10.3	-10.9	-11.1	-0.42			0.71	1.45		
			392		+0.9	a	+1.1	-5.1	c	-4.9	-6.0	-6.2	-0.24			1.14	1.66		
			3177		+0.5	a	+0.6	-9.4	c	-9.3	-9.9	-10.1	-0.38			0.92	1.39		
			3219		+0.9	a	+0.5	-10.8	c	-9.7	-10.0	-10.2	-0.39			0.92	1.59		
			053		+0.6	a	+0.9	-9.2	c	-8.7	-9.7	-9.9	-0.38			1.02	1.42		
			C231		+0.2	a	+0.5	-8.9	c	-8.4	-9.0	-9.2	-0.35			0.88	1.15		
C243	+0.1	a	+0.8	-7.8	c	-7.4	-8.0	-8.2	-0.31			0.88	1.16						
B232	+0.5	a	+0.8	-11.1	c	-10.3	-11.4	-11.6	-0.44			0.94	1.52						
B242	+1.0	a	+1.4	-10.1	c	-9.9	-11.2	-11.4	-0.43			0.94	1.35						
B614	+0.2	a	+0.4	-14.0	c	-13.5	-14.0	-14.2	-0.54			1.44	1.82						
E159	+0.4	a	+0.5	-10.9	c	-10.7	-11.3	-11.5	-0.44			0.71	1.36						
3K (H12)	29	//	331	14.51	+0.7	a	+0.5	-5.4	c	-5.0	-4.6	-4.8	-0.18			1.14	1.84	6.376 in	
			3124		+1.1	a	+0.6	-9.0	c	-8.6	-7.9	-8.1	-0.31			0.92	1.40		
			3242		+0.6	a	+0.1	-8.2	c	-7.5	-7.6	-7.8	-0.29			0.92	1.47		
			044		+0.9	a	+1.0	-7.5	c	-7.4	-8.4	-8.6	-0.53			1.02	1.40		
			C237		+0.6	a	+0.2	-7.9	c	-7.4	-7.4	-7.6	-0.29			0.88	1.15		
			C208		+0.2	a	+0.6	-7.5	c	-7.0	-7.6	-7.8	-0.30			0.88	1.13		
			B151		+1.0	a	+1.1	-8.2	c	-7.4	-8.9	-9.1	-0.35			0.94	1.36		
			B233		+1.0	a	+1.1	-9.5	c	-9.4	-10.5	-10.7	-0.41			0.94	1.36		
			B624		+1.1	a	+1.4	-9.2	c	-8.9	-10.3	-10.5	-0.40			1.44	1.84		
			E165		+0.1	a	+0.3	-9.2	c	-9.0	-9.3	-9.5	-0.36			0.71	1.38		
			337		+0.5	a	+0.8	-3.4	c	-3.0	-3.9	-4.1	-0.16			1.14	1.87		
			3201		+0.5	a	+1.1	-3.2	c	-3.1	-3.4	-3.6	-0.14			0.92	1.88		
			3203		+0.9	a	+1.1	-2.6	c	-2.3	-3.4	-3.6	-0.14			0.92	2.00		
			012		+0.1	a	+0.4	-5.1	c	-4.6	-5.1	-5.3	-0.20			1.02	1.35		
			C209		+1.2	a	+0.4	-8.2	c	-6.4	-6.9	-7.1	-0.27			0.88	1.26		
C246	+0.4	a	+0.6	-7.3	c	-7.1	-7.7	-7.9	-0.30			0.88	1.24						
B228	+0.8	a	+1.4	-9.2	c	-8.7	-10.0	-10.2	-0.39			0.94	1.31						
B238	+0.6	a	+1.1	-8.0	c	-7.5	-8.6	-8.8	-0.34			0.94	1.47						
B634	+0.8	a	+0.9	-10.8	c	-10.6	-11.6	-11.8	-0.45			1.44	1.64						
E118	+0.1	a	+0.4	-7.8	c	-7.5	-7.8	-8.0	-0.30			0.71	1.33						
HI-139 Co-111	29	//	32	8.13	+0.3	a	+0.6	-2.2	c	-1.9	-2.5	-2.7	-0.10			1.14	1.67	6.375 in	
			3218		+2.3	a	+0.9	-7.1	c	-4.1	-6.3	-6.5	-0.25			0.92	1.54		
			3243		+0.2	a	+0.6	-4.4	c	-3.9	-4.5	-4.7	-0.18			0.92	1.59		
			07		+0.1	a	+0.5	-3.9	c	-3.4	-3.9	-4.1	-0.16			1.02	1.27		
			C149		+0.1	a	+0.8	-4.8	c	-4.3	-5.0	-5.2	-0.20			0.88	1.15		
			C163		+0.3	a	+0.6	-6.8	c	-5.1	-6.0	-6.2	-0.24			0.88	1.19		
			B154		+0.8	a	+1.5	-5.9	c	-5.4	-6.8	-7.0	-0.27			0.94	1.42		
			B145		+1.0	a	+1.3	-6.0	c	-5.7	-7.0	-7.2	-0.27			0.94	1.40		
			B631		+0.1	a	+0.1	-7.7	c	-7.4	-7.5	-7.7	-0.29			1.44	1.78		
			E164		+0.6	a	+0.9	-5.7	c	-5.4	-6.3	-6.5	-0.25			0.71	1.24		
			334		+0.5	a	+0.8	-0.6	c	-0.3	-1.1	-1.3	-0.05			1.14	1.72		
			B135		+0.7	a	+1.0	-2.2	c	-2.0	-3.0	-3.2	-0.12			0.92	1.38		
			3261		+0.1	a	+0.2	-2.8	c	-2.5	-2.7	-2.9	-0.11			1.02	1.57		
			C25		0.0	a	+0.4	-2.4	c	-2.1	-2.4	-2.6	-0.10			1.02	1.45		
			C127		+0.3	a	+0.9	-3.7	c	-3.2	-4.0	-4.2	-0.16			0.88	1.23		
C195	+0.9	a	+1.0	-4.2	c	-4.0	-5.0	-5.2	-0.20			0.88	1.36						
B195	+1.1	a	+1.5	-3.5	c	-3.2	-4.6	-4.8	-0.18			0.94	1.38						
B212	+0.9	a	+1.4	-3.7	c	-3.4	-4.7	-4.9	-0.19			0.94	1.35						
B650	+0.9	a	+1.3	-5.3	c	-5.0	-6.2	-6.4	-0.24			1.44	1.79						
E155	+0.6	a	+0.8	-3.1	c	-2.9	-3.7	-3.9	-0.15			0.71	1.29						

Table 3.4  
First Series Metallurgical Elements - Element 1 - Rod 4  
Fuel Element 700 - Position 1/2

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths						Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction For Standards	Length Change %	Thermal Expansion ( $20-400^{\circ}\text{C}$ ) $\times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$		Electrical Resistivity $\mu\Omega\text{ cm}$		Young's Modulus $10^6 \text{ psi}$		Total Length of Container
					Pre-Irradiation			Post-Irradiation						Pre-	Post-	Pre-	Post-	Pre-	Post-	
														Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	
4-1	Solid Spine of PEA																	5.750 in		
4-2	Solid Spine of PEA																	6.316 in		
4-3	Solid Spine of PEA																	6.315 in		
4A	37	↓	4A1	43.30 42.87	-0.7	b	-0.6	-9.3	f	-9.2	-8.6	-8.4	-0.48		1.19	1.57		6.381 in		
	37	//	4A2		-1.0	b	-0.8	-10.6	f	-10.6	-9.7	-9.5	-0.54		1.03	1.35				
	2	//	4A3		-1.6	a	-0.8	-12.6	e	-11.7	-10.9	-11.1	-0.62		0.59	1.11				
	2	↓	4A4		-1.6	b	-1.1	-8.4	f	-8.0	-6.9	-6.7	-0.38		0.77	1.33				
	18	↓	4A5		-1.1	a	-0.4	-15.1	e	-12.1	-11.9	-12.1	-0.66		1.32	1.89				
	18	//	4A6		-0.6	b	-0.1	-12.0	f	-11.7	-11.5	-11.3	-0.65		1.02	1.35				
	57	↓	4A7		+1.6	a	+1.8	-8.3	d	-8.1	-9.9	-20.0	-0.76				2.55			
	57	//	4A8		+0.5	a	+0.9	-10.0	d	-9.3	-10.3	-20.4	-0.78				1.67			
	59	//	4A9		-0.7	a	-0.5	-13.5	e	-13.1	-12.7	-12.9	-0.49		0.48	0.83				
	59	↓	4A10		-1.8	a	-1.5	-9.7	c	-9.1	-7.8	-8.0	-0.38		0.91	1.72				
	37	↓	4A11	40.55 40.12	-0.5	b	-0.2	-9.6	f	-9.4	-9.2	-9.0	-0.51		1.19	1.61				
	37	//	4A12		-1.1	b	-0.9	-11.7	f	-11.6	-10.6	-10.4	-0.59		1.03	1.42				
	2	//	4A13		-1.7	a	-1.1	-13.9	e	-13.0	-12.0	-12.2	-0.47		0.59	1.09				
	2	↓	4A14		-0.9	b	+0.1	-7.9	f	-7.5	-7.3	-7.1	-0.41		0.77	1.34				
	18	↓	4A15		-0.9	a	-0.4	-14.0	e	-13.0	-12.9	-13.1	-0.50		1.32	1.99				
	18	//	4A16		-0.6	b	-0.1	-13.4	f	-13.3	-13.0	-12.8	-0.73		1.02	1.38				
	56	↓	4A17		+4.6	a	+5.4	-14.5	e	-14.0	-19.2	-19.4	-0.74				1.69			
	56	//	4A18		+10.8	a	+11.3	-6.2	e	-5.2	-16.8	-17.0	-0.65				2.10			
	60	↓	4A19		+0.9	a	+1.1	-14.3	e	-13.6	-14.9	-15.1	-0.56	3.75	3.69	1.68	2.50		1.18	1.14
	62	↓	4A20		+0.2	a	+1.0	-5.9	d	-5.5	-6.6	-6.7	-0.64	2.9	2.61	1.20	1.87		0.92	1.42
4B	37	↓	4B1	36.92 36.49	-0.1	b	0.0	-10.0	f	-9.7	-9.8	-9.6	-0.55		1.19	1.67		6.373 in		
	37	//	4B2		+0.1	b	+0.3	-11.0	f	-10.7	-11.0	-10.8	-0.62		1.03	1.54				
	2	//	4B3		-0.9	a	-0.6	-14.9	c	-14.5	-14.0	-14.2	-0.54		0.59	1.16				
	2	↓	4B4		-0.8	b	-0.6	-9.1	f	-8.7	-8.2	-8.0	-0.46		0.77	1.39				
	18	↓	4B5		-1.4	a	-1.3	-15.0	c	-14.5	-13.4	-13.6	-0.52		1.32	2.09				
	18	//	4B6		-0.2	b	-0.1	-13.8	f	-13.3	-13.4	-13.2	-0.75		1.02	1.44				
	57	↓	4B7		-0.4	a	-0.2	-13.4	d	-13.1	-12.9	-13.0	-0.48				2.68			
	57	//	4B8		-1.2	a	-0.8	-10.5	e	-10.0	-9.2	-24.3	-0.93				0.75			
	59	//	4B9		-0.8	a	-0.7	-15.0	c	-14.8	-14.2	-14.4	-0.55		0.48	0.87				
	59	↓	4B10		-0.5	a	0.0	-9.4	c	-8.5	-8.7	-8.9	-0.34		0.91	1.76				
	37	↓	4B11	34.17 33.74	-0.6	b	-0.4	-12.1	f	-11.9	-11.5	-11.3	-0.65		1.19	1.68				
	37	//	4B12		-1.2	b	-1.0	-13.2	f	-13.0	-12.0	-11.8	-0.67		1.03	1.50				
	2	//	4B13		-0.7	b	-0.6	-15.0	c	-14.6	-14.2	-14.4	-0.55		0.59	1.17				
	2	↓	4B14		-0.8	b	-0.5	-8.9	f	-8.4	-8.0	-7.8	-0.45		0.77	1.41				
	18	↓	4B15		0.0	a	+0.5	-14.6	c	-13.6	-14.4	-14.6	-0.56		1.32	2.10				
	18	//	4B16		-0.7	b	-0.3	-14.9	f	-14.7	-14.3	-14.1	-0.61		1.02	1.48				
	56	↓	4B17		+1.6	a	+2.9	-10.5	d	-8.6	-11.8	-21.9	-0.83				1.75			
	56	//	4B18		+6.8	a	+7.1	-7.5	c	-7.1	-14.3	-14.5	-0.55				2.25			
	60	//	4B19		+0.5	a	+0.6	-10.5	e	-10.6	-11.1	-26.2	-1.30		1.00	1.31				
	62	//	4B20		+0.3	a	+0.4	-10.7	e	-10.3	-10.9	-26.0	-0.99	1.3	1.24	0.71	1.12		1.95	3.11
5/2/1	Solid Spine of PEA for Small Bore Fuel Compact																	3.154 in		
4C	37	↓	4C1	27.39 26.96	-0.5	b	-0.3	-12.1	f	-12.0	-11.6	-11.4	-0.65		1.19	1.72		6.382 in		
	37	//	4C2		-0.3	b	-0.2	-13.3	f	-13.1	-13.0	-12.8	-0.73		1.03	1.50				
	2	//	4C3		-1.4	a	-0.4	-7.9	d	-7.0	-6.5	-6.7	-0.63		0.59	1.18				
	2	↓	4C4		-1.3	b	-0.7	-10.5	f	-10.0	-9.2	-9.0	-0.51		0.77	1.42				
	18	↓	4C5		-1.3	a	-0.5	-7.5	d	-6.2	-5.9	-6.0	-0.61		1.32	2.09				
	18	//	4C6		-0.3	b	+0.3	-10.3	g	-10.0	-10.1	-15.7	-0.90		1.02	1.46				
	57	↓	4C7		-0.6	a	-0.3	-10.9	e	-10.3	-9.7	-24.8	-0.95				2.60			
	57	//	4C8		-0.5	a	-0.1	-13.4	e	-12.9	-12.8	-27.9	-1.06				1.74			
	59	//	4C9		-1.3	a	-1.1	-10.0	d	-9.8	-8.7	-18.8	-0.77		0.48	0.90				
	59	↓	4C10		-0.8	a	-0.6	-10.9	c	-10.7	-10.1	-10.3	-0.39		0.91	1.84				
	37	↓	4C11	24.64 24.21	-0.5	b	-0.3	-10.3	f	-10.0	-9.7	-9.5	-0.54		1.19	1.76				
	37	//	4C12		-0.5	b	-0.3	-12.0	f	-11.8	-11.5	-11.3	-0.65		1.03	1.50				
	2	//	4C13		-1.4	a	-0.6	-5.5	d	-4.6	-4.0	-4.1	-0.54		0.59	1.26				
	2	↓	4C14		-0.8	b	-0.3	-8.5	f	-8.0	-7.7	-7.5	-0.43		0.77	1.48				
	18	↓	4C15		-1.1	a	-0.2	-5.7	d	-4.5	-4.5	-4.6	-0.56		1.32	2.18				
	18	//	4C16		-0.9	b	-0.3	-14.1	f	-13.8	-13.3	-13.1	-0.75		1.02	1.64				
	56	↓	4C17		+3.9	a	+4.4	-5.9	d	-5.0	-9.6	-19.7	-0.75				1.66			
	56	//	4C18		+6.6	a	+7.1	-8.0	c	-7.2	-11.5	-14.7	-0.56				2.36			
	60	↓	4C19		+0.6	a	+0.6	-7.2	d	-7.0	-7.7	-17.8	-0.68		1.68	2.28				
	62	↓	4C20		-1.0	a	-0.7	-8.6	d	-8.1	-7.5	-17.6	-0.67	2.9	2.64	1.20	1.94		0.92	1.43

Table 3.4 (contd.)

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths								Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion ( $20-400^{\circ}\text{C}$ ) $\times 10^{-6} \text{ } ^{\circ}\text{C}^{-1}$		Electrical Resistivity $\text{m}\Omega/\text{cm}$		Young's Modulus $10^6 \text{ psi}$		Total Length of Container
					Pre-Irradiation				Post-Irradiation							Pre-	Post-	Pre-	Post-	Pre-	Post-	
																Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	
AD	37	⊥	LD1	21.01	-0.3	b	-0.2	-9.0	f	-8.9	-8.7	-8.5	-0.49			1.19	1.80					
	37	//	LD2		-1.5	b	-1.4	-12.2	f	-12.0	-10.7	-10.5	-0.60			1.03	1.50					
	2	//	LD3		-1.1	a	-0.8	-12.0	e	-11.5	-10.8	-11.0	-0.42			0.59	1.23					
	2	⊥	LD4		-0.9	b	-0.4	-8.0	f	-7.8	-7.3	-7.1	-0.41			0.77	1.46					
	18	⊥	LD5		-1.5	a	-0.5	-13.2	e	-11.8	-11.5	-11.7	-0.45			1.32	1.99					
	18	//	LD6		-0.4	b	-0.3	-13.0	f	-12.5	-12.4	-12.2	-0.70			1.02	1.44					
	57	⊥	LD7		-1.1	a	-0.6	-12.0	d	-11.5	-10.9	-21.0	-0.80					2.71				
	57	//	LD8		+1.1	a	+1.4	-12.0	e	-11.5	-13.0	-23.1	-0.88					1.75				
	59	//	LD9		-1.5	a	-1.3	-13.5	e	-13.3	-12.0	-12.2	-0.47			0.48	1.00					
	59	⊥	LD10		-1.0	a	-0.7	-7.6	e	-7.2	+6.6	-6.8	-0.26			0.91	1.96					
	37	⊥	LD11	18.26	-0.6	b	-0.4	-8.8	f	-8.7	-8.2	-8.0	-0.46			1.19	1.75					
	37	//	LD12		-1.0	b	-0.8	-10.4	f	-10.2	-9.4	-9.2	-0.53			1.03	1.55					
	2	//	LD13		-1.0	a	-0.5	-11.1	e	-10.3	-10.0	-10.2	-0.39			0.59	1.24					
	2	⊥	LD14		-1.4	b	-0.9	-7.0	f	-6.6	-5.7	-5.5	-0.31			0.77	1.50					
	18	⊥	LD15		-0.8	a	-0.6	-11.1	e	-10.8	-10.2	-10.4	-0.40			1.32	2.17					
	18	//	LD16		-0.4	b	0.0	-11.8	f	-11.4	-11.4	-11.2	-0.64			1.02	1.51					
	56	⊥	LD17		+4.4	a	+4.8	-15.1	e	-14.6	-19.3	-19.5	-0.74					1.72				
	56	//	LD18		+11.0	a	+11.5	-7.4	e	-7.1	-18.5	-18.7	-0.71					2.27				
	60	//	LD19		+0.2	a	+0.4	-10.2	d	-9.8	-10.3	-20.4	-0.78	2.0	1.75	1.00	1.43	1.50	2.71			
	62	//	LD20		+0.1	a	0.0	-10.3	d	-10.1	-10.2	-20.3	-0.77	1.3	1.18	0.71	1.22	1.95	3.16			
AE	37	⊥	AE1	14.54	-0.6	b	-0.4	-6.4	f	-6.1	-5.7	-5.5	-0.31			1.19	1.74					
	37	//	AE2		-1.7	b	-1.6	-8.5	f	-8.2	-6.7	-6.5	-0.37			1.03	1.56					
	2	//	AE3		-0.8	a	-0.3	-9.2	e	-8.6	-8.4	-8.6	-0.33			0.59	1.24					
	2	⊥	AE4		-1.1	b	-0.4	-5.0	f	-4.8	-4.2	-4.0	-0.23			0.77	1.54					
	18	⊥	AE5		-0.5	a	+0.2	-9.9	e	-9.0	-9.3	-9.5	-0.36			1.32	2.10					
	18	//	AE6		-0.7	b	-0.6	-9.6	f	-9.1	-8.7	-8.5	-0.49			1.02	1.48					
	57	⊥	AE7		+0.5	a	+0.9	-8.5	d	-8.3	-9.1	-19.2	-0.73					2.21				
	57	//	AE8		+0.5	a	+0.7	-9.5	d	-9.2	-9.9	-20.0	-0.76					1.75				
	59	//	AE9		-0.4	a	-0.1	-8.9	e	-8.1	-8.3	-8.5	-0.32			0.48	0.96					
	59	⊥	AE10		-1.3	a	-0.9	-6.0	e	-5.5	-4.6	-4.8	-0.18	3.2	3.38	0.41	2.03	0.88	0.95			
	37	⊥	AE11	11.99	-0.5	b	-0.1	-4.7	f	-4.5	-4.3	-4.1	-0.23			1.19	1.72					
	37	//	AE12		-0.7	b	-0.5	-6.0	f	-5.9	-5.3	-5.1	-0.29			1.03	1.46					
	2	//	AE13		-1.6	a	-1.1	-7.0	e	-6.3	-5.3	-5.5	-0.21			0.59	1.23					
	2	⊥	AE14		-0.9	b	0.0	-3.3	f	-3.0	-2.7	-2.5	-0.14			0.77	1.46					
	18	⊥	AE15		-0.7	a	+0.3	-7.5	e	-6.4	-6.7	-6.9	-0.26			1.32	2.07					
	18	//	AE16		-1.3	b	-0.8	-7.5	f	-7.3	-6.4	-6.2	-0.35			1.02	1.45					
	56	⊥	AE17		+5.0	a	+5.5	-11.1	e	-10.7	-16.2	-16.4	-0.62					1.75				
	56	//	AE18		+5.5	a	+6.0	-10.3	e	-9.7	-15.8	-16.0	-0.61					2.25				
	60	⊥	AE19		+0.4	a	+0.5	-8.2	e	-7.9	-8.5	-8.7	-0.33	3.75	3.77	1.68	2.73	1.18	1.14			
	62	⊥	AE20		+1.0	a	+1.1	-9.0	e	-8.8	-10.0	-10.2	-0.39	2.9	2.97	1.20	2.06	0.92	1.45			
AF	37	⊥	AF1	8.26	-0.4	b	-0.2	-3.3	f	-3.0	-2.8	-2.6	-0.15			1.19	1.80					
	37	//	AF2		-0.8	b	-0.6	-4.1	f	-4.0	-3.3	-3.1	-0.18			1.03	1.66					
	2	//	AF3		-0.8	a	-0.6	-3.0	e	-2.8	-2.2	-2.4	-0.09			0.59	1.34					
	2	⊥	AF4		-1.4	b	-1.1	-1.3	f	-1.6	-0.5	-0.5	-0.02			0.77	1.51					
	18	⊥	AF5		-2.2	a	-1.7	-5.6	e	-5.1	-3.4	-3.6	-0.14			1.32	2.21					
	18	//	AF6		-0.1	b	+0.2	-3.8	f	-3.4	-3.5	-3.3	-0.19			1.02	1.55					
	57	⊥	AF7		+0.7	a	+0.9	-14.2	e	-13.9	-14.8	-15.0	-0.57					2.87				
	57	//	AF8		+0.4	a	+0.6	-14.1	e	-13.8	-14.4	-14.6	-0.56					1.83				
	59	//	AF9		-0.4	a	-0.3	-3.5	e	-3.4	-3.1	-3.3	-0.13			0.48	1.00					
	59	⊥	AF10		-1.3	a	-0.9	-2.1	e	-1.7	-0.8	-1.0	-0.04	3.2	3.24	0.91	2.01	0.88	0.96			
	37	⊥	AF11	7.83	-0.2	b	-0.1	-2.3	f	-1.7	-1.9	-1.7	-0.10			1.19	1.97					
	37	//	AF12		-0.8	b	-0.7	-3.4	f	-3.3	-2.6	-2.4	-0.14			1.03	1.74					
	2	//	AF13		-1.4	a	-1.2	-3.0	e	-2.7	-1.5	-1.7	-0.07			0.59	1.55					
	2	⊥	AF14		-1.1	b	-0.8	-1.5	f	-0.8	-0.2	0.0	0.0			0.77	1.59					
	18	⊥	AF15		-1.6	a	-0.6	-4.1	e	-3.0	-2.4	-2.6	-0.09			1.32	2.18					
	18	//	AF16		-0.6	b	-0.1	-3.6	f	-2.8	-2.9	-2.7	-0.13			1.02	1.57					
	56	⊥	AF17		+4.2	a	+4.7	-7.6	e	-7.2	-11.9	-12.1	-0.46					1.79				
	56	//	AF18		+10.0	a	+10.3	-3.1	e	-2.0	-12.7	-12.9	-0.49					2.65				
	60	//	AF19		-0.3	a	-0.3	-6.0	e	-5.9	-5.6	-5.8	-0.22	2.0	1.82	1.00	1.45	1.5	2.75			
	62	//	AF20		-0.1	a	-0.1	-5.7	e	-5.5	-5.6	-5.8	-0.22	1.3	1.33	0.71	1.20	1.95	3.24			
4.0	Solid Spine of PGA																			3.950 in		

Table 3.5  
 First Series Metallurgical Elements - Element 1 - Rod 5  
 Fuel Element 700 - Position 1/2

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum In	Length of Specimens in Units of 0.001 in on the Standard Lengths				Difference in Gauge Readings (0.001 in.)	Length Change (0.001 in.), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-400°C) x 10 <sup>-6</sup> °C <sup>-1</sup>		Electrical Resistivity mΩ cm		Young's Modulus 10 <sup>6</sup> psi		Total Length of Container		
					Pre-Irradiation		Post-Irradiation					Pre-	Post-	Pre-	Post-	Pre-	Post-			
												Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation			
5-1	Solid spine of PGA																	5.705 in		
5-2	Solid spine of PGA																	6.314 in		
5-3	Solid spine of PGA																	6.315 in		
5A	1	⊥	5A1	63.16	-0.2	a	0.0	- 6.4	c	- 6.1	- 6.1	-0.24		0.95	1.55			6.375 in		
	1	//	5A2		+0.7	a	+1.0	- 6.3	c	- 5.7	- 6.9	- 7.1	-0.27		0.94	1.49				
	5	//	5A3		-0.9	a	+0.5	-13.8	c	-12.1	-12.7	-12.9	-0.45	4.52	4.77	0.91	1.16		1.80	2.63
	5	⊥	5A4		-5.7	a	-2.4	- 6.3	d	- 2.1	- 0.2	-10.3	-0.39	4.74	5.30	0.82	1.26		1.78	2.36
	6	//	5A5		-8.6	a	-0.0	Shipped								1.77	2.30			
	6	⊥	5A6		-0.7	a	+1.4	- 7.5	c	- 6.0	- 7.0	- 7.2	-0.27		1.02	2.30				
	7	//	5A7		-0.9	a	+0.8	-11.8	c	-10.5	-11.1	-11.3	-0.43	4.06	3.96	0.76	1.17		1.75	2.40
	7	⊥	5A8		-3.8	a	-2.3	-11.0	c	- 9.2	- 7.1	- 7.3	-0.25	4.59	4.62	0.82	1.31		1.61	2.14
	59	//	5A9		-0.9	a	+0.6	-11.3	c	-10.8	-10.3	-10.3	-0.40		0.68	0.87				
	60	//	5A10		+0.1	a	+0.2	-10.4	d	-10.3	-10.3	-10.6	-0.78	4.0	1.09	1.00	1.38		1.5	2.64
	1	⊥	5A11	+0.3	a	+0.6	- 6.6	c	- 6.1	- 6.8	- 7.0	-0.27	4.90	5.01	0.95	1.57	1.24		1.57	
	1	//	5A12	-0.4	a	-0.1	- 8.0	c	- 7.8	- 7.7	- 7.9	-0.30		0.94	1.54					
	3	//	5A13	-8.7	a	-7.6	-13.2	d	-12.5	- 4.7	-14.8	-0.56	4.57	4.57	0.81	1.19	1.84		2.56	
	3	⊥	5A14	-0.3	a	+0.6	-12.0	d	-10.9	-11.6	-11.8	-0.45	4.74	5.06	0.82	1.21	1.78		2.50	
	6	//	5A15	-2.9	a	+1.0	- 6.0	d	- 4.8	- 3.2	-13.3	-0.51	4.84	4.17	1.77	2.24	1.11		1.39	
	6	⊥	5A16	+0.8	a	+1.5	- 9.0	c	- 7.0	- 0.7	- 8.9	-0.34	5.24	5.53	1.44	2.45	0.93		1.19	
	7	//	5A17	-0.6	a	+0.1	- 6.5	d	- 6.1	- 6.1	-16.4	-0.62	4.06	3.04	0.74	1.14	1.73		2.45	
	7	⊥	5A18	-2.3	a	-0.3	-12.4	c	-10.2	- 9.5	-10.1	-0.36	4.55	4.26	0.82	1.30	1.61		2.15	
	62	//	5A19	+0.1	a	+0.2	-11.5	d	-11.2	-11.5	-11.6	-0.82		0.71	1.09					
	60	⊥	5A20	+0.8	a	+1.1	-14.8	c	-14.5	-15.6	-15.6	-0.60	3.75	3.68	1.66	2.36	1.18		1.29	
16/4/2	Solid Spine of PGA for Small Bore Fuel Compact																	5.145 in		
5B	1	⊥	5B1	53.64	+0.1	a	+1.4	- 8.3	c	- 8.0	- 9.0	- 9.4	-0.35		0.75	1.50		6.301 in		
	1	//	5B2		+0.6	a	+0.8	- 9.7	c	- 9.5	-10.3	-10.5	-0.40		0.94	1.43				
	3	//	5B3		-1.0	a	-0.4	- 7.6	d	- 6.5	- 6.1	-16.2	-0.62	4.24	4.60	0.91	1.16		1.83	2.86
	5	⊥	5B4		-3.0	a	-1.3	- 7.2	d	- 5.8	- 4.4	-14.5	-0.55	4.74	5.10	0.92	1.22		1.78	2.21
	6	//	5B5		-0.4	a	+1.7	-10.0	c	-13.8	-10.4	-10.4	-0.39	4.84	4.67	1.71	2.30		1.11	1.57
	6	⊥	5B6		-2.4	a	-0.7	-14.7	c	-11.0	-10.6	-10.4	-0.41	5.52	5.17	1.82	2.42		0.93	1.43
	7	//	5B7		-0.7	a	+1.5	-10.5	d	- 7.8	- 9.5	-10.6	-0.74		0.74	1.10				
	7	⊥	5B8		-0.9	a	-0.1	-12.3	c	-11.5	-11.4	-11.5	-0.44	4.59	4.79	1.32	1.39		1.51	2.14
	59	⊥	5B9		-1.7	a	+1.2	-11.1	c	-10.2	- 9.2	- 9.4	-0.36		0.91	1.70				
	60	⊥	5B10		+0.5	a	+0.5	- 6.6	d	- 6.5	- 7.0	-17.1	-0.63	3.75	3.21	1.34	1.21		1.14	1.14
	1	⊥	5B11	-0.4	a	3.0	- 9.7	c	- 9.1	- 9.1	- 9.3	-0.35	4.50	4.79	0.95	1.49	1.24		1.66	
	1	//	5B12	-0.3	a	+0.1	-10.1	c	- 9.9	- 9.9	-10.1	-0.39	4.70	4.62	0.94	1.59	1.27		1.51	
	3	//	5B13	-0.2	a	+0.7	- 7.6	d	- 6.5	- 7.3	-17.4	-0.66	4.24	4.53	0.91	1.10	1.84		2.57	
	3	⊥	5B14	-0.3	a	+0.1	-14.6	c	-14.0	-14.5	-14.7	-0.46	4.74	5.09	0.92	1.29	1.79		2.37	
	6	//	5B15	-0.1	a	+0.3	- 9.0	d	- 6.5	- 5.7	-15.9	-0.60		1.77	2.16					
	6	⊥	5B16	-0.7	a	+1.0	-10.0	c	- 8.5	- 9.8	-10.0	-0.33		1.34	1.62					
	7	//	5B17	+0.3	a	+1.4	-13.3	c	-12.6	-13.9	-14.1	-0.34	4.06	4.03	2.74	1.21	1.73		2.40	
	7	⊥	5B18	-6.5	a	-3.1	-13.3	c	-12.0	- 8.8	- 9.0	-0.34	4.29	4.59	0.92	1.29	1.61		2.19	
	62	⊥	5B19	-0.1	a	0.0	- 5.2	d	- 7.9	- 8.0	-18.1	-0.69		1.40	1.95					
	11	⊥	5B20	-0.6	a	-0.3	-12.0	d	-12.1	-11.9	-22.0	-0.84		0.68	1.10					
5C	1	⊥	5C1	27.26	-0.5	a	-0.4	- 3.3	c	- 9.0	- 8.7	- 8.9	-0.34	4.90	3.06	0.95	1.35	1.24	1.50	6.375 in
	1	//	5C2		+0.4	a	+0.4	- 9.0	c	- 8.9	- 9.2	- 9.4	-0.36	4.70	4.40	0.94	1.60	1.27	1.50	
	3	//	5C3		-0.9	a	+0.6	- 6.4	c	- 4.5	- 3.3	-15.4	-0.58		0.91	1.19				
	5	⊥	5C4		-1.3	a	+1.0	-15.0	c	-14.3	-13.8	-16.0	-0.61		0.82	1.16				
	6	//	5C5		-3.2	a	-0.6	- 7.7	c	- 5.6	- 4.7	-14.8	-0.36	4.04	3.14	1.77	2.40	1.11	1.24	
	6	⊥	5C6		+5.9	a	+1.7	-10.0	c	- 9.1	-10.9	-11.1	-0.42	5.54	5.11	1.44	2.48	0.93	1.30	
	7	//	5C7		-3.0	a	-2.0	-12.0	d	-11.0	- 9.0	-19.1	-0.73		0.74	1.14				
	7	⊥	5C8		-3.3	a	-2.1	-12.4	c	-11.7	- 9.2	- 9.4	-0.36		0.82	1.21				
	59	//	5C9		+0.3	a	+0.6	-14.2	d	-13.8	-14.5	-14.7	-0.23		0.68	0.87				
	60	//	5C10		+0.7	a	+0.8	-14.9	d	-14.7	-15.6	-25.7	-0.97	2.0	1.06	1.00	1.73	1.0		
	1	⊥	5C11	-0.4	a	+0.2	- 9.3	c	- 9.0	- 8.6	- 9.0	-0.34		0.95	1.35					
	1	//	5C12	-0.8	a	+0.0	- 9.4	c	- 9.0	- 8.4	- 8.6	-0.33		0.94	1.45					
	5	//	5C13	-2.3	a	+1.3	- 7.3	d	- 6.5	- 5.2	-15.3	-0.58	4.52	4.77	0.91	1.25	1.80	2.23		
	5	⊥	5C14	-2.4	a	-0.2	- 5.9	d	- 4.7	- 3.7	-13.8	-0.53	4.74	4.87	0.94	1.30	1.78	2.45		
	6	//	5C15	-2.3	a	+1.1	- 7.4	d	- 6.0	- 4.9	-15.0	-0.57	4.84	4.40	1.77	1.70	1.11	1.48		
	6	⊥	5C16	-1.6	a	-0.5	-11.6	c	-10.7	-10.1	-10.3	-0.39		1.42	2.44					
	7	//	5C17	-7.6	a	-6.2	-11.4	c	-10.2	- 3.8	-13.9	-0.33	4.06	4.37	0.74	1.26	1.73	2.38		
	7	⊥	5C18	-0.9	a	-0.1	-11.3	c	-10.7	-10.6	-10.8	-0.41	4.59	4.35	0.82	1.37	1.61	2.18		
	62	//	5C19	+0.3	a	+0.4	-13.5	d	-13.3	-13.8	-13.9	-0.91	1.3	1.24	0.71	1.20	1.95	3.16		
	60	⊥	5C20	+0.5	a	+1.0	-13.1	c	-12.8	-15.7	-15.9	-0.61	3.75	3.98	1.30	1.67	1.10	1.10		

Table 3.5 (contd.)

Container Number	Graphite Reference No.	Orientation	Specimen Number	Position of Centre of Specimen versus Datum in	Length of Specimens in Units of 0.001 in on the Standard Lengths						Difference in Gauge Readings (0.001 in)	Length Change (0.001 in), i.e. Gauge Difference Plus Correction for Standards	Length Change %	Thermal Expansion (20-300°C) x 10 <sup>-6</sup> °C <sup>-1</sup>		Electrical Resistivity Ω cm		Young's Modulus 10 <sup>6</sup> psi		Total Length of Container
					Pre-Irradiation			Post-Irradiation						Pre-	Post-	Pre-	Post-	Pre-	Post-	
														Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	Irradiation	
50	1	⊥	5D1	20.88	+0.3	a	+0.5	-6.0	e	-5.6	-6.2	-6.4	-0.24	4.98	5.08	0.95	1.66	1.21	1.51	6.580 in
	1	//	5D2		+0.6	a	+1.1	-6.7	e	-6.0	-7.2	-7.4	-0.28	4.78	4.90	0.94	1.57	1.27	1.61	
	5	//	5D3		-3.1	a	-1.9	-14.6	e	-13.6	-13.6	-13.8	-0.53	4.52	4.99	0.81	1.26	1.90	2.57	
	5	⊥	5D4		-3.6	a	-2.1	-14.5	e	-13.5	-11.2	-11.4	-0.43	4.74	5.40	0.82	1.32	1.70	2.53	
	6	//	5D5		-0.7	a	+0.2	-12.7	e	-11.8	-12.0	-12.2	-0.46	4.84	4.99	1.77	2.39	1.11	1.45	
	6	⊥	5D6		-0.1	a	+1.5	-7.4	e	-5.9	-7.3	-7.5	-0.29	5.52	5.16	1.82	2.65	0.93	1.58	
	7	//	5D7		+0.3	a	+1.1	-11.3	e	-10.0	-11.3	-11.5	-0.44	4.06	4.29	0.74	1.26	1.73	2.47	
	7	⊥	5D8		-0.8	a	+0.5	-7.0	e	-5.5	-6.1	-6.3	-0.24	4.59	4.93	0.82	1.40	1.61	2.16	
	59	⊥	5D9		-0.7	a	-0.5	-7.5	e	-5.2	-5.7	-6.9	-0.26			0.91	1.85			
	60	⊥	5D10		+0.9	a	+0.9	-14.5	e	-14.0	-15.1	-15.3	-0.58	3.75	3.34	1.68	2.19	1.18	1.49	
	1	⊥	5D11	-0.2	a	+0.3	-5.3	e	-4.6	-5.0	-5.2	-0.20	4.98	4.75	0.95	1.71	1.24	1.59		
	1	//	5D12	-0.1	a	0.0	-6.0	e	-5.8	-5.9	-6.1	-0.23	4.78	4.68	0.94	1.63	1.27	1.61		
	5	//	5D13	-2.7	a	-1.7	-13.2	e	-11.7	-10.2	-10.4	-0.40			0.81	1.23				
	5	⊥	5D14	-2.8	a	-1.7	-12.6	e	-11.5	-9.8	-10.0	-0.38			0.82	1.32				
	6	//	5D15	+0.7	a	+1.8	-9.6	e	-8.6	-10.4	-10.6	-0.40	4.84	4.55	1.77	2.47	1.11	1.44		
	6	⊥	5D16	0.0	a	+1.2	-6.1	e	-5.0	-6.1	-6.3	-0.24	5.52	5.10	1.82	2.62	0.93	1.22		
	7	//	5D17	-4.9	a	-1.3	-10.2	e	-4.0	-2.7	-2.8	-0.49			0.74	1.26				
	7	⊥	5D18	-3.2	a	-2.0	-8.5	e	-7.3	-5.3	-5.5	-0.21	4.59	4.70	0.82	1.44	1.61	2.18		
	62	⊥	5D19	+0.2	a	+0.5	-12.5	e	-12.2	-12.6	-12.8	-0.49	2.9	2.61	1.20	2.04	0.92	1.53		
	60	//	5D20	+0.4	a	+0.6	-8.0	e	-7.5	-8.2	-8.5	-0.77	2.0	1.90	1.00	1.48	1.5	2.80		
58	1	⊥	581	14.50	+0.4	a	+0.6	-3.4	e	-3.0	-3.7	-3.9	-0.15			0.95	1.63			6.581 in
	1	//	582		+0.1	a	+0.4	-4.3	e	-3.9	-4.4	-4.6	-0.18			0.94	1.59			
	5	//	583		-5.9	a	-4.1	-14.4	e	-13.0	-8.7	-8.9	-0.34	4.52	4.93	0.81	1.30	1.80	2.65	
	5	⊥	584		-1.0	a	-0.5	-10.6	e	-9.0	-9.1	-9.3	-0.35			0.82	1.32			
	6	//	585		+0.1	a	+0.4	-8.6	e	-7.9	-8.5	-8.7	-0.33			1.77	2.11			
	6	⊥	586		-0.8	a	-0.5	-8.2	e	-7.3	-7.1	-7.3	-0.28			1.84	2.45			
	7	//	587		-0.5	a	0.0	-13.5	e	-11.5	-12.3	-12.5	-0.48			0.74	1.26			
	7	⊥	588		-0.8	a	+0.5	-7.2	e	-5.8	-5.9	-6.1	-0.23	4.59	4.98	0.84	1.43	1.61	2.15	
	59	//	589		-0.5	a	-0.4	-10.0	e	-9.6	-9.4	-9.6	-0.36			0.46	1.05			
	60	//	5810		-0.1	a	0.0	-8.0	e	-8.0	-8.0	-8.1	-0.69	2.0	1.74	1.00	1.44	1.5	2.74	
	1	⊥	5811	-0.2	a	+0.1	-2.5	e	-2.3	-2.4	-2.6	-0.10	4.98	4.94	0.95	1.65	1.24	1.62		
	1	//	5812	-0.3	a	+0.2	-3.5	e	-2.6	-3.0	-3.2	-0.12	4.78	4.49	0.94	1.61	1.27	1.63		
	5	//	5813	-2.0	a	+0.6	-7.7	e	-5.8	-6.0	-6.2	-0.24			0.81	1.29				
	5	⊥	5814	-0.8	a	+0.5	-7.0	e	-3.2	-6.0	-6.2	-0.24	4.74	5.44	0.82	1.59	1.78	2.49		
	6	//	5815	-7.4	a	-1.1	-13.0	e	-10.6	-5.1	-5.3	-0.24	4.84	4.64	1.77	2.47	1.11	1.42		
	6	⊥	5816	+0.3	a	+1.2	-3.5	e	-2.5	-3.0	-3.0	-0.12	3.74	3.84	1.82	2.74	0.93	1.17		
	7	//	5817	-1.5	a	-0.9	-8.1	e	-7.5	-6.6	-6.8	-0.26	4.06	4.05	0.74	1.50	1.73	2.30		
	7	⊥	5818	-1.9	a	-0.6	-10.5	e	-9.3	-8.5	-8.7	-0.33			0.32	1.26				
	62	//	5819	+0.4	a	+0.5	-12.0	e	-11.8	-12.4	-12.6	-0.48	1.3	1.22	0.71	1.48	1.95	3.31		
	60	⊥	5820	+0.3	a	+0.4	-7.9	e	-7.8	-8.2	-8.4	-0.32	3.75	3.67	1.58	2.71	1.12	1.18		
59	1	⊥	591	8.13	+0.5	a	+0.9	-0.9	e	-0.5	-1.4	-1.6	-0.06			0.95	1.63			6.574 in
	1	//	592		+0.3	a	+0.8	-1.5	e	-0.3	-1.7	-1.9	-0.07			0.94	1.64			
	5	//	593		-3.9	a	-0.6	-9.6	e	-6.0	-3.6	-3.8	-0.22	4.52	4.93	0.81	1.32	1.30	3.85	
	5	⊥	594		-2.3	a	0.0	-6.9	e	-4.2	-4.4	-4.6	-0.18	4.74	5.26	0.82	1.38	1.78	2.50	
	6	//	595		-1.7	a	+0.2	-5.8	e	-4.5	-4.4	-4.6	-0.18	4.84	4.80	1.77	2.65	1.11	1.35	
	6	⊥	596		-0.7	a	-0.1	-3.5	e	-3.0	-2.8	-3.0	-0.11	5.52	5.34	1.82	2.57	0.93	1.10	
	7	//	597		-5.5	a	+3.9	-12.3	e	-10.3	-4.1	-4.3	-0.16	4.06	4.77	0.74	1.32	1.73	2.37	
	7	⊥	598		0.0	a	-0.3	-1.6	e	-0.9	-1.1	-1.3	-0.05			0.82	1.49			
	59	⊥	599		-0.2	a	0.0	-1.9	e	-1.3	-1.6	-1.8	-0.07			0.91	1.85			
	60	⊥	5910		+0.3	a	+0.3	-6.2	e	-6.0	-5.4	-6.5	-0.25	3.75	3.66	1.63	2.23	1.18	1.51	
	1	⊥	5911	+0.4	a	+0.7	-0.4	e	-0.1	-0.8	-1.0	-0.04	4.98	4.63	0.95	1.72	1.24	1.56		
	1	//	5912	-0.6	a	-0.3	-1.7	e	-1.4	-1.1	-1.3	-0.03	4.78	5.04	0.94	1.59	1.27	1.64		
	5	//	5913	-4.5	a	-2.4	-6.1	e	-3.3	-3.3	-3.5	-0.13	4.74	4.79	0.81	1.34	1.30	2.66		
	5	⊥	5914	-3.2	a	-1.9	-7.0	e	-5.8	-3.9	-4.1	-0.16	4.74	5.43	0.82	1.64	1.78	2.65		
	6	//	5915	-2.0	a	-0.5	-6.6	e	-4.1	-3.8	-4.0	-0.15	4.84	4.94	1.77	2.63	1.11	1.28		
	6	⊥	5916	-1.8	a	-0.1	-4.0	e	-2.0	-2.1	-2.3	-0.09	3.52	3.29	1.32	2.32	0.93	1.20		
	7	//	5917	+0.7	a	-0.1	-3.9	e	-3.0	-3.0	-3.1	-0.12	4.06	4.75	0.74	1.32	1.73	2.36		
	7	⊥	5918	-3.4	a	-0.8	-4.7	e	-4.1	-1.8	-2.0	-0.10	4.59	4.76	0.82	1.40	1.61	2.14		
	62	⊥	5919	+0.3	a	+0.6	-5.2	e	-5.0	-5.6	-5.8	-0.24	2.9	2.63	1.20	2.02	0.92	1.43		
	60	//	5920	+0.1	a	+0.2	-7.6	e	-7.5	-7.7	-7.9	-0.30	2.0	2.00	1.00	1.42	1.5	2.81		
50	Solid Spine of PCA																	6.594 in		

Reed [7] has shown, by Monte Carlo calculations that the graphite damage function for Dragon is equal to that of the Dragon/THTR capsule position in HFR Petten and is equal to 1.7 times that of Dido. Hence:

$$\text{Ni dose Dragon} = \text{Ni dose HFR Petten} = 1.7 \text{ Ni dose Dido.}$$

### 3. POST-IRRADIATION DATA

#### 3.1 Irradiation History

Fuel element 700 was loaded into Position 1/5 of the Dragon core on 4.4.66 and remained in that position until 11.9.66, when it was removed from the core. Fig. 2 shows that during the first 5 days irradiation of the experiment, the reactor power was varied between 2 MW and 7 MW, after which it remained at the full power of 20 MW for a period of 98 days. During the complete run, there were in all 9 reactor trips which totalled about 80 h. The primary coolant helium mass flow of  $24 \text{ lb s}^{-1}$ , during the first 18 days of operation, provided a slightly lower gas exit temperature, of  $\sim 685^{\circ}\text{C}$ , than for the remainder of the run, when the mass flow was decreased to  $21 \text{ lb s}^{-1}$  to obtain the normal gas exit temperature of  $\sim 730^{\circ}\text{C}$ . As the gas exit temperature varied, throughout the run, so the temperature of the element varied slightly, as shown in Fig. 2.

There were no thermocouples, in the spines of element 700, to measure temperatures directly, but in the adjacent centre element (Position 0/0), there was one thermocouple; the readings of which are shown in Fig. 2. This was the only mid-plane spine thermocouple near enough to element 700 to be of any value. Only two other thermocouples, in similar mid-plane positions, were operating and these were in elements towards the edge of the core. Consequently, they were far too remote from element 700 to provide any relevant data.

#### 3.2 Physical Properties

##### 3.2.1 Physical Appearance

After irradiation, it was found that many of the spine containers and their respective specimens, were coated with a layer of fine sooty dust. This deposit was most apparent on those containers irradiated in the hottest region of the element, and it is possible that the cause might be the conditions, under which the compacts were degassed, prior to assembly of the element. It had the appearance of being deposited from a gas phase, which had diffused through the walls of the spine containers. This is quite probable because the containers were manufactured from PGA; a graphite with a fairly high coefficient of permeability.

This sooty deposit hindered, somewhat, the post-irradiation examination of the specimens, because each specimen had to be wiped clean with a filter paper, in a special fume cupboard, before identification of the specimens was possible.

### 3.2.2 Activity of the Specimens

Each container of specimens (i.e., twenty specimens per container) was monitored in an aluminium can, and the radiation levels, on 31.10.66, were as below:

<u>Rod No.</u>	<u>Activity (mR)</u> on contact with Al can (twenty specimens)
1	50
2	50
3	500
4	300
5	50

Some of the activity was associated with the sooty deposit on the specimens, because, swabs from individual specimens gave a few thousand cps ( $\beta$ ).

### 3.2.3 Dimensional Changes

Post-irradiation measurements of specimen lengths were carried out using the same apparatus and method described earlier, for the pre-irradiation measurements. Results from these measurements, together with an indication of the standard length used for every measurement, are recorded in Table 3. A letter coding system was adopted to identify the different standard lengths and this is explained in Table 2.

The mean values of the pre-irradiation length measurements and the corresponding post-irradiation measurements, were then subtracted to find the "apparent" length change. The "actual" length change, finally expressed as a percentage, was obtained by applying a correction for the different dimensions of the standard lengths used for pre-irradiation measurements and those used for post-irradiation measurements. These calculations are shown, step by step, in Table 3.

## 4. INTERPRETATION OF DATA

### 4.1 Derivation of Axial Temperature Profile

By plotting the shrinkage of the specimens against height above the core base, curves can be plotted for every graphite, similar to those in Figs. 3, 4 and 5. However, these curves illustrate the shrinkage of the graphite as a function not only of height above core base, but also, of asymmetrical temperature and neutron dose curves. Therefore, they can

only be used to demonstrate the irradiation anisotropy and for the derivation of the axial temperature profile. It has been assumed, in this report that all the rods had the same neutron dose profile and the same axial temperature profile, except for Rod 1, which is considered as having operated approximately 40°C cooler than the other rods. These assumptions are substantiated by considering the plots of G5 and PGA (i.e., Figs. 4 and 5). These two plots are composed of results from all the rods. The fact that Rod 1 ran cooler, is shown on the two plots by the broken lines. Using these two plots and data from Petten, for these graphites, it is now possible to derive temperature curves for element 700. The Petten data, is available for the temperatures 600°C, 900°C and 1200°C and for increasing neutron dose.

If the Petten results for 1200°C are plotted on Fig. 5, for the corresponding neutron doses in the Dragon core, a second set of curves is obtained, which intersect the Dragon data. The points of intersection are the points at which the specimens in the Dragon Reactor would have been irradiated at the temperature of 1200°C. This is so for G5 // and ⊥ and for PGA ⊥. The PGA // curves if plotted do not intersect, but it is interesting to note that one isolated point is in the expected region of the ⊥ curve. Lack of correlation between the Dragon and Petten results for PGA might be explained by the fact that slightly different materials were used. It is known that the PGA graphite used by Petten is that manufactured by Anglo Great Lakes which is doubly impregnated but the PGA graphite used in the Dragon experiments is manufactured by British Acheson Electrodes Limited which is only singly impregnated. Because of this difference in PGA material it is preferable to use in the main, the G5 results, because the same material was used in both experiments.

If the Petten results for G5 at 900°C are also plotted in the same manner, then points of intersection are obtained for both the // and ⊥ directions, see Fig. 5.

It should be noted at this point, that it is quite legitimate to make a direct comparison between the neutron dose of Dragon and that of Petten HFR, because both have the same damage function for graphite.

As points in the Dragon Reactor, which correspond to temperatures of 900°C and 1200°C, have now been established, it is now necessary to find some means of interpolation for the intermediate temperatures. It is assumed that for a neutron dose of the order  $3 \times 10^{20}$  n cm<sup>-2</sup> and temperatures in the region 600°C to 1200°C, the rate of shrinkage of the graphite per unit neutron dose, as a function of temperature (T) can be characterized by an activation energy. This is based on the assumption, that the rate of shrinkage of the graphite, over the temperature range 600°C to 1200°C and within the neutron dose range 0 to  $3.3 \times 10^{20}$  n cm<sup>-2</sup> is related to temperature dependent rates of diffusion of the vacancies in the graphite. Therefore, a plot of log rate of shrinkage versus

$\frac{10^4}{T - T_0}$  should be linear. Figs. 6 and 7 show that, for G5 graphite this is

nearly so, but for PGA graphite, the plot appears to be influenced by the slight initial expansion at 600°C. The graphs for G5 and PGA graphite are of Petten data and apply to neutron doses of 2, 3 and  $3.3 \times 10^{20}$  n cm<sup>-2</sup>. Now at the points in the Dragon Reactor, which have these same neutron doses. Shrinkage values can be obtained from the plots of specimen shrinkage against height in the core. For these shrinkages to have been obtained, in fuel element 700, specimens must have been at temperatures, between 900°C and 1200°C, which can be read from the Petten curves in Figs. 6 and 7. With these figures, it is now possible to construct a temperature profile for element 700, with respect to height above the core base. This profile, with that of the neutron dose, is illustrated in Fig. 8.

By using the same procedure on Petten data for graphite 16 and PGA graphite, the same temperature profile is obtained, however, for reasons already given results for PGA have been ignored.

#### 4.2 Results

Using the temperature distribution curves, given by the shrinkage of G5 graphite, and the original plots of dimensional shrinkage versus height above core base, it is now possible to obtain the shrinkage of "hypothetical" specimens of every graphite for the temperatures 900, 1000, 1100 and 1200°C. For some of the graphites, these curves are not very definite in the 900°C region and, hence no relevant valid information can be derived for that temperature.

Assuming that any effect of initial expansion of the specimens is very small compared with that of the shrinkage of the specimens at neutron doses of  $3 \times 10^{20}$  n cm<sup>-2</sup>, then these results can be expressed as an average rate of shrinkage per unit neutron dose. These results are illustrated as functions of temperature in Figs. 9 to 15 and tabulated in Table 4.

Physical property measurements (i.e., thermal expansion, electrical resistivity and Young's Modulus) have been made on the specimens of some selected graphites, the results from which are given in Table 3 and illustrated, for comparison with typical pre-irradiation values, in Figs. 17 to 25.

#### 5. DISCUSSION

The axial temperature profile of element 700 has been constructed, mainly, from Petten data on G5 graphite. However, Petten data on graphite 16, HX30 and PGA 1 has been used in confirmation.

Results for PGA present an anomaly in that the ratio of shrinkage in the parallel direction to shrinkage in the perpendicular direction, has different values for the same temperature and neutron dose conditions (i.e., 900°C and  $3 \times 10^{20}$  n cm<sup>-2</sup> respectively). Data from Petten gives a ratio of 2:1, but that from Dragon gives a ratio of only 1:5 - Simmons and Reynolds have



reported a ratio of 1:4 [6]. It is important to remember that the PGA graphite used in the Petten HFR was of a different variety to that used in the Dragon Reactor.

Estimation of errors, shows that, at 1200°C, it is probable that an error of 10% in the specimen length measurement or the neutron flux measurement, would give rise to an error in the estimated temperature of ±40°C. This uncertainty in temperature is increased to ±60°C at 900°C, for probable errors of 20% in length or flux measurements. This larger error at 900°C, can be explained, by the fact that there were fewer specimens at 900°C; that the specimen shrinkage is smaller and that the curve of shrinkage versus height above core base is steep, in this region.

Acceptance of the derived temperature profile makes it possible to compare this curve with those obtained from calculations and the thermocouples, in adjacent fuel elements. Fig. 16 shows that there is a reasonable agreement between the curves calculated from physics and heat transfer data, but there is disagreement with the plot of the thermocouple readings. At mid-core height the derived temperature is approximately 80°C higher than that from the thermocouples, and at the top of the core, the thermocouples indicated a higher temperature than do the graphite specimens. The lack of agreement can in part be explained by the following three points:

- (a)  $\gamma$  heating of the spine container and its specimens which raises its temperature above that of the inner wall of the fuel compacts.
- (b) Uncertainty of the degree thermal contact between the specimens and the container and between the container and the fuel compact.
- (c) The sooty deposits on the specimens which could reduce the radial thermal conductivity.

Apart from a very few cases, the results from the graphite specimens only give single point plots of shrinkage for a specified material, temperature and neutron dose, because element 700 is the first in a series of "metallurgical" elements. No other data is available at the present, but in time more data will be produced with respect to increasing dose. The results from the first and second uprated elements, which apply to neutron doses of up to  $\sim 1 \times 10^{20} \text{ n cm}^{-2}$  and have been analysed by Graham [4], could not be utilised in this report because of the uncertainty of the operating temperatures in the uprated elements.

With normal operation of the Dragon Reactor, under 20 MW conditions, it is not possible to irradiate the graphite specimens at a temperature lower than 900°C in a normal fuel element. As it would be more desirable to cover a range of temperatures between 600°C and 1200°C, the only alternative to normal running conditions is to include specimens in a special element containing derated fuel.

Results from the specimens of pyrocarbon, show that there was a large expansion in the "perpendicular" direction and a contraction in the "parallel" directions. For the non-heat treated specimens, the contraction in one of the "parallel" directions was about half that in the other "parallel" direction.

Table 5

Details and Dimensional Changes of Pyrolytic  
Graphite Samples (Ex Winfrith)

Sample	Height Above Base of Core (in)	Neutron Dose (n cm <sup>-2</sup> )	Temperature (°C)	Dimensional Change (%)		
				(a)	(b)	(c)
'U.T.'	40.56	2.56 x 10 <sup>20</sup>	1230	-5.3	-2.0	+7.0
'T'	27.80	3.13 x 10 <sup>20</sup>	1220	-4.2	-6.2	+7.6
'U.T.'	11.88	2.23 x 10 <sup>20</sup>	1030	-4.6	-2.3	+5.9

(a) is the 1.7 in long axis of the 0.25 in square section specimen, (i.e., one of the "parallel" directions. (c) is the "perpendicular" direction).

'U.T.' is the pyrocarbon as deposited, from CH<sub>4</sub>, at 1800°C to 2000°C.

'T' is as above, but heat treated at 3000°C

Table 6

Details and Dimensional Changes of Pyrolytic  
Graphite Samples (Ex R.M.L. Culcheth)

Samples	Neutron Dose ( $\times 10^{20}$ n cm <sup>-2</sup> )	Temperature (°C)	C.T.E. (20-120°C) ( $\times 10^{-6}$ °C <sup>-1</sup> )		$\frac{\Delta X_c}{X_c}$ (%)	$\frac{\Delta X_a}{X_a}$ (%)
			$\alpha_c$	$\alpha_a$		
(a)	2.70	930	22.2		3.18	
	3.20	1104	22.7		7.59	
	3.30	1180		-0.23	8.87	-3.28
	3.22	1210	24.0	-0.40	8.75	-3.28
	3.00	1218	22.8	-0.20	8.37	-3.22
	2.66	1216	23.0	-0.80	7.24	-2.99
(b)	2.70	930	22.8		0.72	
	3.20	1104	22.6		0.48	
	3.30	1180	22.4		2.32	
	3.22	1210	23.3		0.28	
	3.00	1218	23.5		0.59	
	2.66	1216	22.7		0.93	
(c)	2.70	930	23.8		2.56	
	3.20	1104	22.3		2.60	
	3.30	1180	24.5		2.95	
	3.22	1210	23.6		4.89	
	3.00	1218	22.3		5.93	
	2.66	1216	21.3		1.99	

Samples (a) are as deposited.

Samples (b) are heat treated at 2900°C.

Samples (c) are heat treated at 3200°C.

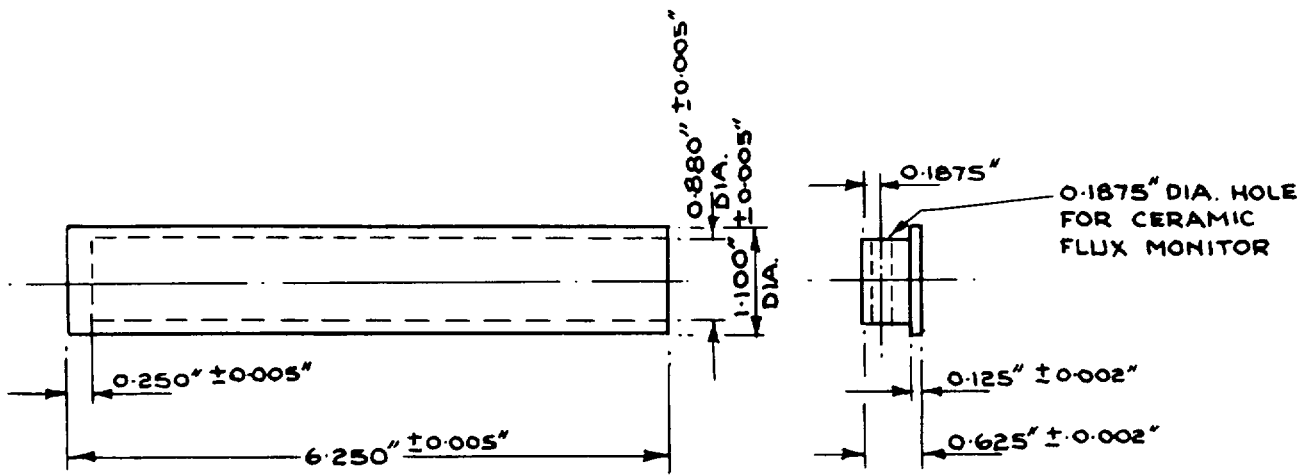
The above measurements and calculations were made by R.M.L. Culcheth.

## 6. CONCLUSIONS

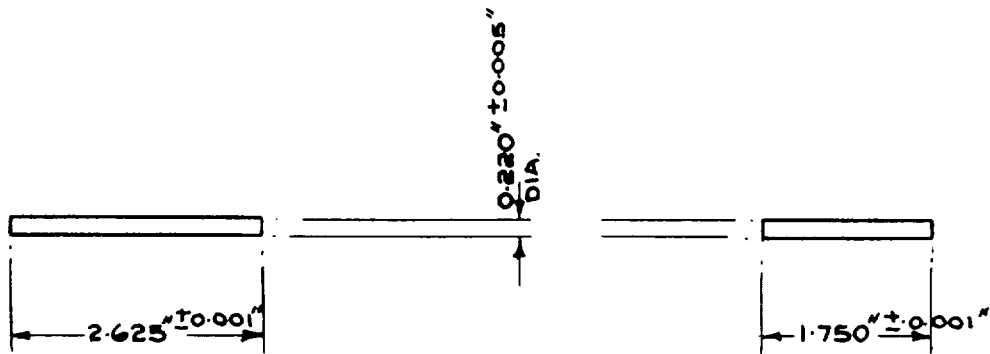
1. Characteristic temperatures for the graphite specimens, in element 700, have been derived, using the Petten data on the shrinkage of G5 graphite. Temperatures which range from 900°C to 1200°C appear to be approximately 80°C higher than those indicated by the spine thermocouples in the adjacent elements.
2. Neutron doses, experienced by the specimens in this element, were between  $2.4$  and  $3.3 \times 10^{20}$  n cm<sup>-2</sup>.
3. Average rates of shrinkage of improved isotropic graphites at 1200°C, and  $3 \times 10^{20}$  n cm<sup>-2</sup> (Ni dose Dragon) varied from 0.085% per  $10^{20}$  n cm<sup>-2</sup> to 0.170% per  $10^{20}$  n cm<sup>-2</sup>.

## 7. REFERENCES

- [1] R. Blackstone, P. F. Sens, L. W. Graham and E. H. Voice, "Experiments on the Irradiation of Graphites at High Temperatures." D.P. Report 351.
- [2] E. H. Voice, "Graphite Specimens in the Uprated Element, First Charge Position 3/1." D.P. Report 343.
- [3] E. H. Voice, "Graphite Specimens in the Second Uprated Element, First Charge Position 3/5." D.P. Report 382.
- [4] L. W. Graham, "Dragon Project Internal Document".
- [5] M. R. Everett, L. W. Graham, "Dimensional Changes of Graphite Specimens Irradiated in Dragon Fuel Element 700," Part II, "Some Comments on the Irradiation Shrinkage of Graphite." D.P. Report 556 - Part II.
- [6] W. N. Reynolds, P. A. Thrower and J. H. W. Simmons. Second Industrial Carbon Conference, April, 1965.
- [7] D. L. Reed, "The Comparison of Carbon-Atom Displacement Rate in Graphite in the Dragon Reactor, the Petten HFR and Low Enrichment HTR," D.P. Report 559.

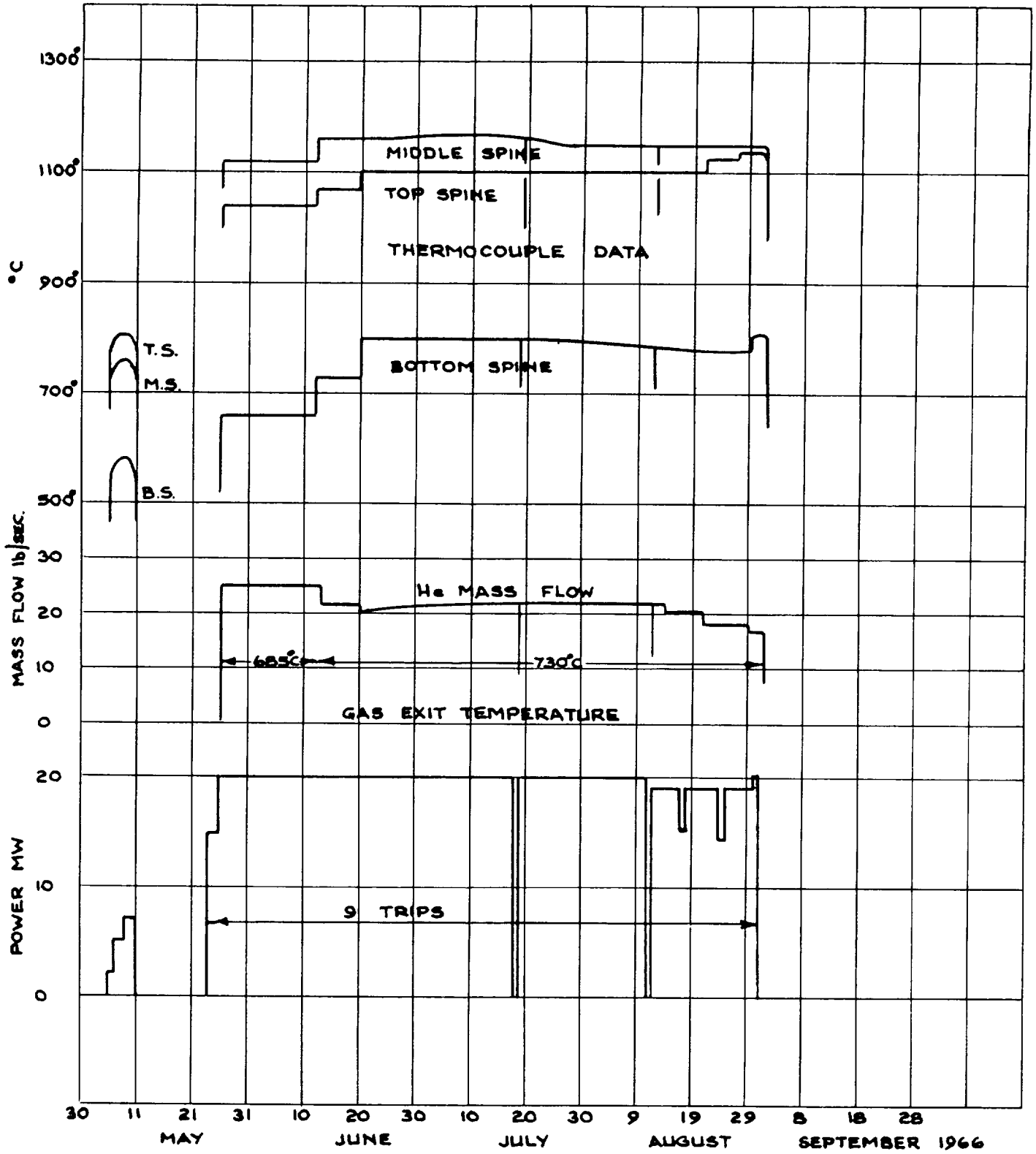


SPECIMEN CONTAINER



SPECIMEN

FIG. 1 GRAPHITE SPECIMENS AND CONTAINERS



**FIG. 2 IRRADIATION HISTORY OF FUEL ELEMENT 700**

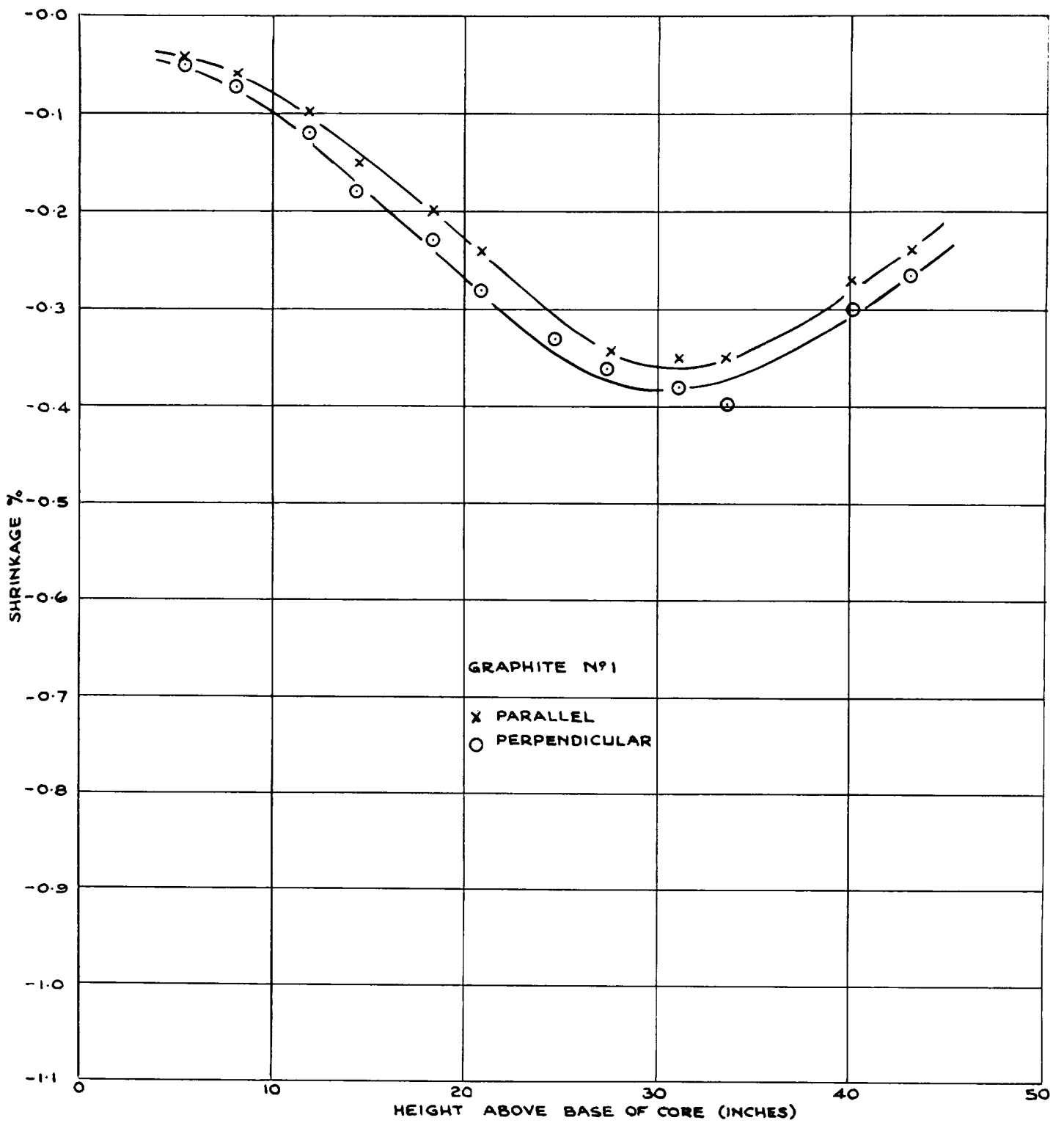


FIG. 3 SHRINKAGE OF GRAPHITE No. 1  $V_s$  HEIGHT IN REACTOR CORE

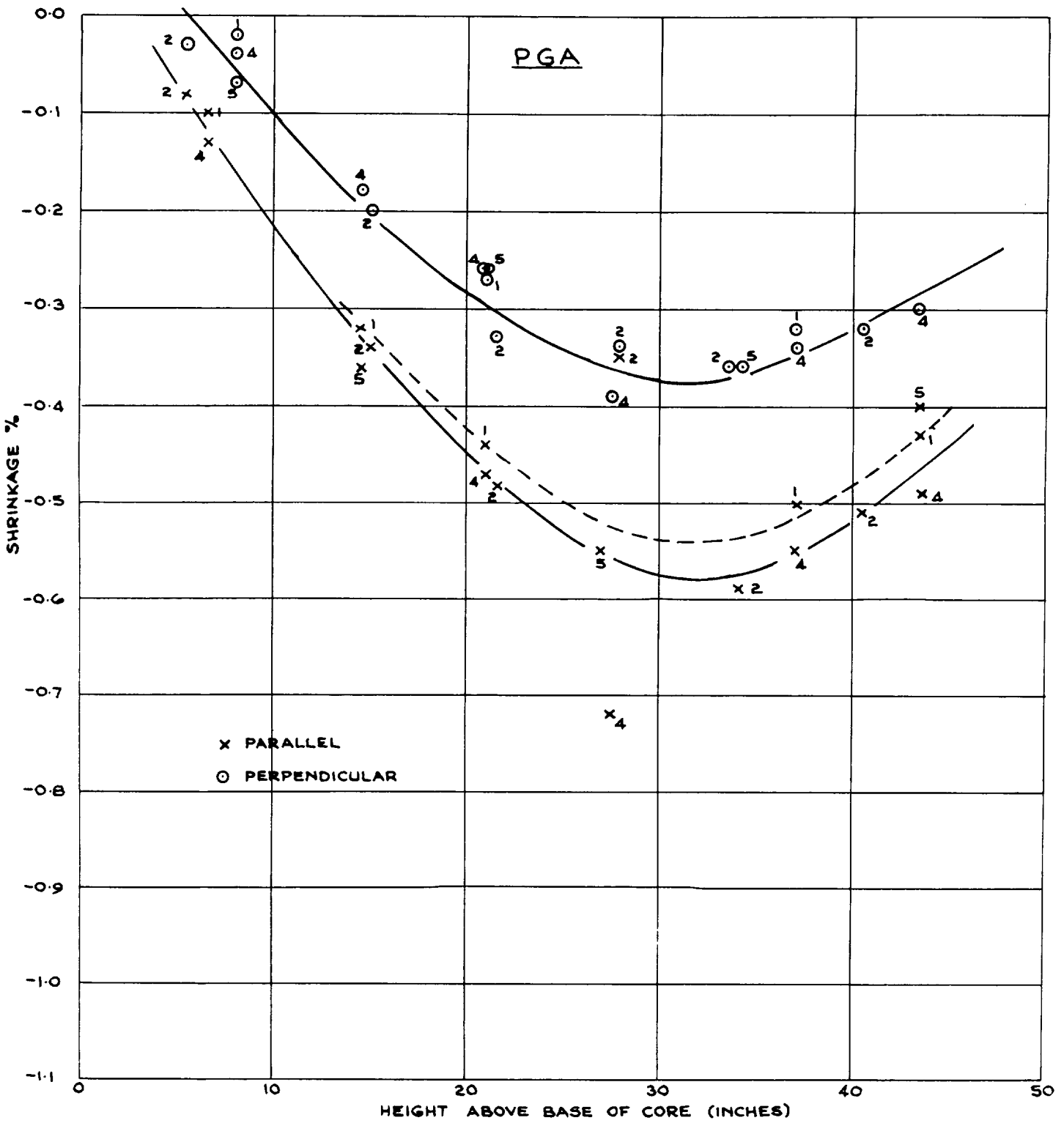
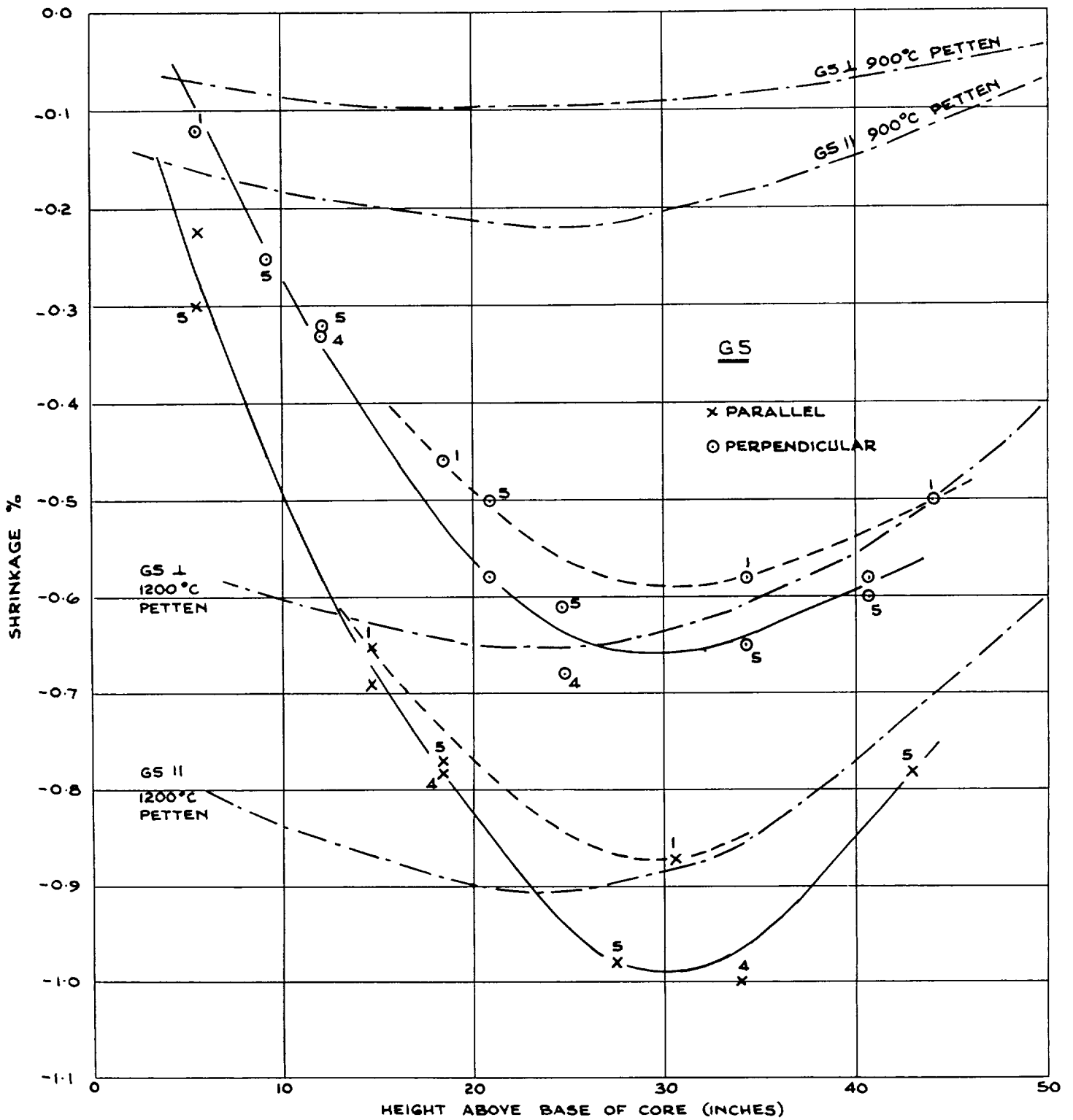


FIG. 4 SHRINKAGE OF PGA GRAPHITE VS HEIGHT IN REACTOR CORE



**FIG. 5 SHRINKAGE OF G5 GRAPHITE V<sub>s</sub> HEIGHT IN REACTOR CORE WITH PETTEN DATA SUPERIMPOSED**

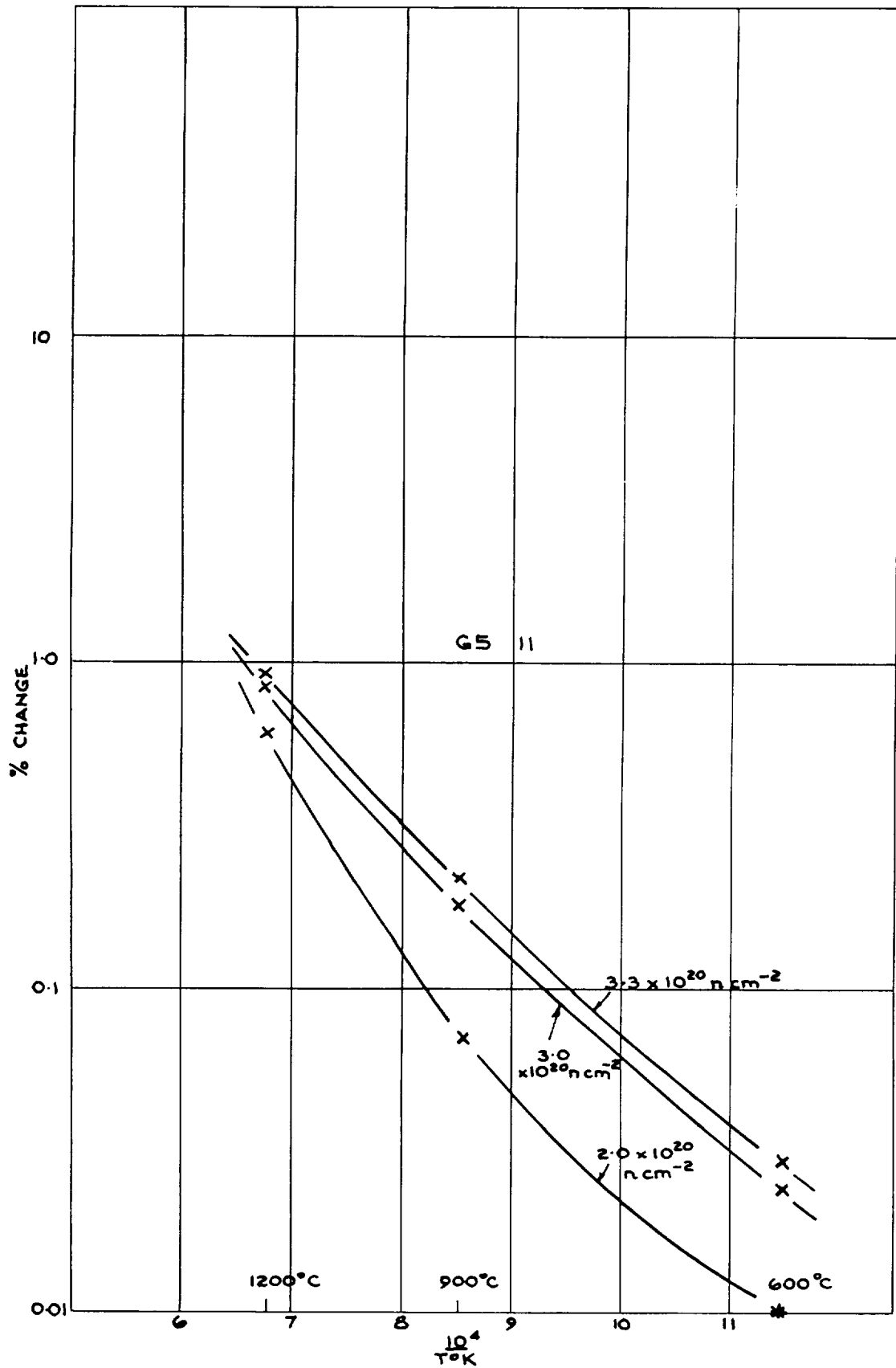


FIG. 6 LOG SHRINKAGE OF G5 11 GRAPHITE VS  $\frac{10^4}{T^{\circ}K}$  FOR A RANGE OF NEUTRON DOSES (PETTEN DATA)

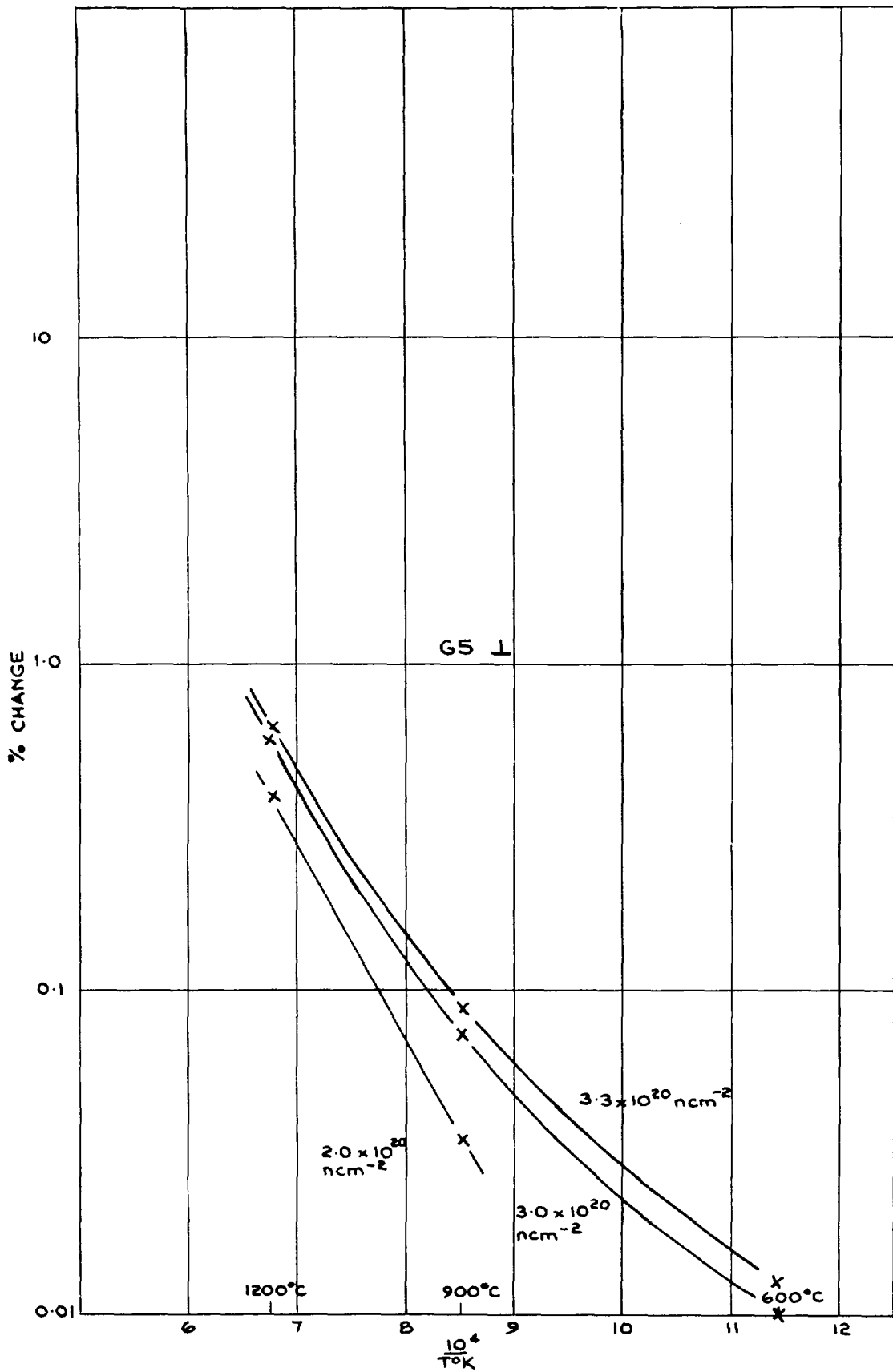


FIG. 7 LOG SHRINKAGE OF G5 ⊥ GRAPHITE VS  $\frac{10^4}{T^{\circ}K}$  FOR A RANGE OF NEUTRON DOSES (PETTEN DATA)

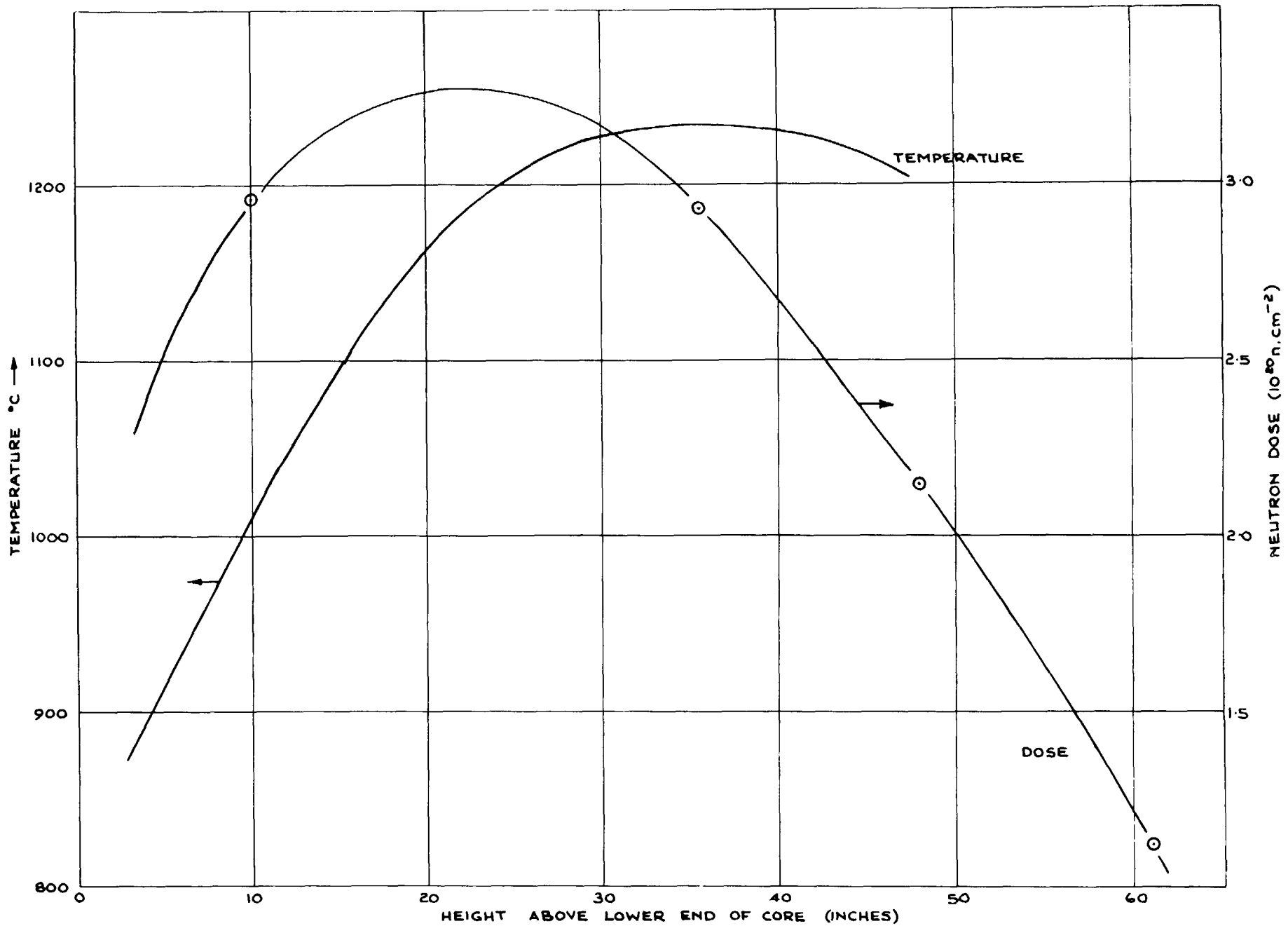


FIG. 8 TEMPERATURE AND DOSE CURVES  $\frac{1}{6}$  HEIGHT IN REACTOR CORE FOR FUEL ELEMENT 700

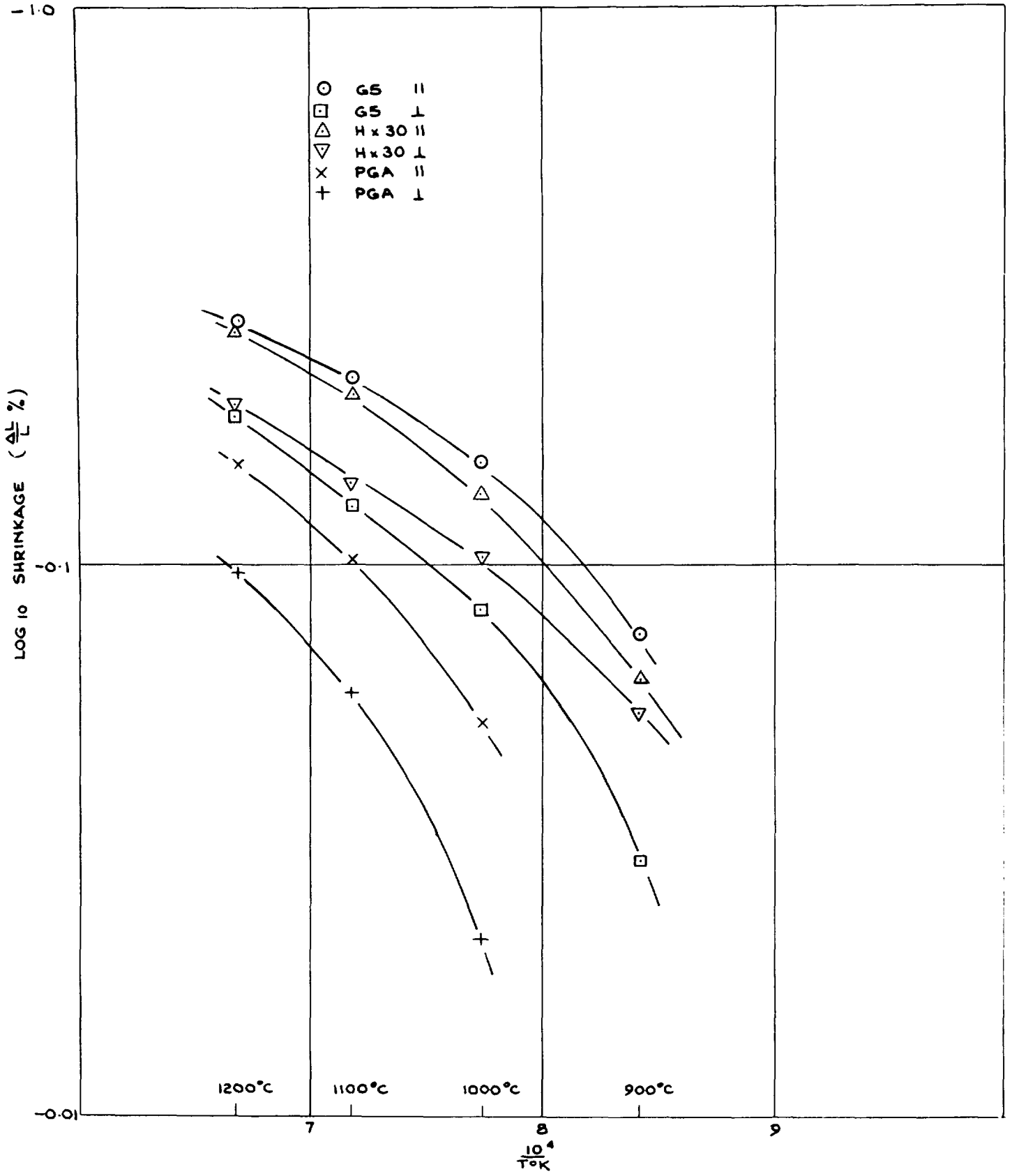


FIG. 9 LOG<sub>10</sub> SHRINKAGE OF PGA, G5 AND Hx30 GRAPHITE Vs  $\frac{10^4}{T \text{ °K}}$

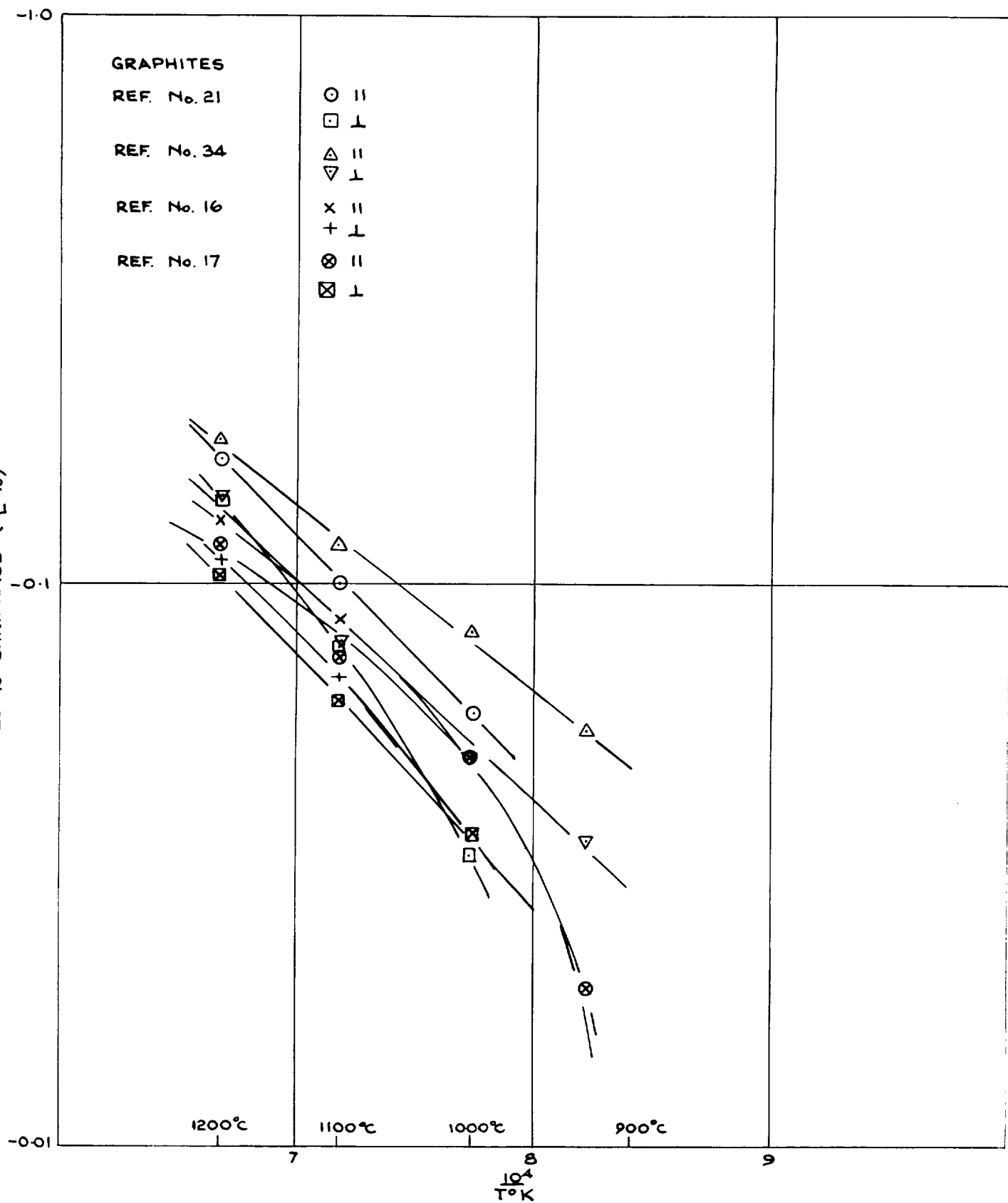


FIG. 10 LOG<sub>10</sub> SHRINKAGES OF GRAPHITES IN ROD 1 Vs  $\frac{10}{T^\circ K}$

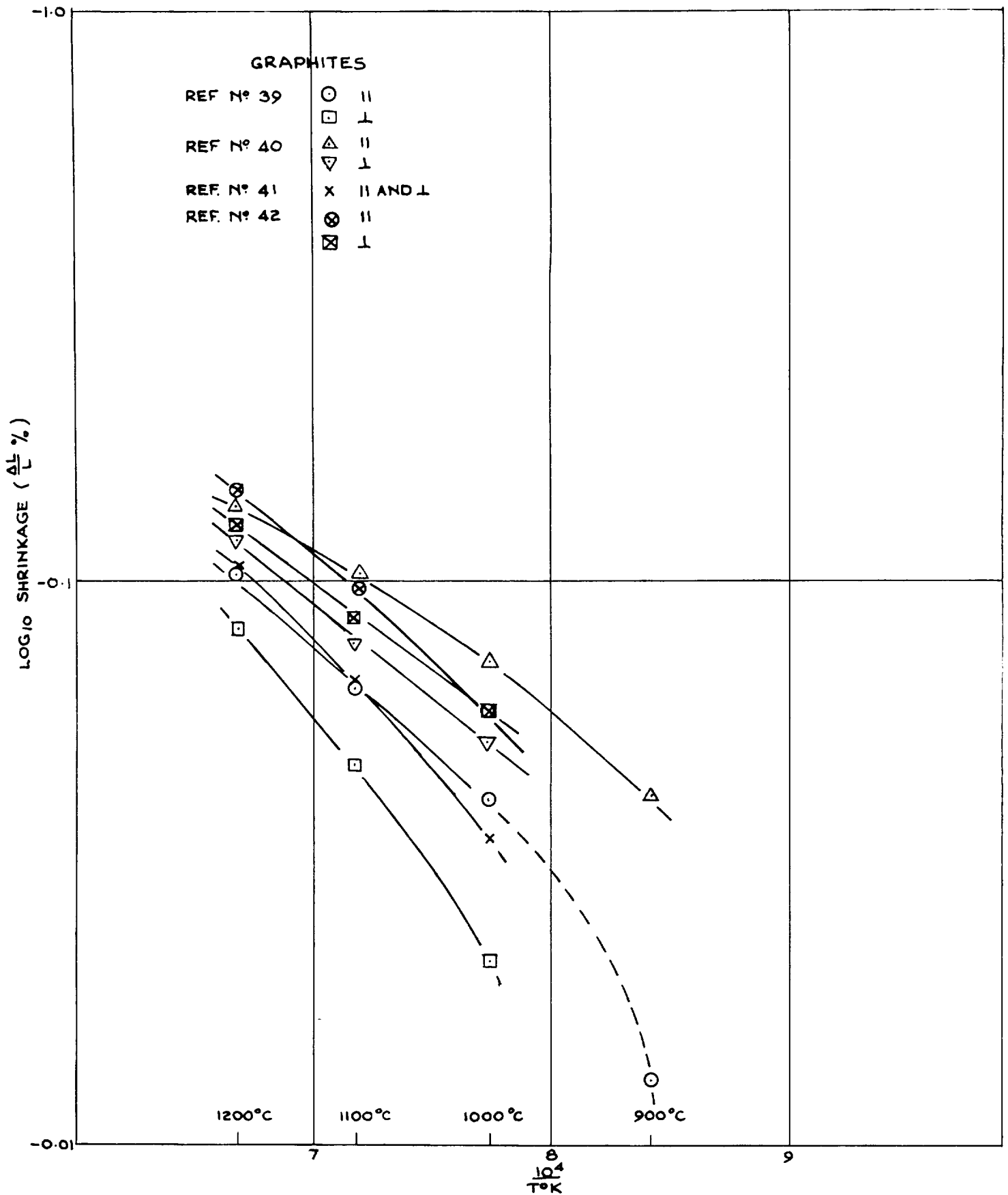


FIG. 11 LOG<sub>10</sub> SHRINKAGE OF GRAPHITES IN ROD 2 VS  $\frac{10^4}{T \text{ } ^\circ\text{K}}$

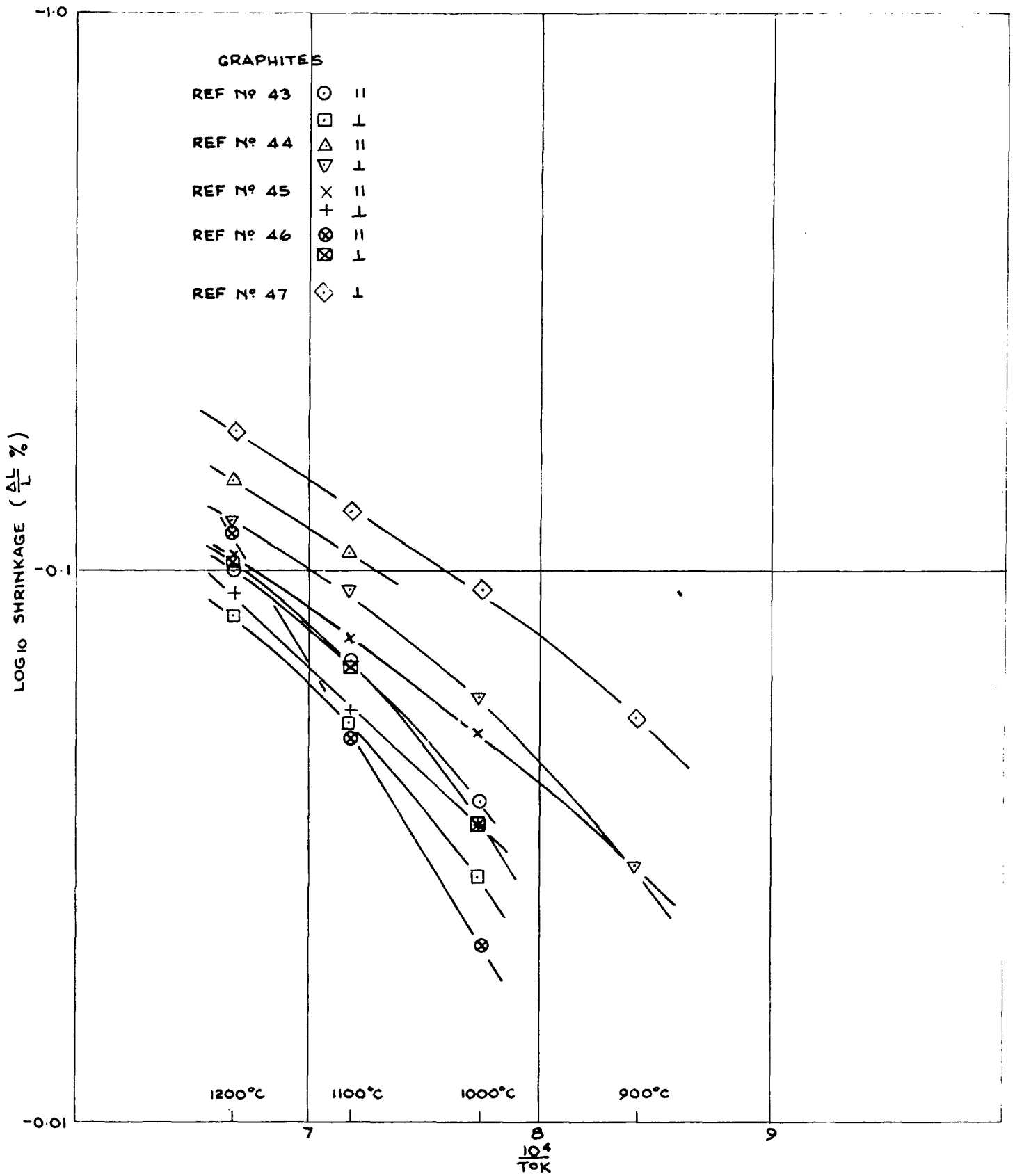


FIG. 12 LOG<sub>10</sub> SHRINKAGE OF GRAPHITES IN ROD 2, Vs  $\frac{10^4}{T^{\circ}K}$

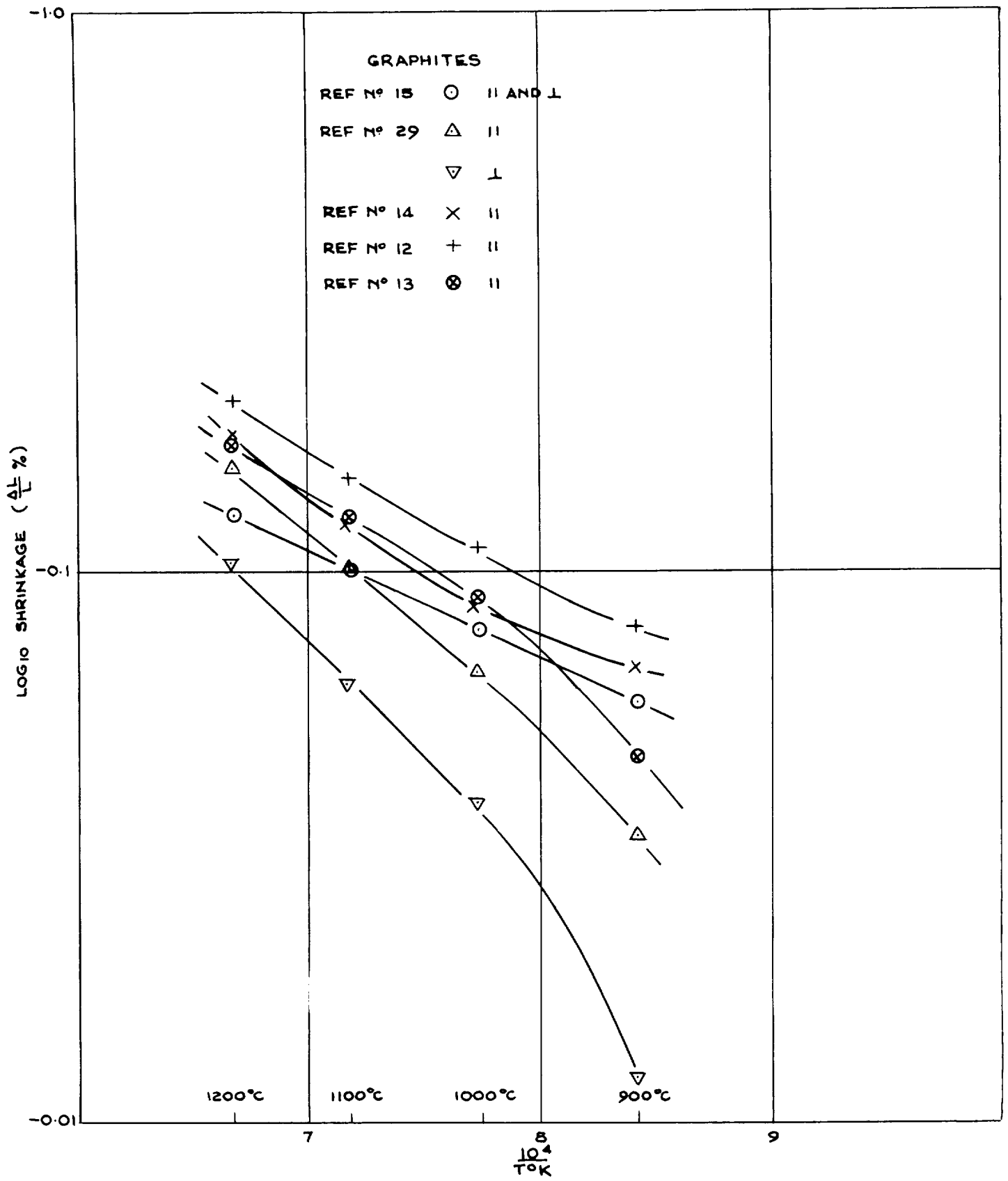


FIG. 13 LOG<sub>10</sub> SHRINKAGE OF GRAPHITES IN ROD 3, Vs  $\frac{10}{T}$ K

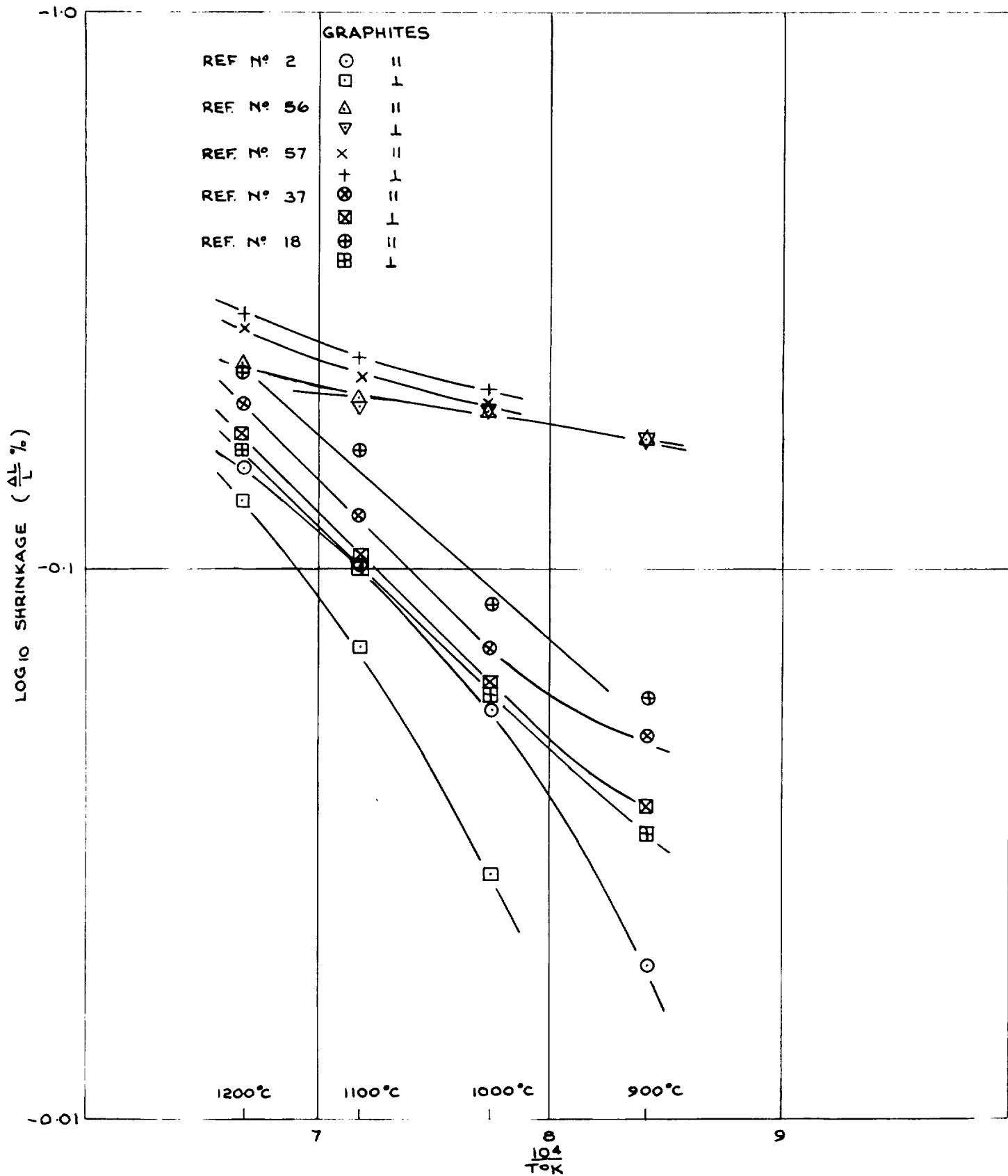


FIG. 14 LOG<sub>10</sub> SHRINKAGE OF GRAPHITES FROM ROD 4, Vs  $\frac{10^4}{T^{\circ}K}$

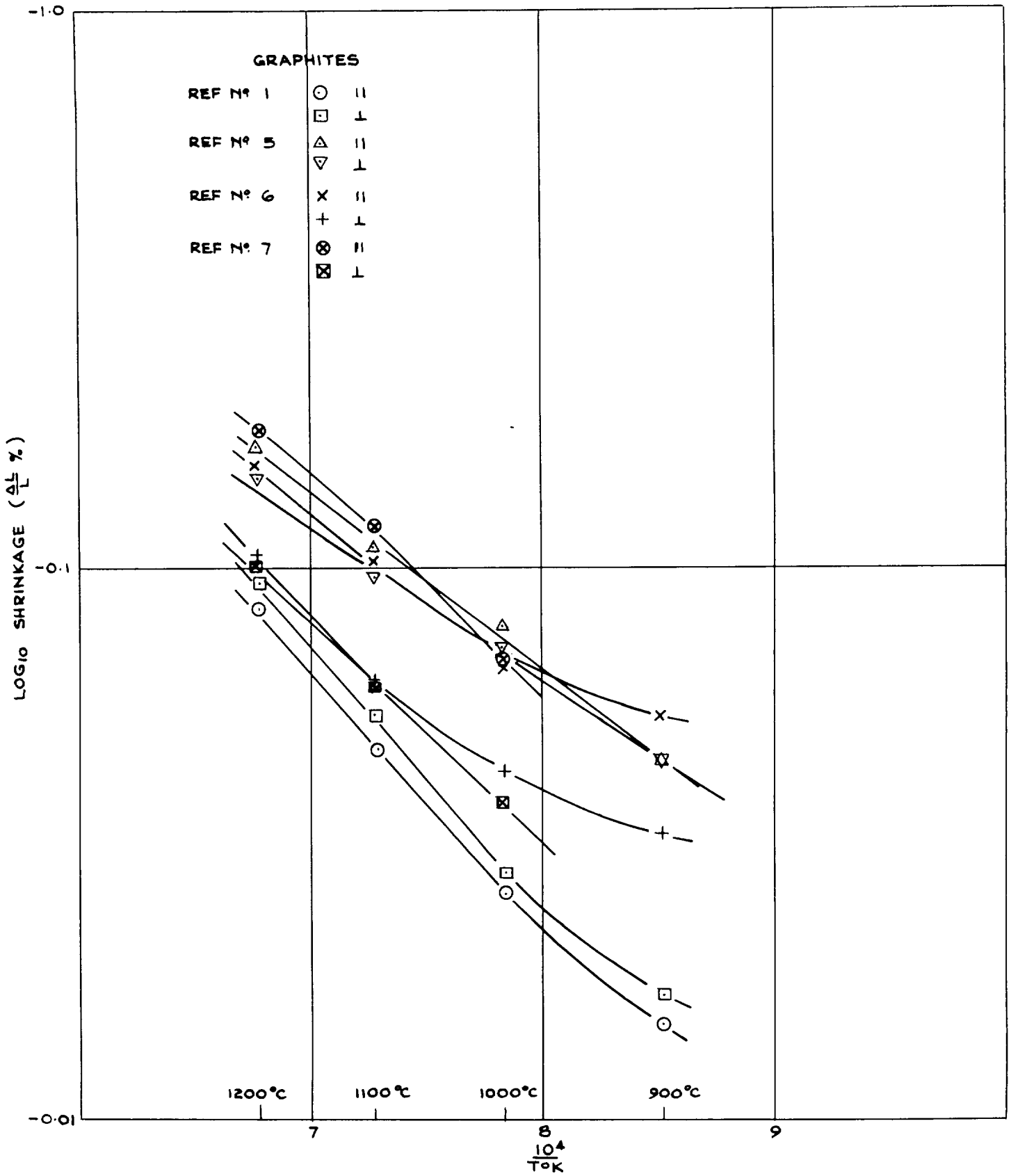


FIG. 15 LOG<sub>10</sub> SHRINKAGE OF GRAPHITES FROM ROD 5, Vs  $\frac{10^4}{T^{\circ}K}$

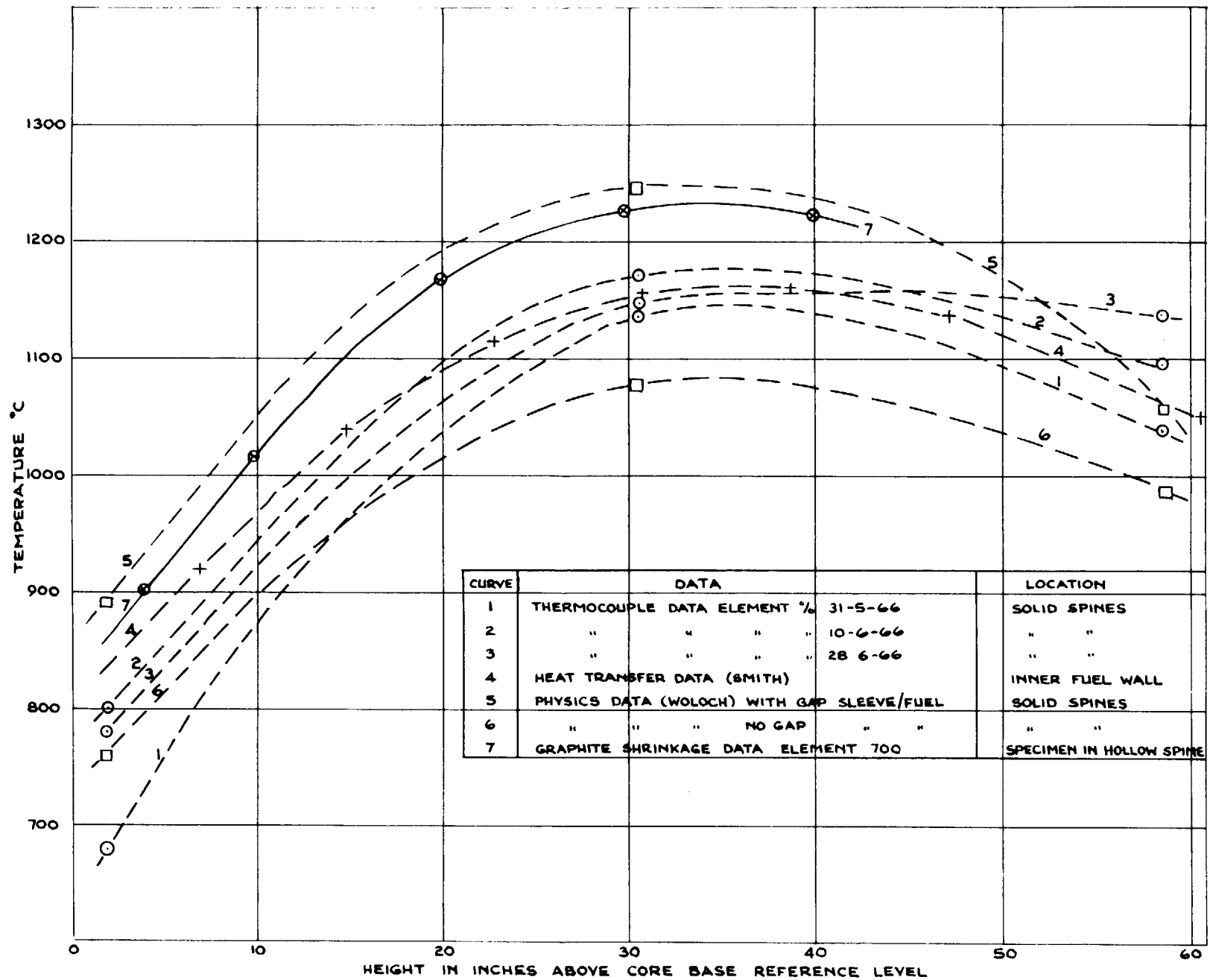


FIG. 16 AXIAL TEMPERATURE PROFILES IN FUEL ELEMENT (G5 OR HX3) FUEL SLEEVE)

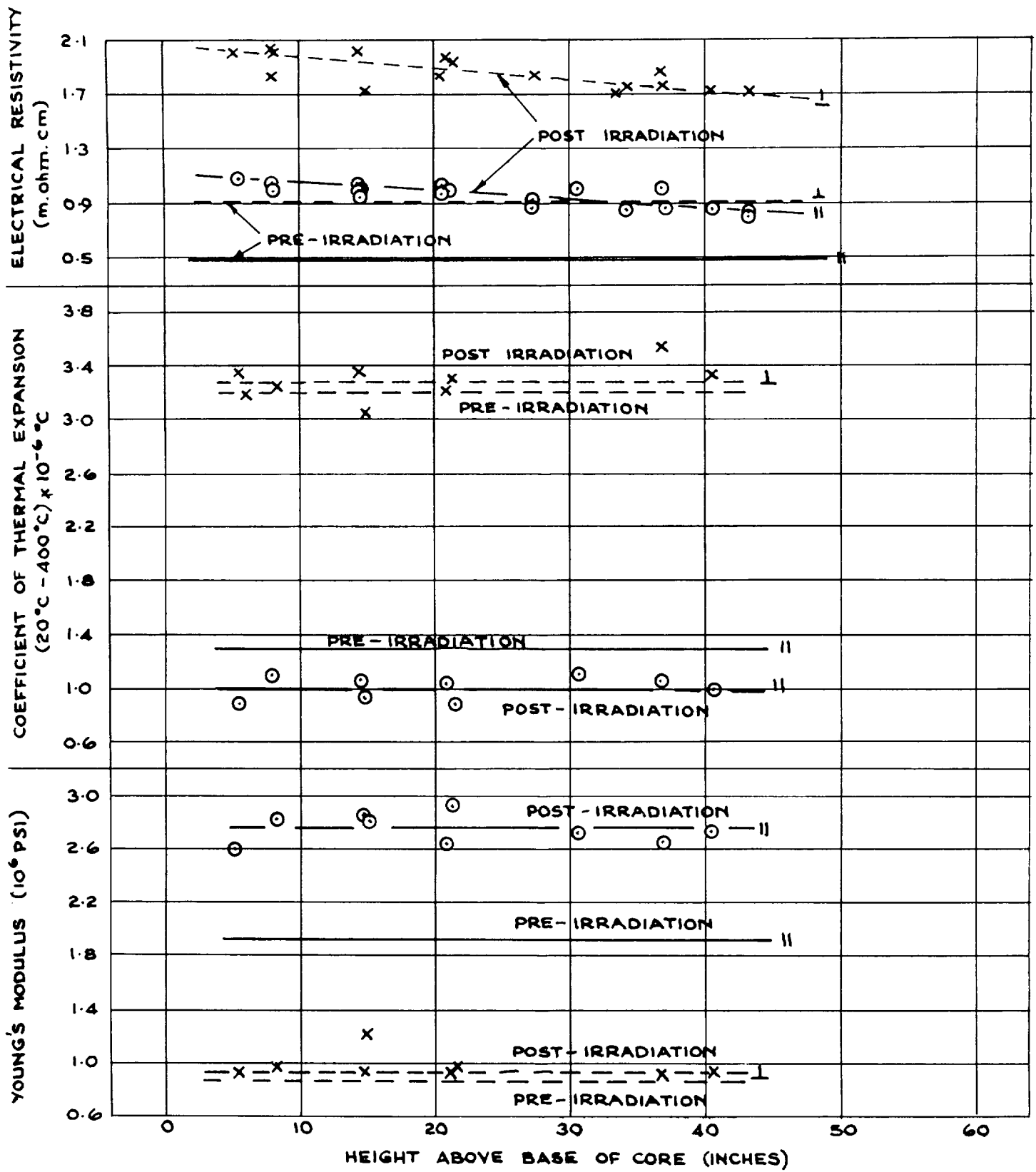


FIG. 17 PHYSICAL PROPERTIES OF PGA GRAPHITE EX. F.E. 700  
(ALL POINTS PLOTTED ARE POST-IRRADIATION)

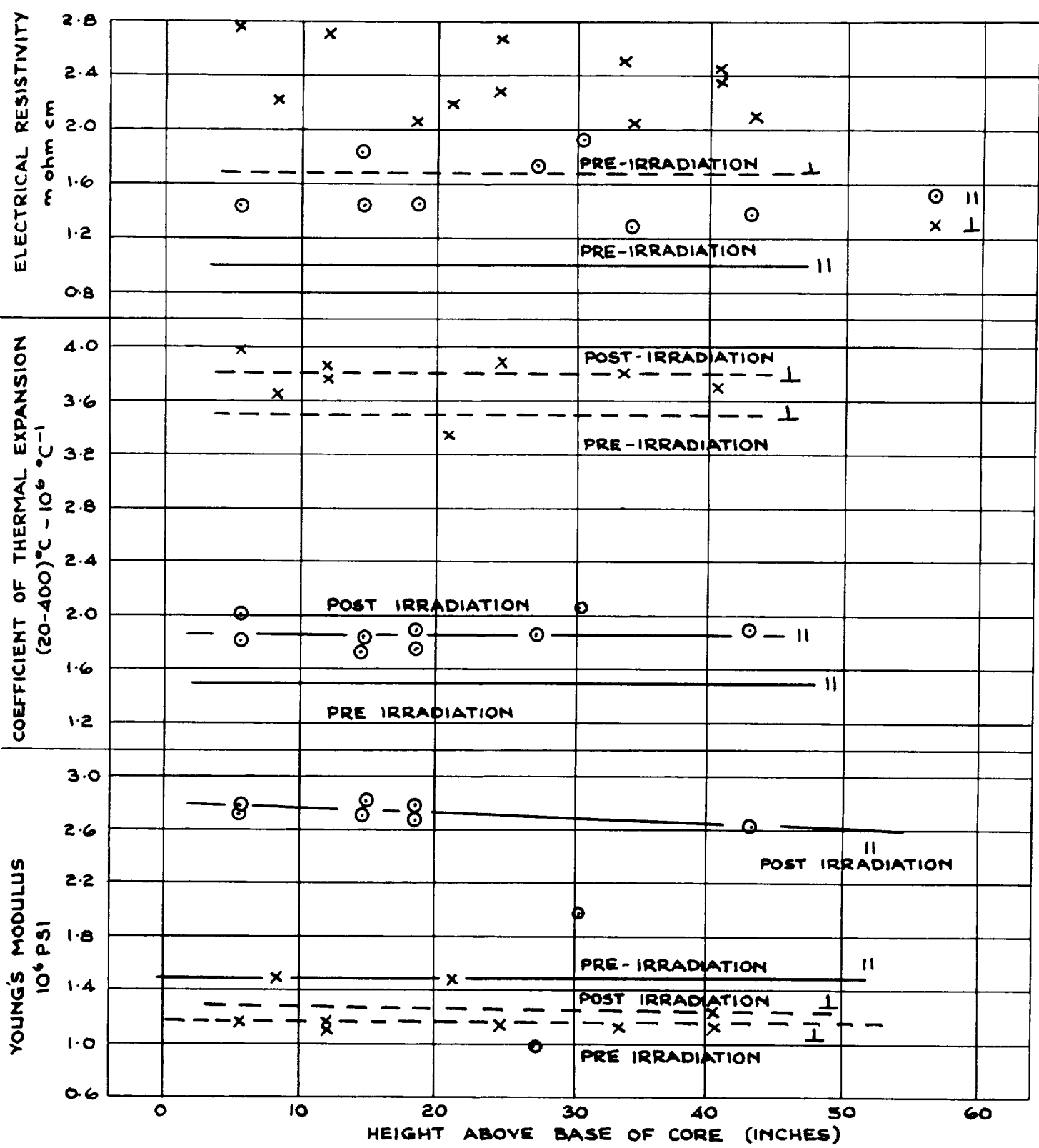


FIG. 18 PHYSICAL PROPERTIES OF G5 GRAPHITE EX. F.E.700  
 (ALL POINTS PLOTTED ARE POST-IRRADIATION)

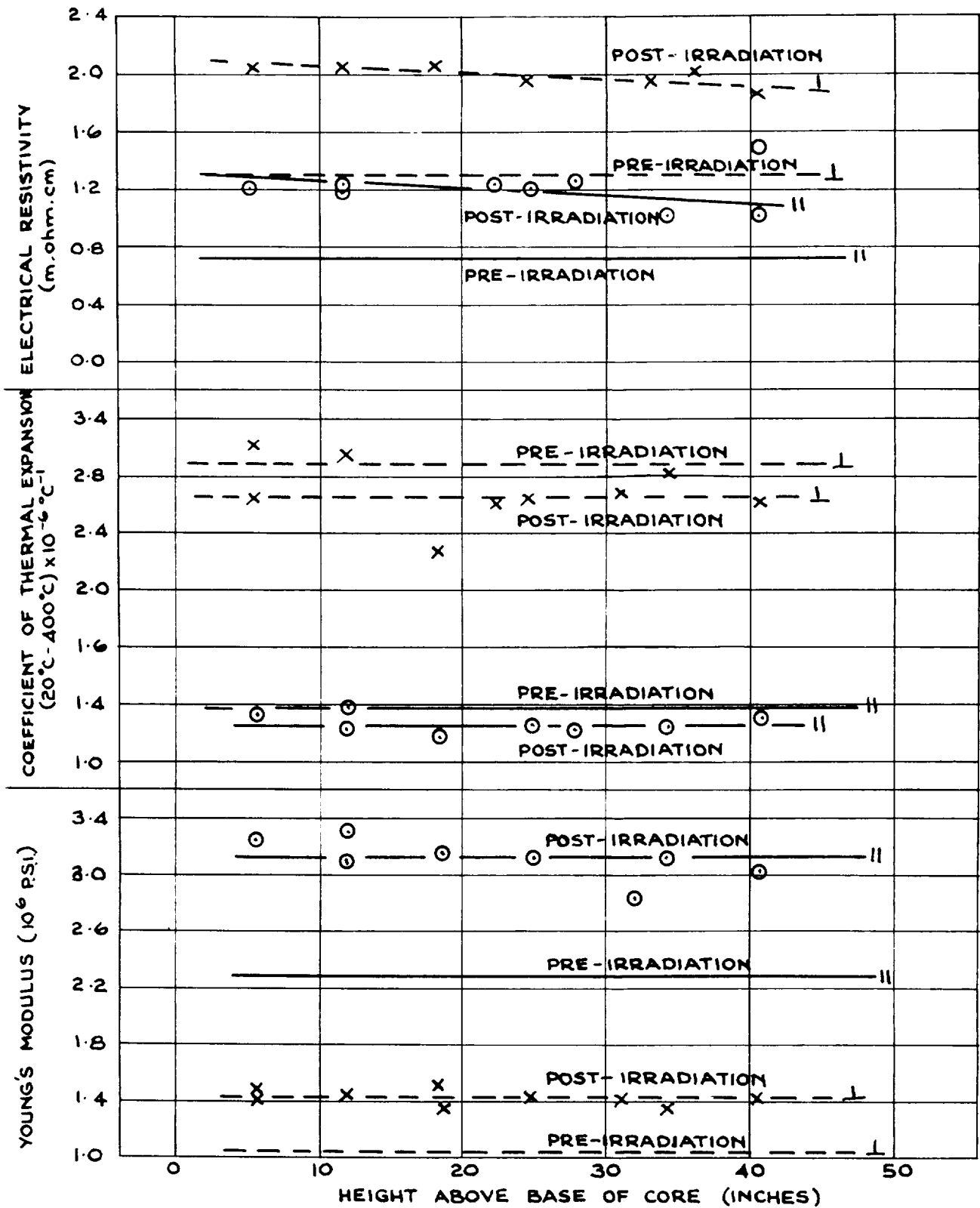


FIG. 19 PHYSICAL PROPERTIES OF HX30 GRAPHITE EX. FE. 700  
 (ALL POINTS PLOTTED ARE POST IRRADIATION)

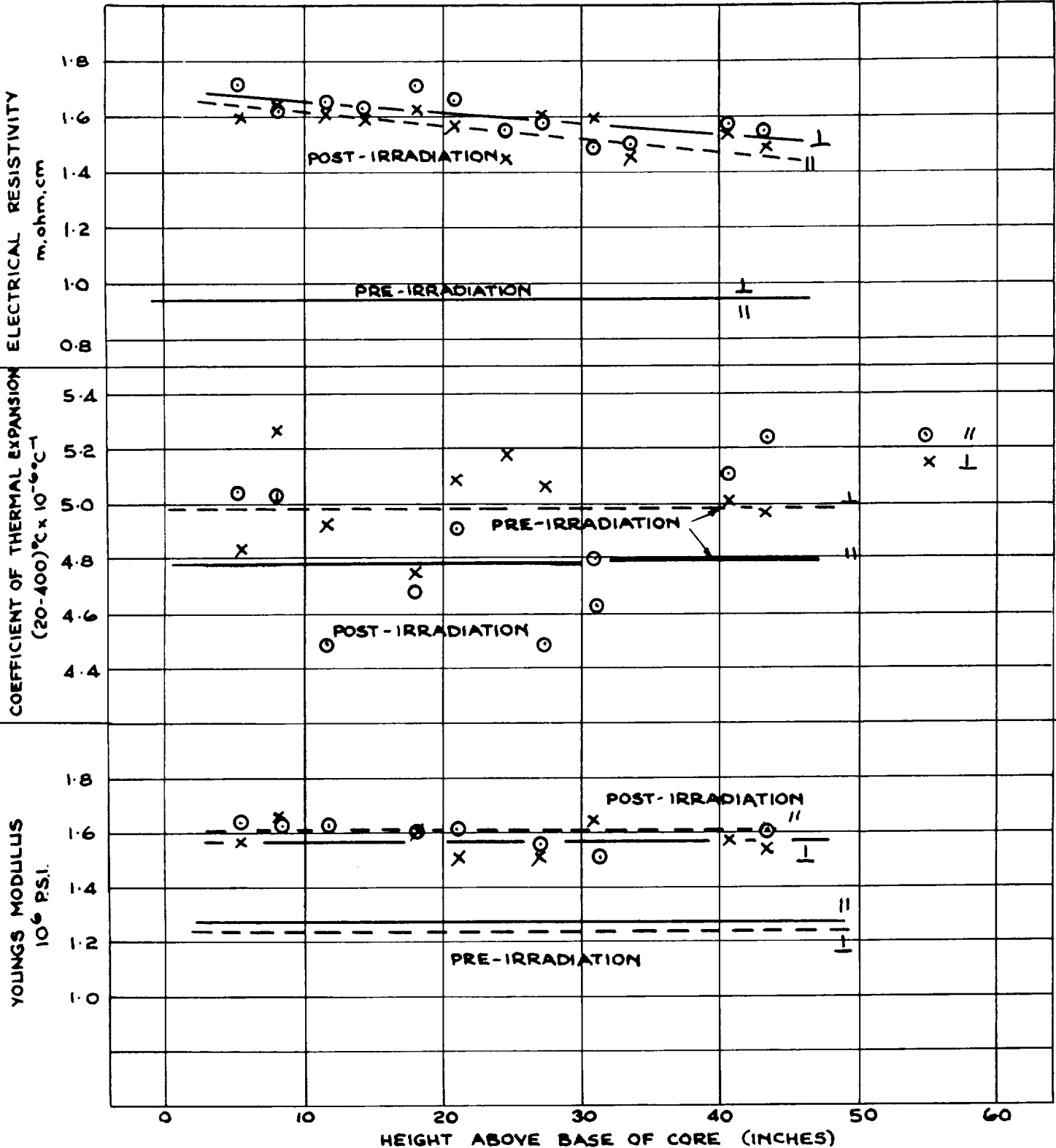
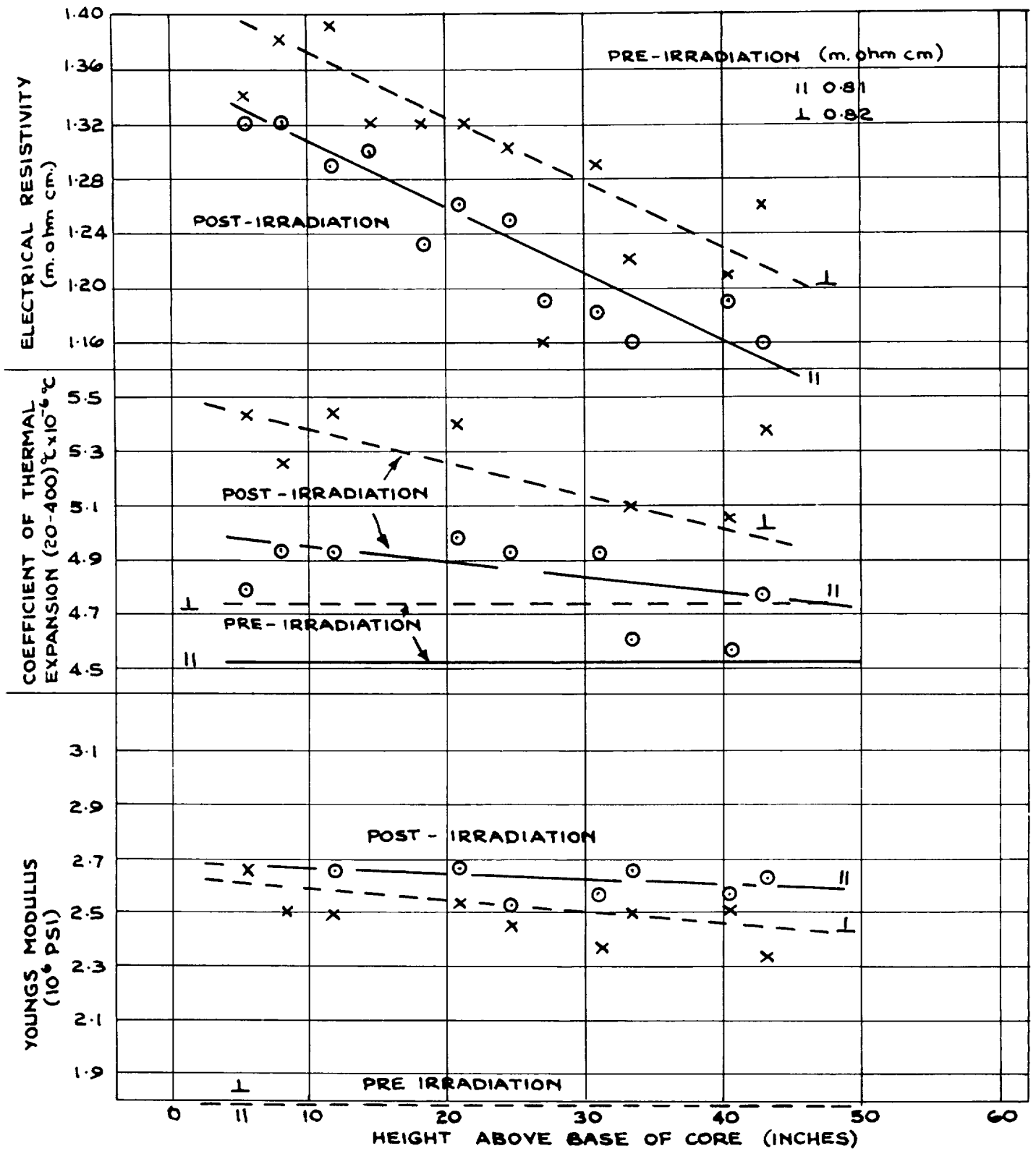


FIG. 20 PHYSICAL PROPERTIES OF GRAPHITE No 1 EX. F.E.700  
(ALL POINTS PLOTTED ARE POST IRRADIATION)



**FIG. 21** PHYSICAL PROPERTIES OF GRAPHITE 5 EX. F.E.700  
 (ALL POINTS PLOTTED ARE POST IRRADIATION)

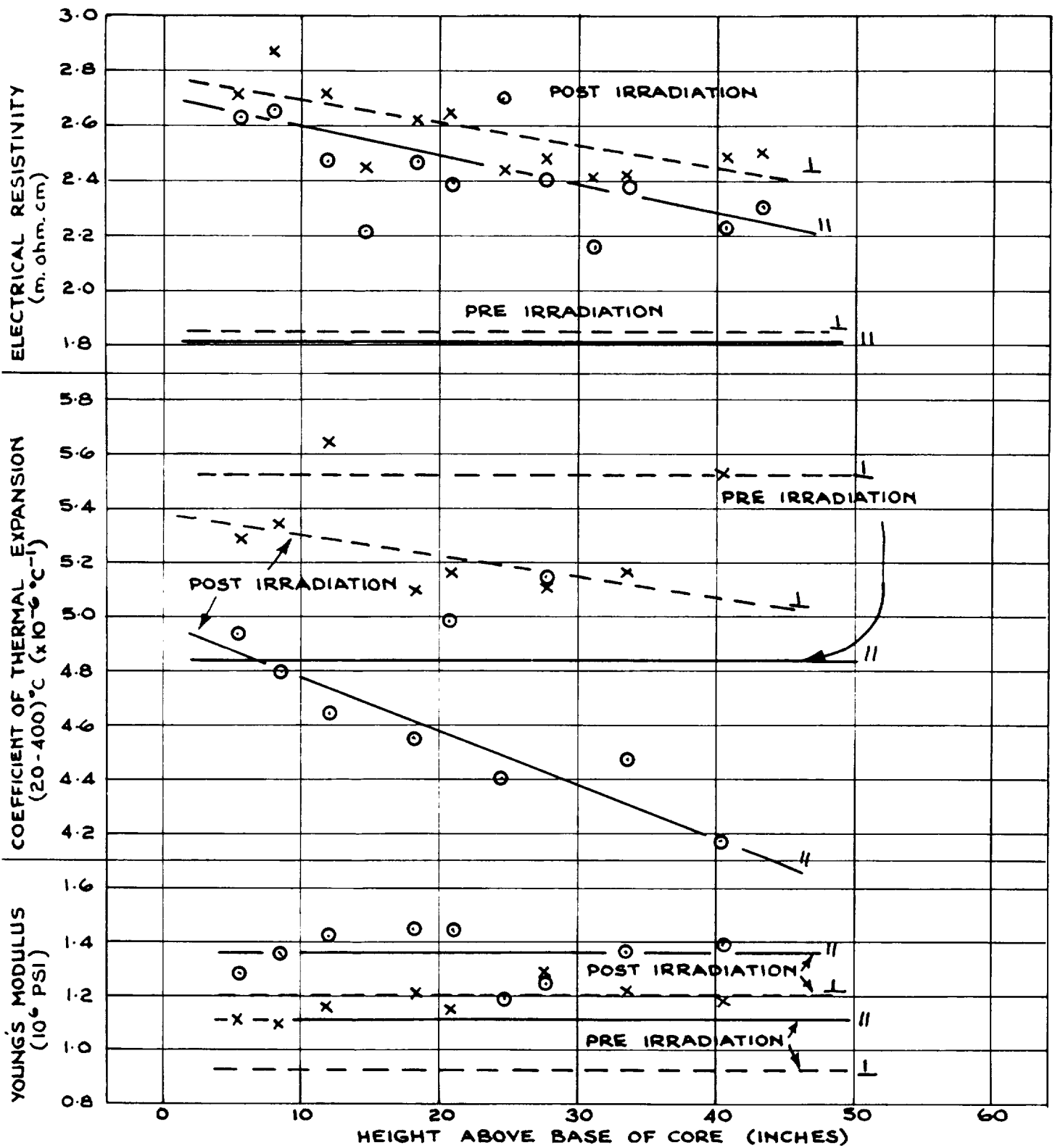
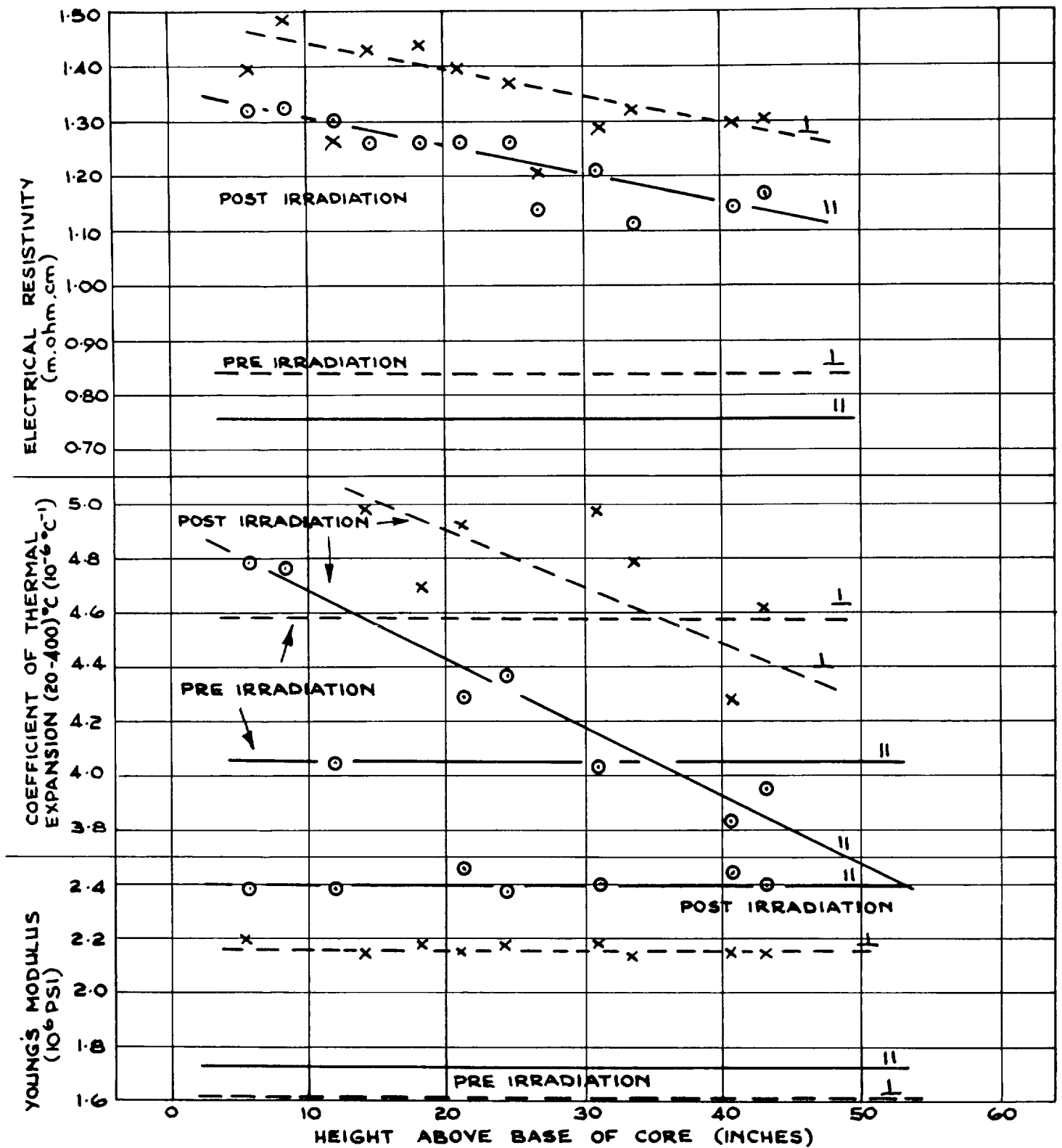
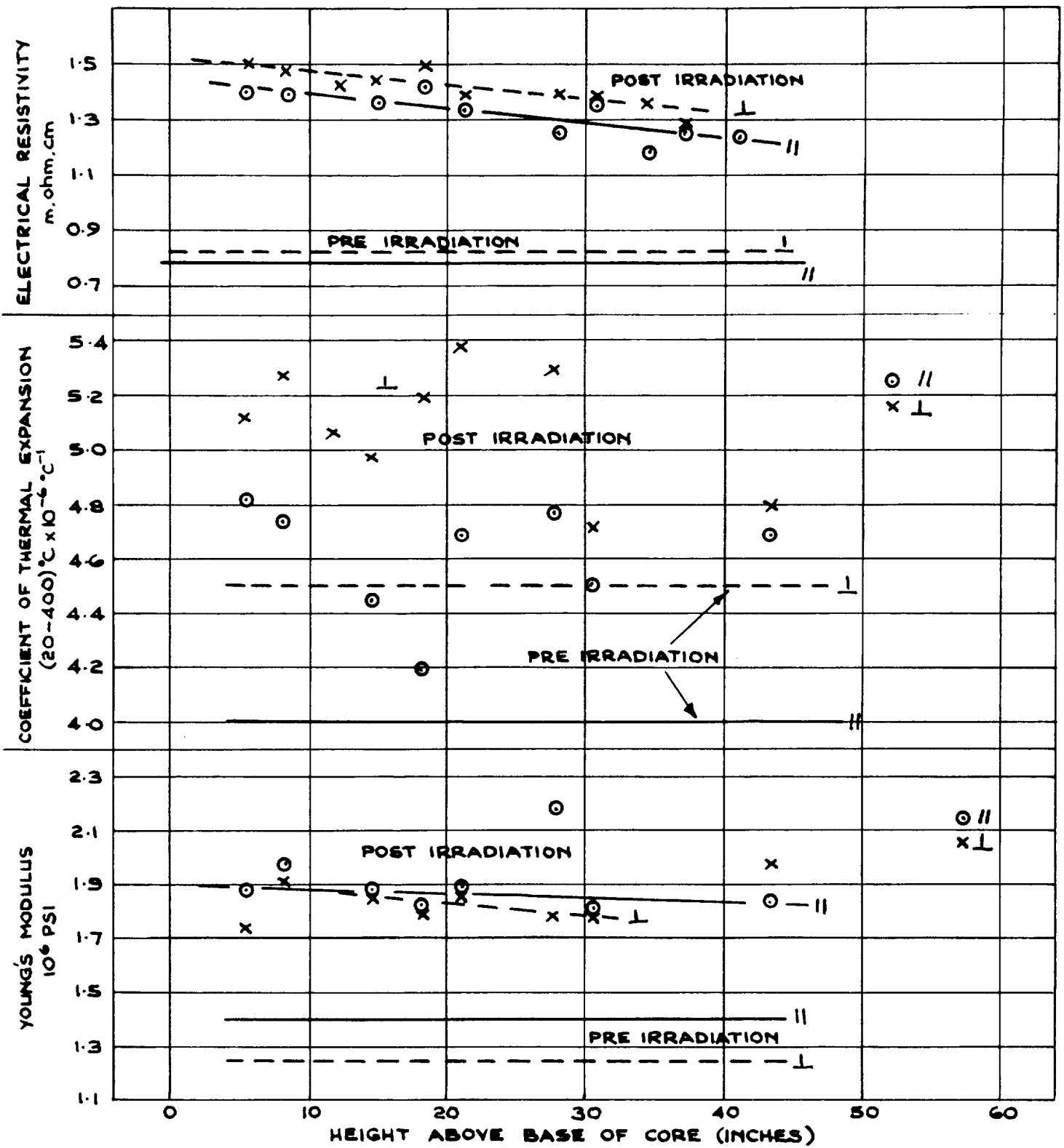


FIG. 22 PHYSICAL PROPERTIES OF GRAPHITE 6 EX. F.E. 700  
 (ALL POINTS PLOTTED ARE POST IRRADIATION)



**FIG. 23 PHYSICAL PROPERTIES OF GRAPHITE 7 EX. F.E. 700**  
**(ALL POINTS PLOTTED ARE POST IRRADIATION)**



**FIG. 24** PHYSICAL PROPERTIES OF GRAPHITE No. 16 EX. F. E. 700  
(ALL POINTS PLOTTED ARE POST IRRADIATION)

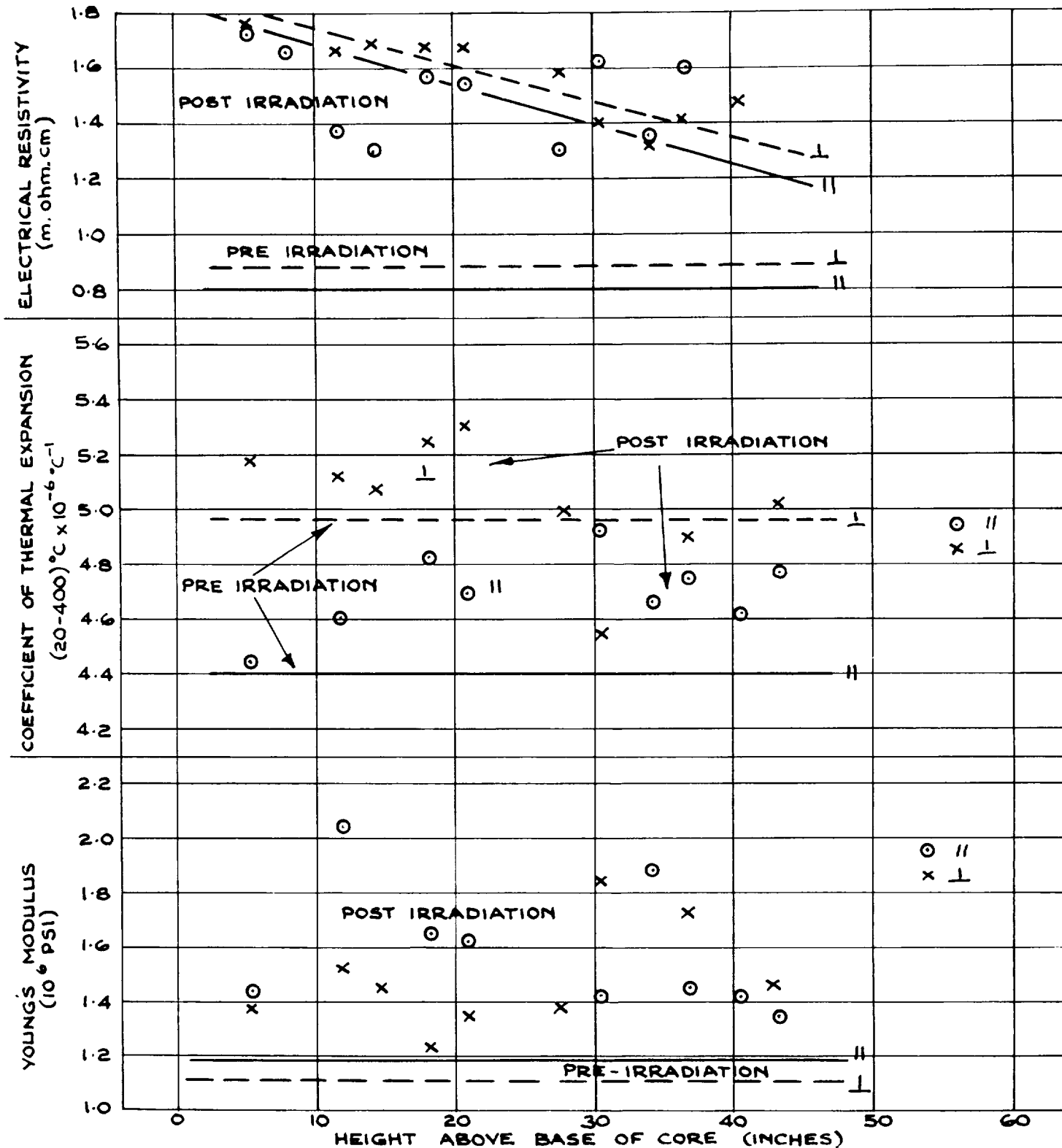


FIG. 25 PHYSICAL PROPERTIES OF GRAPHITE No. 17 EX. F.E. 700  
 (ALL POINTS PLOTTED ARE POST IRRADIATION)