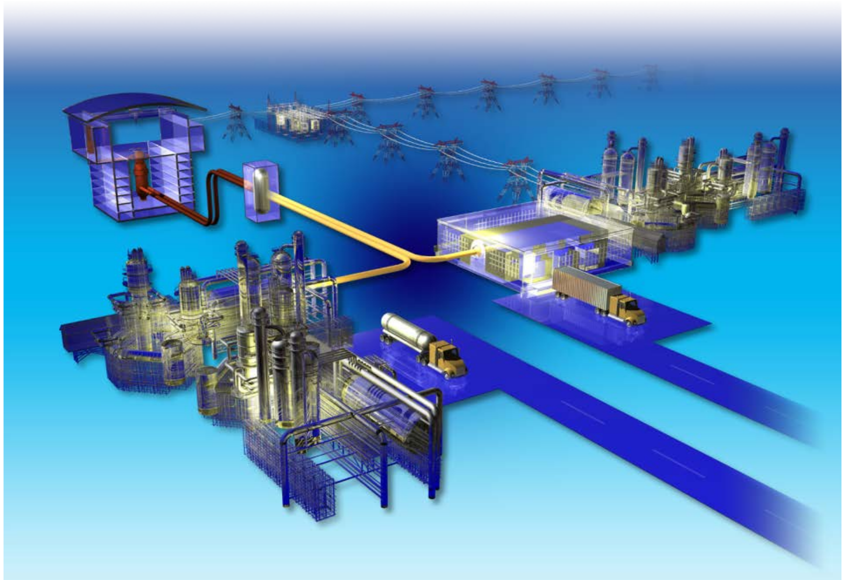
ORNL/TM-2014/255

AGC-1 Irradiation Creep Strain Data Analysis

Tim Burchell
Oak Ridge National Laboratory

September 2014



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Contents

Figures

Tables

Abbreviations

AG	Against Grain
AGC	Advance Graphite Creep
ATR	Advanced Test Reactor
CTE	Coefficient of Thermal Expansion
dpa	Displacements per Atom
HFIR	High Flux Isotope Reactor
INL	Idaho National Laboratory
LAMDA	Low Activation Materials Development & Analysis
ORNL	Oak Ridge National Laboratory
PIE	Post Irradiation Examination
N.B.	Nota Bena (Note well)
PR	Poisson's Ratio
TM	Technical Memorandum
VHTR	Very High Temperature Reactor
WG	with- Grain

Summary

This Technical Memorandum (TM) fulfills milestone 4.2 of SOW-112178 “VHTR TDO GRAPHITE R&D – FY2014”, a level 2 deliverable due to the Department of Energy on September 30, 2014.

Here we report the creep strain data and the analysis of the creep strain data from the irradiation creep capsule AGC-1 specimens that were supplied to ORNL. This is the first (prototype) of a series of five or six capsules planned as part of the Advanced Graphite Creep (AGC) experiment to fully characterize the neutron irradiation effects and radiation creep behavior of current nuclear graphites. The data reported include: specimen dimensions and hence the dimensional change upon irradiation. A comparison of these data for specimen matched pairs yields the creep strain; mass and volume, hence density. The creep strain analysis is by graphite grade.

The AGC-1 capsule was irradiated in the Advanced Test Reactor (ATR) at INL at approximately 700°C and to a peak dose of 7 dpa (displacements per atom). The specimens final dose, temperature and stress conditions have been reported by INL[1,2] are also tabulated here and used in the analysis.

Additional analysis of the AGC data will be required to allow:

1. Improved fits to the existing models of graphite irradiation induced creep strain.
2. With the eventual advent of temperature dependency data from the additional AGC series of capsules, and microstructural data from piggy back specimens in AGC capsules, the development of new and improved models for the phenomena of irradiation induced creep strain in graphite is anticipated.
3. An Investigation into the effects of creep strain on the physical properties of irradiated graphite.

The derived creep coefficients have been calculated for each grade and are found to compare well to literature data, despite the enormous spread in specimen temperatures.

1. Introduction

The graphite creep irradiation program is directed toward generating moderate dose creep data (1-8 dpa) at high temperatures (600-1200°C) for the Very High Temperature Reactor Program. The Advanced Graphite Creep (AGC) experiment comprises five or six instrumented capsules to be irradiated in the Advanced Test Reactor (ATR) at the Idaho National Laboratory. The AGC experimental capsules are summarized in Table 1.

Table 1 Irradiation capsules that make up the Advanced Graphite Creep experiment

AGC capsule number	Nominal Irradiation Temperature, °C	Irradiation dose range (dpa)	Major Grades of Graphite in Capsule
1	700	3-8	NBG-18; NBG-17; H-451; PCEA; IG-110; IG-430
2	700	1-3	NBG-18; NBG-17; PCEA; IG-110; 2114
3	800	1-3	NBG-18; NBG-17; PCEA; IG-110; 2114
4	800	3-8	NBG-18; NBG-17; PCEA; IG-110; 2114
5	1100	1-3	NBG-18; NBG-17; - PCEA; IG-110; 2114
6	1100	3-8	NBG-18; NBG-17; - PCEA; IG-110; 2114

In addition to the 25.4mm (1 inch) long by 12mm (0.5 inch) diameter "major" grades above which provide creep data there are numerous 6mm (¼ inch) thick by 12mm (0.5 inch) diameter "minor" grades of graphite and carbon which only provide dimensional change and thermal conductivity degradation data. These "minor" grades include:

1. Highly Oriented Pyrolytic Graphite (HOPG)
2. A3 Carbon Matrix
3. Grade HLM
4. Grade NGB-25
5. Grade PGX
6. Grade PPEA
7. Grade NBG-25
8. Grade 2020
9. Grade PCIB
10. Experimental Grade BAN

Each capsule contains approximately 30 samples per "major" grade (half of them stressed and half of them unstressed). In addition there are approximately 10 of each "minor" grade in each capsule.

The creep and control specimen are contained in six channels. Two at each stress level of: 2 ksi (13.8 MPa): 2.5 ksi (17.3 MPa) and 3 ksi (20.7 MPa). The capsules unstressed center channel is where the piggy back samples are located. All specimens take advantage of the ATR's flux buckling to give similar neutron doses to the matched pair creep (stressed) and control (unstressed) specimens. Similarly, by arranging the specimen pairs throughout the capsule a range of creep doses are attained at each of the three stress levels for all the ”major” grades in the capsule.

Each of the AGC capsules are fully instrumented, containing numerous thermocouples in axial and radial locations, allowing the exact specimen temperature to be derived from calibrated thermal models. As a back-up the first (prototype) capsule (AGC-1) additionally contained Silicon Carbide temperature monitors at regular intervals along the center channel.

The creep load is applied through a series if pneumatic pistons and the load monitored via load cells. The entire channel stack is periodically raised by a separate pneumatic pistons located at the bottom of each channel to assure the specimens are not jammed and can move freely in the channel. Capsule temperature control is maintained by having pre-set gas gaps and capsule gas environment control.

The first “prototype’ capsule, AGC-1, has completed irradiation, disassembly and specimen post irradiation examination (PIE). Analysis of the creep data is complete (reported here). Capsule AGC-2 has completed irradiation, has been disassembled and PIE is currently in progress. Capsule AGC-3 has completed irradiation and is currently scheduled for disassembly at the end of 2014. Design and construction of AGC-4 is currently scheduled to be completed at the end of 2014. Pre irradiation examination of AGC-4 specimens is complete and insertion of AGC-4 test train is scheduled for 2015. Design data (graphite swelling, etc.) for capsules AGC-5 and-6 will be obtained from the HTV capsule (HFIR High Temperature Target Capsule) which will be irradiated in HFIR to a dose range of 2-4 dpa, at temperatures from 900 to 1400°C. The need for capsule AGC-6 will be established later.

The pre- and post-irradiation examination (PIE) dimensions of the creep, and control specimens from the irradiation creep capsule AGC-1 are reported here for the 160 specimens returned to ORNL. AGC-1 was the first of a series of five or six capsules planned as part of the Advanced Graphite Creep (AGC) experiment to fully characterize the neutron irradiation and radiation creep behavior of current nuclear graphite grades. Here the irradiation creep strain is defined as the difference between the irradiation induced dimensional changes of the stressed and unstressed specimen under similar temperature and dose conditions. The AGC-1 capsule was irradiated in the Advanced Test Reactor (ATR) at INL. The temperatures achieved by the specimens ranged from ≈ 472°C to ≈ 710°C and to a peak dose of ≈7 dpa (displacements per atom). The large spread of irradiation temperatures in the irradiation capsule definitely complicated the creep strain data analysis. The specimen’s final dose, average temperature and stress conditions have been reported by INL[1,2] and are also tabulated here for completeness. The AGC-1 Experimental Plan[3] and revised capsule layout[4] discuss the details of the AGC-1 experiment and provide background on the capsules scope and purpose. Given that this was the prototype AGC capsule design the problems experienced with AGC-1 are to be expected and should not reoccur.

The irradiation induced creep of graphite (dimensional change occurring under the simultaneous influence of neutron irradiation <u>and</u> stress) remains one of the enduring mysteries for the nuclear graphite community. The responsible graphite damage mechanisms at large neutron doses remain to be fully elucidated. Stresses are induced in graphite components by temperature and/or neutron flux gradients, and this coupled with other stresses (externally applied, design stresses, etc.) are sufficient to cause irradiation creep (which is fluence or time dependent) in the graphite at temperatures well below that at which thermal creep would be observed.

Conventionally, this phenomenon has been studied by performing irradiation experiments in Material Test Reactors (MTR's). Small graphite specimens are kept under a constant load, and the apparent creep strain determined by comparing the irradiation induced dimensional changes (strains) in specimens irradiated under identical conditions, but where one is loaded and the other is not (the control specimen). The difference between the dimensional change of the stressed and unstressed specimen gives the creep strain.

Creep experiments of this nature, with both tensile and compressive applied stresses have been performed for the past forty years to relatively high neutron doses. Generally, three stages of graphite irradiation creep are recognized:

Stage 1; during the first stage of creep, strain accumulates with dose initially rapidly, but subsequently at a diminishing rate, and has been shown to saturate at one elastic stain [$\sigma_{(applied)}/E_0$], where $\sigma_{(applied)}$ is the applied stress and E_0 is the unirradiated Young's Modulus.

Stage 2; during the second stage of irradiation induced creep, referred to as "steady state creep" or "linear creep", the creep strain is proportional to the neutron dose and applied stress. The slope of a plot of second stage, or secondary, creep strain should be a straight line with slope K, the creep coefficient. Typically, this stage is dominant between 1 and 10 dpa but the dose range over which secondary creep occurs is temperature and graphite grade dependent.

Stage 3; this is the third and final stage of irradiation induced creep, occurring at higher doses, typically > 10 dpa, where the rate of accumulation of irradiation creep strain accelerates with dose.

The three stages of irradiation creep are illustrated in Fig 1.

Creep during stages I and II are thought to be dominated by dislocation formation and flow processes (i.e., in-crystal effects). Whereas stage III creep (which occurs at higher doses, after the point of volume change turn-around) is thought to be related to graphite structure changes (i.e., both in-crystal AND pore volume effects). Research worldwide is currently directed at developing a more complete understanding of the deformation processes in graphite at ALL stages of irradiation induced creep.

The details of any particular reactor design will dictate the peak dose to which the creep data, accompanying mechanistic understanding and sound models are required. For example, if the Reactor design is of the Prismatic Block type (as proposed for the NGNP design) then the data, mechanistic understanding and creep model(s) would only be required to a peak dose of some 7 dpa but at temperatures from approximately 300°C to 1200°C. If the reactor's design is such that the graphite passes through volume turnaround and into net volume swelling (as proposed for a Pebble Bed design), the dose to which data, mechanistic understanding and creep model(s) are required (creep stage III) is much higher.

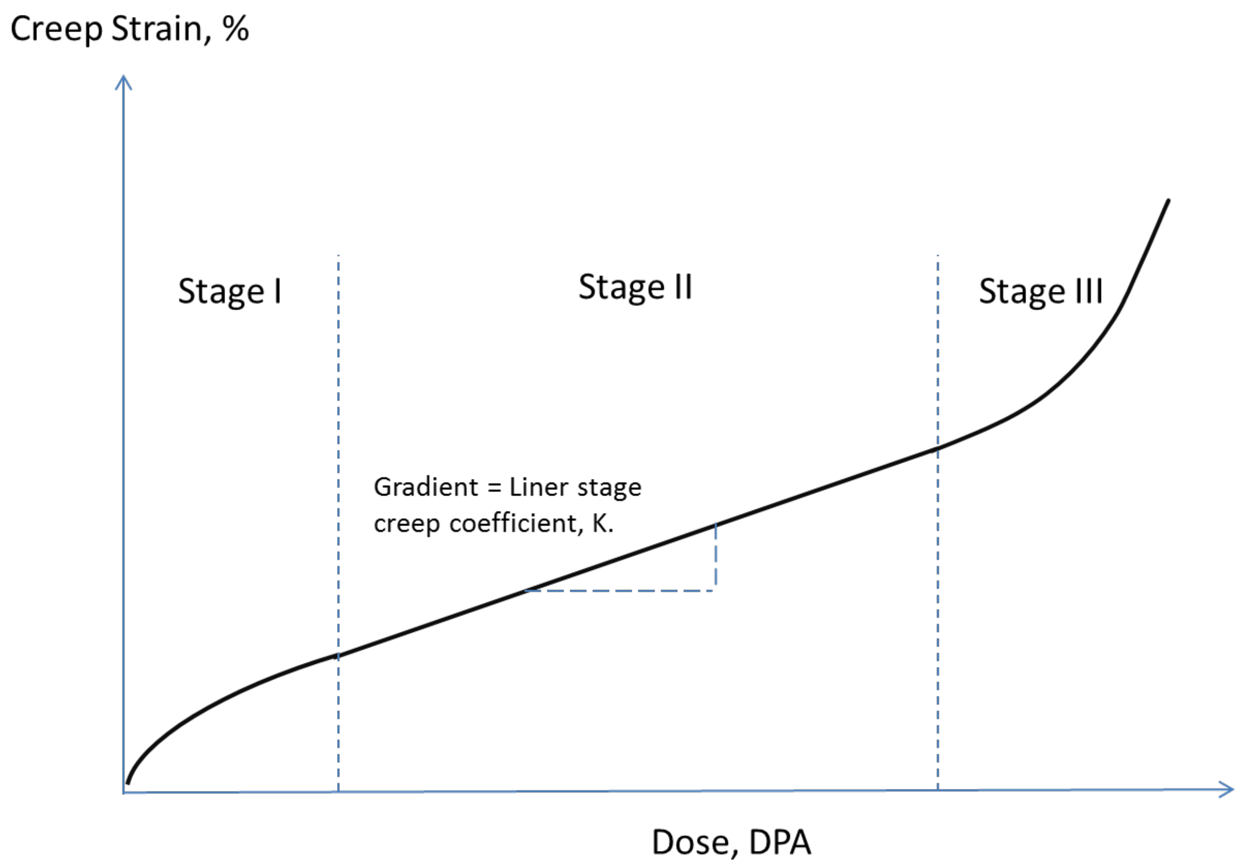

Figure 1 A schematic representation of the three stages of irradiation induced creep

The AGC-I experiment was designed to operate in a dose and irradiation temperature window were the linear visco-elastic creep law should apply (linear stage in Figure 1). Under the linear visco-elastic creep law. The normalized secondary creep data are linear indicating no structure effects at these (lower) doses. Using this relationship, the total creep strain is given by:

$$\varepsilon_{c(TOTAL)} = \varepsilon_{c\,PRIMARY} + \varepsilon_{c\,SECONDARY}\ (\%)$$

$$\varepsilon_{c\,PRIMARY} = \frac{A\sigma}{E_0}[1 - Exp(-b\gamma)] \approx \frac{\sigma}{E_0}\ (\%)$$

$$\varepsilon_{c\,SECONDARY} = K\sigma\gamma\ (\%)$$

$$\varepsilon_{c(TOTAL)} = \frac{\sigma}{E_0} + K\sigma\gamma\ (\%)$$

Where K = K′/σ(max) = secondary creep constant in %/dpa.MPa or $10^{-30}cm^2/n.Pa$

σ = Applied Stress (MPa)

ϒ = neutron dose, dpa

E_0 = Initial (pre-irradiation) Young's Modulus

A and b are constants (A is usually = 1), and K is the secondary (linear) creep coefficient

The creep strain data reported here has successfully been fitted to this linear equation.

2. Experimental

2.1. The AGC-1 Creep Capsule

A schematic of the AGC-1 Creep Capsule is shown in Figure 2.

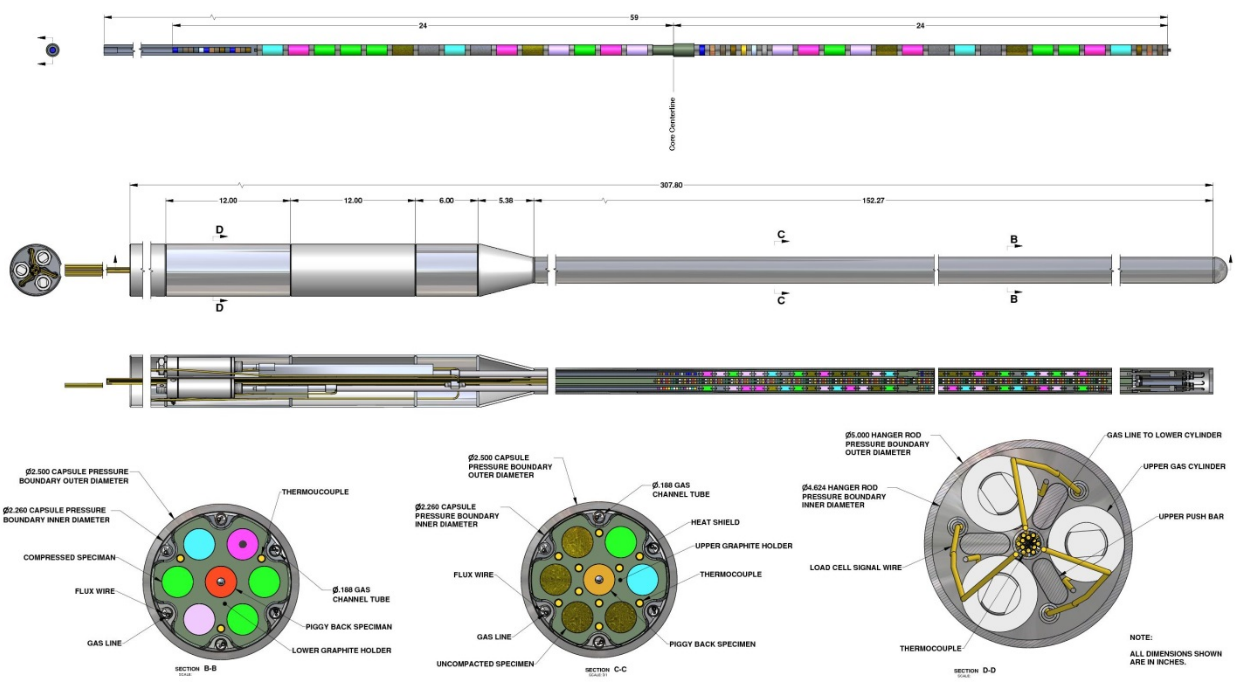

Figure 2 The AGC-1 Creep Capsule (refer to INL Drawing 630431)

The capsule had six channels with an applied load and a center channel with no load applied. The sections of the outer channels above the reactor mid-plane were stressed and the sections of the channels below the reactor mid-plane were unstressed. By pre-ordering the specimen's axial location it was thus possible to attain matched pairs with similar neutron fluence (due to flux buckling) at the same stress. Three stress levels large enough to induce irradiation creep within the nuclear graphite grades (2.0 ksi, 2.5 ksi and 3.0 ksi nominally) were chosen to ascertain the effects of stress and irradiation creep levels on changes to the material properties in graphite. The original design of the irradiation capsule specified two stress levels with three channels receiving a higher stress level and 3 channels receiving a lower stress level.[3] However formal review of the design determined that unacceptable bending moments could be imposed upon the entire test capsule if one of the channels could not be loaded to the specified level. The capsule design was modified and a third stress state was added with diametrically opposed channels carrying equal stresses[4]. If one of the channels was not able to be loaded to the desired level the opposing channel would be unloaded so no bending moments would be applied to the capsule.

The AGC-1 capsule had a dose range of 1.4-6.9 dpa and an irradiation temperature range from 472–710 °C. The capsule mean temperatures were calculated from thermocouple inputs and corroborated with SiC temperature monitors (located in the central channel along the capsule centerline). Doses were calculated using MCNP models and operating conditions in the ATR core and corroborated from flux wire data.

The graphites grades in the AGC-1 capsule can be categorized as follows.

a. Major Grades (Irradiation creep and companion specimens)

   These graphites are reactor vendor's candidates for the core structures of NGNP, and include four new grades (NBG-17, NBG-18, PCEA, and IG-430) as well as two historical (reference) grades (H-451 and IG-110). These grades are most likely to receive reasonably large neutron doses in their lifetime and were subjected to the applied loads of the AGC-1 capsule. These grades occupied the stressed and companion unstressed positions in the AGC-1 capsule and hence make up the irradiation creep specimens.

b. Minor Grades (piggyback specimens)

   These grades are NGNP relevant grades that are most likely to be used in low neutron dose regions of the core; e.g., the permanent structure of the prismatic block very high temperature reactor (VHTR) design and includes grades PGX, HLM, NBG-10, and NBG-25.

c. Alternate Grades (piggyback specimens)

   Grades that NGNP vendors have identified as being of interest as alternate graphites for certain components within the reactor, and includes grades PPEA, 2020, and PCIB.

d. Experimental Grades (piggyback specimens)

   Two experimental graphites are included in AGC-1 (BAN and A3 matrix). BAN graphite is an experimental grade whose manufacturing process and raw materials are such that it should offer superior irradiation stability. A3 matrix is the blend of graphites and carbonized phenolic resin used as the matrix in the NGNP fuel compact or fuel pebble. Samples of A3 matrix were obtained from the NGNP program and were produced at Oak Ridge National Laboratory (ORNL).

e. Single Crystal Graphite (piggyback specimens)

   The dimensional change behavior of graphite is particularly significant to the behavior of polycrystalline (polygranular) graphite. Therefore, samples of HOPG are included in AGC-1.

The six major grades of graphite for which the creep strain response is reported here are summarized in Table 2 and Table 3.

Table 2 The major graphite grade within the AGC-1 capsule[3]

Graphite Grade	Forming Method	Intended Purpose	AGC Code Letter
NBG-17	Vibrational molded	AREVA NGNP Design	A
NBG-18	Vibrational molded	PBMR (not currently being pursued)	B
H-451	Extruded	Historical Grade (REF)	C
PCEA	Extruded	AREVA NGNP Design	D
IG-110	Isostatically Pressed	PMBR-DM (China) – Under construction	E
IG-430	Isostatically Pressed	Candidate Graphite	F

For grades NBG-17, NBG-18 and PCEA (codes A, B & D) both with-grain (WG) and against grain (AG) specimen orientations were included in the capsule.

Table 3 Number of stressed/unstressed samples, and their graphite grades, included in the outer peripheral channels of irradiation capsule AGC-1[3]

Graphite Grade	Source	Number of stressed/unstressed peripheral column samples
NBG-17 (both WG and AG)	SGL Carbon	34
NBG-18 (both WG and AG)	SGL Carbon	34
H-451 (Reference Grade) WG only	SGL Carbon	20
PCEA (both WG and AG)	GrafTech International	34
IG-110 (Reference Grade)	Toyo Tanso	20
IG-430	Toyo Tanso	32
TOTAL		**174**

Following irradiation in the Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL) the AGC-1 capsule was disassembled. All specimens recovered from disassembly were visually inspected and physically measured[5]. The majority of the creep and control specimens were shipped to Oak Ridge National Laboratory (ORNL) for PIE in the Low Activation Materials Development & Analysis (LAMDA) laboratories. Figure 3 shows the AGC-1 shipping drum used to ship the specimens to ORNL. After removal from the transit tubes the specimens were visually examined and digitally photographed.

Examples of the digital pictures are given in Figure 4 and Figure 5. The specimen nominal dimensions are nominally 25.4 mm length by 12.7 mm diameter.

Figure 3 The AGC-1 specimen shipping cask at ORNL

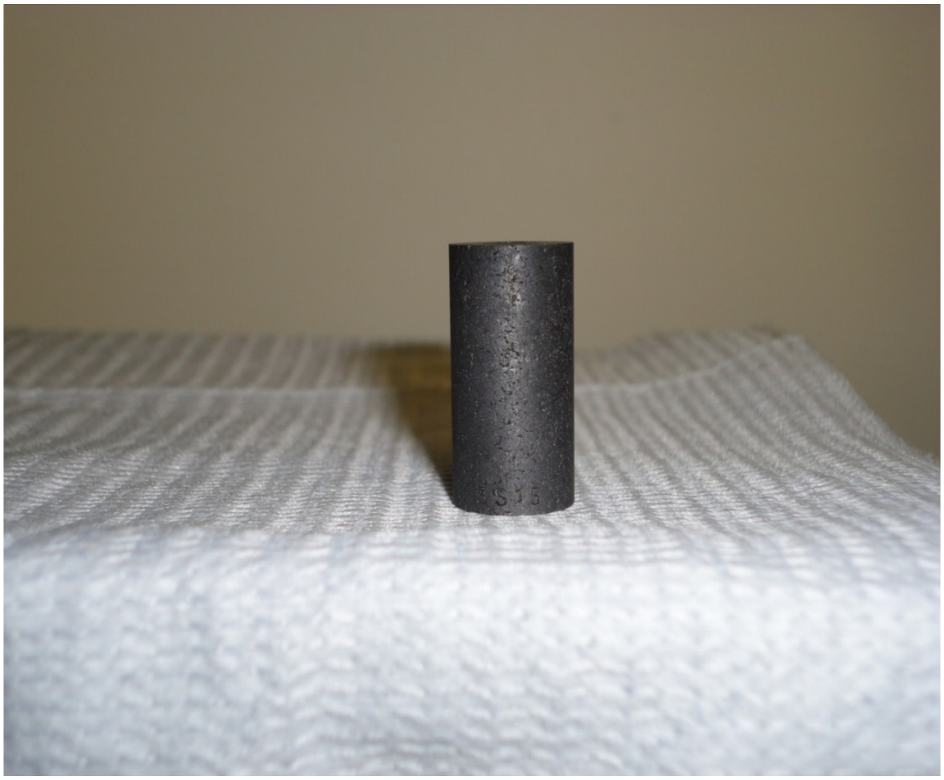

Figure 4 AGC-1 creep specimen 3S-15, DW 5-02 (PCEA Graphite)

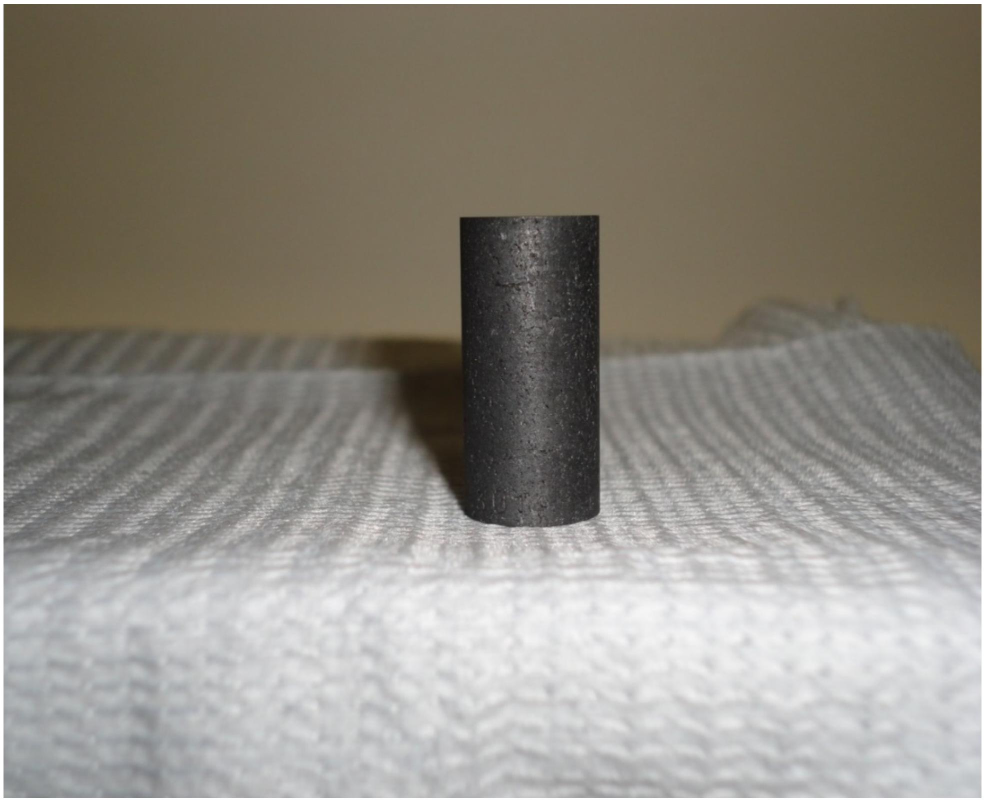

Figure 5 AGC-1 control specimen 3U14, DW 6-10 (PCEA Graphite)

2.2. Testing Methods

The experimental methods followed for dimensional and mass determination in the pre- and post-irradiation conditions have been previously reported[3,6,7,8,9]. AGC-1 testing followed ASTM test methods as prescribed in the Experimental Plan[10] (Table 4).

Table 4 Physical properties determined in this work and the relevant ASTM test standards

Test Property	Standard Title	ASTM Standard
General	Testing Graphite and Boronated Graphite Materials for High-Temperature Gas-Cooled Nuclear Reactor Components	C781
Dimensions, mass, density	Bulk Density by Physical Measurements of Manufactured Carbon and Graphite Articles	C559

2.3. AGC-1 Creep specimen final temperatures, doses, and stresses

The individual creep specimen's average irradiation (mean) temperature (°C), peak fluence (dpa), and load (lbf) are reported in Table 5 through Table 10 for the stressed specimens[1] and Table 11 through Table 16 for the unstressed (control) specimens[1]. The stress levels applied to the stressed creep specimens were nominally 2 ksi (channels 1 & 4), 2.5 ksi (channels 2 & 5), and 3 ksi (channels 3 & 6)[4]. Flux levels experienced by each specimen during irradiation were dependent upon its axial position within the stack, and as a consequence within the ATR core. Specimens located at the core midplane (COM = 0) received the highest flux levels while specimens located near the top and bottom axial core locations received the lowest flux levels. The tabulated specimen fluence data are calculated based on the ATR operating history (time in reactor, core power levels, and position within the core) and corrected using flux wires and "MCNP" models. The tabulated specimen temperature data are calculated for specimen position using TC data and thermal models.

Table 5 AGC-1 fluence, temperature, and load values for channel 1 (North Channel) specimens

S-1, Compressed

(Fluence and temperature are corrected)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-34	1S12	NBG-17	19.250	589	3.47	377
-35	BW12-02	NBG-18	18.000	597	3.93	377
-33	1S14	PCEA	16.750	606	4.36	377
-37	1S9	IG-110	15.500	621	4.75	377
-37	1S7	IG-110	14.250	635	5.11	377
-32	1S15	H-451	13.000	649	5.44	377
-36	FW13-01	IG-430	11.750	662	5.72	377
-34	1S11	NBG-17	10.500	668	5.97	377
-35	3S2	NBG-18	9.250	671	6.19	377
-33	4S1	PCEA	8.000	680	6.37	377
-34	1S3	NBG-17	6.750	690	6.51	377
-35	1S4	NBG-18	5.500	700	6.63	377
-33	1S2	PCEA	4.250	706	6.73	377
-36	1S5	IG-430	3.000	708	6.79	377
-32	1S8	H-451	1.750	706	6.84	377
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence, Corrected (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	2	Fe+Nb	18.625		3.70	3.33
-71	3	Fe+Nb	13.625		5.28	5.04
-71	4	Fe+Nb	7.375		6.44	7.12
-78	8F	Fe+Nb+Ti	2.375		6.82	7.28

Table 6 AGC-1 fluence, temperature, and load values for channel 2 (North-East Channel) specimens

S-2, Compressed

(Fluence and temperature are corrected)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-34	2U4	NBG-17	19.250	592	3.49	467
-35	5U5	NBG-18	18.000	599	3.95	467
-33	2S14	PCEA	16.750	609	4.38	467
-36	2S15	IG-430	15.500	625	4.78	467
-36	2S9	IG-430	14.250	639	5.15	467
-34	2S6	NBG-17	13.000	653	5.47	467
-35	2S11	NBG-18	11.750	665	5.76	467
-33	2S8	PCEA	10.500	670	6.02	467
-37	2S7	IG-110	9.250	674	6.24	467
-32	2S13	H-451	8.000	683	6.42	467
-36	2S3	IG-430	6.750	693	6.58	467
-34	2S4	NBG-17	5.500	703	6.70	467
-35	2S2	NBG-18	4.250	709	6.80	467
-33	2S1	PCEA	3.000	711	6.87	467
-32	6S5	H-451	1.750	708	6.92	467
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence, Corrected (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	H	Fe+Nb	13.625		5.31	5.07
-71	I	Fe+Nb	2.375		6.89	7.66

Table 7 AGC-1 fluence, temperature, and load values for channel 3 (South-East Channel) specimens

S-3, Compressed

(Fluence and temperature are corrected)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-34	3S13	NBG-17	19.250	594	3.42	565
-36	3S7	IG-430	18.000	602	3.87	565
-36	3S5	IG-430	16.750	612	4.30	565
-37	1U9	IG-110	15.500	628	4.69	565
-37	3S9	IG-110	14.250	642	5.05	565
-35	3S14	NBG-18	13.000	656	5.38	565
-33	3S15	PCEA	11.750	669	5.66	565
-34	AW13-02	NBG-17	10.500	674	5.92	565
-35	3S11	NBG-18	9.250	678	6.13	565
-33	DW11-01	PCEA	8.000	687	6.32	565
-32	3S10	H-451	6.750	697	6.47	565
-36	3S4	IG-430	5.500	707	6.59	565
-34	EW10-02	NBG-17	4.250	713	6.69	565
-35	3S12	NBG-18	3.000	714	6.76	565
-32	3S1	H-451	1.750	712	6.81	565
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence, Corrected (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	K	Fe+Nb	13.625		5.21	4.92
-71	N	Fe+Nb	2.375		6.78	6.21

Table 8 AGC-1 fluence, temperature, and load values for channel 4 (South Channel) specimens

S-4, Compressed

(Fluence and temperature are corrected)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-34	4S12	NBG-17	19.250	594	3.32	359
-35	4S14	NBG-18	18.000	603	3.76	359
-33	4S6	PCEA	16.750	612	4.17	359
-32	4S13	H-451	15.500	628	4.56	359
-32	4S2	H-451	14.250	642	4.91	359
-34	4S8	NBG-17	13.000	656	5.23	359
-36	4S10	IG-430	11.750	669	5.51	359
-35	BW12-03	NBG-18	10.500	675	5.76	359
-33	4S15	PCEA	9.250	679	5.97	359
-36	3S3	IG-430	8.000	688	6.15	359
-35	4S5	NBG-18	6.750	698	6.30	359
-37	4S9	IG-110	5.500	708	6.42	359
-33	4U1	PCEA	4.250	714	6.52	359
-36	4S3	IG-430	3.000	716	6.59	359
-37	4S4	IG-110	1.750	713	6.63	359
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence, Corrected (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	S	Fe+Nb	18.625		3.54	3.11
-71	T	Fe+Nb	13.625		5.07	4.86
-71	V	Fe+Nb	7.375		6.23	6.77
-78	U8	Fe+Nb+Ti	2.375		6.61	7.40

Table 9 AGC-1 fluence, temperature, and load values for channel 5 (South-West Channel) specimens

S-5, Compressed

(Fluence and temperature are corrected)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-36	6U7	IG-430	19.250	593	3.37	474
-37	5S13	IG-110	18.000	601	3.82	474
-33	5S12	PCEA	16.750	611	4.25	474
-32	6U5	H-451	15.500	627	4.64	474
-32	5S7	H-451	14.250	641	5.00	474
-34	3S8	NBG-17	13.000	655	5.33	474
-35	5S15	NBG-18	11.750	668	5.62	474
-33	5S9	PCEA	10.500	674	5.87	474
-34	5S14	NBG-17	9.250	677	6.09	474
-35	5S8	NBG-18	8.000	686	6.28	474
-36	5S10	IG-430	6.750	697	6.43	474
-33	5S4	PCEA	5.500	706	6.55	474
-34	5S6	NBG-17	4.250	712	6.65	474
-36	5S2	IG-430	3.000	714	6.72	474
-37	5S1	IG-110	1.750	712	6.77	474
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence, Corrected (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	CJ	Fe+Nb	13.625		5.17	No Data
-71	CK	Fe+Nb	2.375		6.74	7.69

Table 10 AGC-1 fluence, temperature, and load values for channel 6 (North-West Channel) specimens

S-6, Compressed						
(Fluence and temperature are corrected)						
Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-34	6S15	NBG-17	19.250	593	3.51	558
-35	4S7	NBG-18	18.000	599	3.96	558
-33	6S11	PCEA	16.750	610	4.39	558
-36	6S10	IG-430	15.500	626	4.78	558
-36	6S7	IG-430	14.250	639	5.14	558
-32	6S9	H-451	13.000	653	5.46	558
-37	6S14	IG-110	11.750	666	5.75	558
-34	6S8	NBG-17	10.500	670	6.00	558
-35	6S13	NBG-18	9.250	674	6.21	558
-33	1S6	PCEA	8.000	683	6.39	558
-37	2S5	IG-110	6.750	693	6.54	558
-34	6S1	NBG-17	5.500	703	6.66	558
-35	6S6	NBG-18	4.250	709	6.76	558
-33	6S4	PCEA	3.000	710	6.83	558
-36	6S2	IG-430	1.750	708	6.87	558
Flux Wire Dash No.	Flux Wire ID No.	Flux Wire Type	Flux Wire COM Elevation (in)		MCNP Fluence, Corrected (DPA)	PIE Flux Wire Fluence (DPA)
-71	CE	Fe+Nb	13.625		5.30	5.59
-71	CA	Fe+Nb	2.375		6.85	6.79

The individual specimen core location, irradiation temperature (°C), and tabulated dose level (dpa) for the unstressed specimens are reported in Table 11 through Table 16.

Table 11 AGC-1 fluence and temperature values for channel 1 (North Channel) control specimens

S-1, Uncompressed

(Fluence and temperature correction negligible)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-64	1PB16	NBG-17	-1.625	677	6.86	No Load
-68	1PB17	PCEA	-2.125	678	6.85	No Load
-66	1PB18	NBG-18	-2.625	678	6.83	No Load
-69	1PB19	IG-430	-3.125	678	6.82	No Load
-66	BW15C05	NBG-18	-3.625	678	6.80	No Load
-67	1PB21	IG-110	-4.125	677	6.78	No Load
-46	1PB22	BAN	-4.625	676	6.75	No Load
-52	1U8	H-451	-5.500	674	6.70	No Load
-51	1U5	IG430	-6.750	672	6.61	No Load
-49	1U2	PCEA	-8.000	672	6.49	No Load
-48	1U4	NBG-18	-9.250	664	6.34	No Load
-50	1U3	NBG-17	-10.500	650	6.17	No Load
-49	3S6	PCEA	-11.750	632	5.96	No Load
-48	3U2	NBG-18	-13.000	611	5.72	No Load
-50	1U11	NBG-17	-14.250	592	5.44	No Load
-51	1U10	IG430	-15.500	580	5.12	No Load
-52	1U14	H-451	-16.750	580	4.76	No Load
-53	1U7	IG-110	-18.000	562	4.36	No Load
-49	1U13	PCEA	-19.250	533	3.91	No Load
-48	1U1	NBG-18	-20.500	504	3.41	No Load
-50	1U12	NBG-17	-21.750	468	2.87	No Load
-69	1PB23	IG-430	-22.625	438	2.46	No Load
-68	1PB24	PCEA	-23.125	426	2.22	No Load
-66	1PB25	NBG-18	-23.625	409	1.98	No Load
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	6	Fe+Nb	-7.375		6.55	7.41
-71	7	Fe+Nb	-13.625		5.58	5.87
-71	F	Fe+Nb	-21.125		3.14	3.45

Table 12 AGC-1 fluence and temperature values for channel 2 (North-East Channel) control specimens

S-2, Uncompressed

(Fluence and temperature correction negligible)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-64	2PB16	NBG-17	-1.625	679	6.94	No Load
-68	2PB17	PCEA	-2.125	681	6.93	No Load
-66	2PB18	NBG-18	-2.625	681	6.92	No Load
-69	2PB19	IG-430	-3.125	681	6.90	No Load
-65	2PB20	H-451	-3.625	680	6.88	No Load
-67	2PB21	IG-110	-4.125	679	6.86	No Load
-46	2PB22	BAN	-4.625	678	6.83	No Load
-52	4U2	H-451	-5.500	677	6.77	No Load
-49	2U1	PCEA	-6.750	674	6.68	No Load
-48	2U2	NBG-18	-8.000	675	6.55	No Load
-50	1S13	NBG-17	-9.250	667	6.40	No Load
-51	2U3	IG430	-10.500	653	6.22	No Load
-52	2U12	H-451	-11.750	635	6.00	No Load
-53	2U7	IG-110	-13.000	613	5.76	No Load
-49	2U8	PCEA	-14.250	594	5.47	No Load
-48	2U11	NBG-18	-15.500	582	5.15	No Load
-50	2U6	NBG-17	-16.750	582	4.78	No Load
-51	2U9	IG430	-18.000	564	4.37	No Load
-49	2U13	PCEA	-19.250	534	3.91	No Load
-48	6U3	NBG-18	-20.500	505	3.41	No Load
-50	2U10	NBG-17	-21.750	470	2.86	No Load
-67	2PB23	IG-110	-22.625	439	2.46	No Load
-66	2PB24	NBG-18	-23.125	427	2.22	No Load
-69	2PB25	IG-430	-23.625	411	1.97	No Load
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	J	Fe+Nb	-13.625		5.61	6.61

Table 13 AGC-1 fluence and temperature values for channel 3 (South-East Channel) control specimens

S-3, Uncompressed

(Fluence and temperature correction negligible)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-64	3PB16	NBG-17	-1.625	683	6.83	No Load
-68	3PB17	PCEA	-2.125	684	6.82	No Load
-66	3PB18	NBG-18	-2.625	685	6.80	No Load
-69	3PB19	IG-430	-3.125	685	6.79	No Load
-65	3PB20	H-451	-3.625	684	6.77	No Load
-67	3PB21	IG-110	-4.125	683	6.74	No Load
-46	3PB22	BAN	-4.625	682	6.72	No Load
-52	3U1	H-451	-5.500	681	6.66	No Load
-48	2S12	NBG-18	-6.750	678	6.56	No Load
-50	EW10-03	NBG-17	-8.000	678	6.43	No Load
-51	3U4	IG430	-9.250	670	6.28	No Load
-52	3U10	H-451	-10.500	657	6.09	No Load
-49	3U6	PCEA	-11.750	638	5.88	No Load
-48	3U11	NBG-18	-13.000	617	5.63	No Load
-50	3U8	NBG-17	-14.250	597	5.35	No Load
-49	3U14	PCEA	-15.500	585	5.02	No Load
-48	3U13	NBG-18	-16.750	585	4.66	No Load
-53	3U9	IG-110	-18.000	567	4.25	No Load
-51	3U5	IG430	-19.250	537	3.80	No Load
-51	3U7	IG430	-20.500	508	3.32	No Load
-50	3U12	NBG-17	-21.750	472	2.79	No Load
-68	3PB23	PCEA	-22.625	441	2.40	No Load
-69	3PB24	IG-430	-23.125	430	2.17	No Load
-68	3PB25	PCEA	-23.625	413	1.93	No Load
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	O	Fe+Nb	-13.625		5.49	5.76

Table 14 AGC-1 fluence and temperature values for channel 4 (South Channel) control specimens

S-4, Uncompressed

(Fluence and temperature correction negligible)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-64	4PB16	NBG-17	-1.625	684	6.65	No Load
-68	4PB17	PCEA	-2.125	686	6.65	No Load
-66	4PB18	NBG-18	-2.625	686	6.63	No Load
-69	4PB19	IG-430	-3.125	686	6.62	No Load
-65	4PB20	H-451	-3.625	685	6.60	No Load
-67	4PB21	IG-110	-4.125	684	6.58	No Load
-46	4PB22	BAN	-4.625	683	6.55	No Load
-53	4U4	IG-110	-5.500	682	6.49	No Load
-51	4U3	IG430	-6.750	679	6.40	No Load
-49	4U6	PCEA	-8.000	679	6.27	No Load
-53	4U9	IG-110	-9.250	671	6.13	No Load
-48	4U5	NBG-18	-10.500	658	5.95	No Load
-51	3U3	IG430	-11.750	639	5.74	No Load
-49	4U14	PCEA	-13.000	618	5.50	No Load
-48	4U7	NBG-18	-14.250	599	5.22	No Load
-51	4U10	IG430	-15.500	587	4.91	No Load
-50	4U8	NBG-17	-16.750	587	4.55	No Load
-52	4U12	H-451	-18.000	568	4.16	No Load
-49	5S11	PCEA	-19.250	538	3.72	No Load
-48	4U13	NBG-18	-20.500	509	3.24	No Load
-50	4U11	NBG-17	-21.750	473	2.73	No Load
-66	4PB23	NBG-18	-22.625	442	2.34	No Load
-68	4PB24	PCEA	-23.125	431	2.11	No Load
-66	4PB25	NBG-18	-23.625	414	1.88	No Load
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	X	Fe+Nb	-7.375		6.34	7.30
-71	XX	Fe+Nb	-13.625		5.36	6.39
-71	Y	Fe+Nb	-21.125		2.98	3.32

Table 15 AGC-1 fluence and temperature values for channel 5 (South-West Channel) control specimens

S-5, Uncompressed

(Fluence and temperature correction negligible)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-43	5PB16	NBG-25	-1.625	683	6.79	No Load
-44	5PB17	S-2020	-2.125	684	6.78	No Load
-45	5PB18	PCIB	-2.625	685	6.76	No Load
-46	5PB19	BAN	-3.125	685	6.75	No Load
-47	5PB20	NBG-10	-3.625	684	6.73	No Load
-68	DW15C04	PCEA	-4.125	683	6.70	No Load
-39	5PB22	A3	-4.625	682	6.68	No Load
-53	5U1	IG-110	-5.500	681	6.62	No Load
-51	5U2	IG430	-6.750	678	6.52	No Load
-50	5U6	NBG-17	-8.000	678	6.40	No Load
-49	5U4	PCEA	-9.250	670	6.24	No Load
-51	5U10	IG430	-10.500	656	6.06	No Load
-48	5U8	NBG-18	-11.750	638	5.85	No Load
-50	5U13	NBG-17	-13.000	617	5.61	No Load
-49	5U9	PCEA	-14.250	597	5.33	No Load
-48	5U14	NBG-18	-15.500	585	5.01	No Load
-50	4S11	NBG-17	-16.750	585	4.65	No Load
-52	5U7	H-451	-18.000	567	4.24	No Load
-49	5U11	PCEA	-19.250	537	3.80	No Load
-53	5U12	IG-110	-20.500	507	3.31	No Load
-51	2U14	IG430	-21.750	472	2.78	No Load
-46	5PB23	BAN	-22.625	441	2.38	No Load
-43	5PB24	NBG-25	-23.125	430	2.15	No Load
-42	5PB25	PPEA	-23.625	413	1.91	No Load
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	CC	Fe+Nb	-13.625		5.47	No Data

Table 16 AGC-1 fluence and temperature values for channel 6 (North-West Channel) control specimens

S-6, Uncompressed

(Fluence and temperature correction negligible)

Drawing 630431 Dash No.	Drawing 630431 Specimen ID No.	Graphite Type	Initial Specimen COM Elevation (in)	Experiment Averaged Specimen Temperature (C)	Fluence (DPA)	Power Averaged Load (lbf)
-69	FW19C04	IG-430	-1.625	679	6.89	No Load
-39	6PB17	A3	-2.125	681	6.88	No Load
-40	6PB18	HLM	-2.625	681	6.87	No Load
-41	6PB19	PGX	-3.125	681	6.85	No Load
-42	6PB20	PPEA	-3.625	680	6.83	No Load
-65	6PB21	H-451	-4.125	679	6.81	No Load
-39	6PB22	A3	-4.625	678	6.79	No Load
-51	6U2	IG430	-5.500	677	6.73	No Load
-49	6U4	PCEA	-6.750	674	6.63	No Load
-48	6U6	NBG-18	-8.000	674	6.51	No Load
-50	5U3	NBG-17	-9.250	667	6.36	No Load
-53	2U5	IG-110	-10.500	653	6.18	No Load
-49	1U6	PCEA	-11.750	634	5.96	No Load
-48	6U12	NBG-18	-13.000	613	5.72	No Load
-50	6U8	NBG-17	-14.250	594	5.43	No Load
-53	6U13	IG-110	-15.500	582	5.11	No Load
-52	6U9	H-451	-16.750	582	4.74	No Load
-51	6U10	IG430	-18.000	564	4.34	No Load
-49	6U11	PCEA	-19.250	534	3.88	No Load
-48	5S5	NBG-18	-20.500	505	3.39	No Load
-50	6U14	NBG-17	-21.750	470	2.85	No Load
-44	6PB23	S-2020	-22.625	439	2.45	No Load
-40	6PB24	HLM	-23.125	427	2.21	No Load
-45	6PB25	PCIB	-23.625	411	1.97	No Load
Flux Wire Dash No.	**Flux Wire ID No.**	**Flux Wire Type**	**Flux Wire COM Elevation (in)**		**MCNP Fluence (DPA)**	**PIE Flux Wire Fluence (DPA)**
-71	CH	Fe+Nb	-13.625		5.58	6.15

3. Creep Strain data by Grade

In this sub-section we report the creep strain data by graphite grade. Table 17 reports the individual grade code letters, the graphite grades and the tables in which the creep strain data are reported.

Table 17 Grade code letters and the Tables reporting the creep strain data

Graphite Grade	Forming Method	Table Numbers	AGC Code Letter
NBG-17	Vibrational molded	18 19	A
NBG-18	Vibrational molded	20,21	B
H-451	Extruded	22, 23	C
PCEA	Extruded	24, 25	D
IG-110	Isostatically Pressed	26, 27	E
IG-430	Isostatically Pressed	28, 29	F

For each grade there are two data Tables, the first reports the specimen dimensions, mass, bulk density, and volume change. The second Table reports the dimensional change, the creep strain, the specimen loading details, and the irradiation conditions (dose and temperature). Both Tables are sorted first by applied stress (nominally, 2 ksi, 2.5 ksi, and 3 ksi or 13.9 MPa, 16.4 MPa and 19.6 MPa, respectively) and within each stress group by ascending neutron dose (dpa).

3.1. Grade NGB-17 (A)

Table 18 Specimen dimensions, mass, bulk density, and volume change for grade NBG-17

	Specimen Number	Thickness Measurements, mm. T1	T2	T3	T4	Outside Diameter Measurements,mm. D1	D2	D3	D4	D1^90	D2^90	D3^90	D4^90	Hole Diameter ,mm. H1	H2	H1'	H2'	Weight g	Means: Thickness m	Means: Diameter m	Means: Cross-section m²	Means: 2- hole Volume m³	Creep specimens: Volume m³	Creep specimens: Volume Change m³	Creep specimens: (ΔV/Vo),%	Specimen Type: Creep	Specimen Type: Control	Control specimens: Volume m3	Control specimens: Volume Change m3	Control specimens: (ΔV/Vo),%	Density kg/m³	Density g/cm³
Pre-Irradiation	AL8-01	25.354	25.357	25.356	25.356	12.737	12.732	12.724	12.724	12.737	12.710	12.724	12.724	3.175	3.170	3.175	3.170	5.9178	2.536E-02	1.273E-02	1.272E-04	5.22023E-08	3.17319E-06	-9.37423E-08	-2.954						1864.94	1.8649
Post-Irradiation		24.785	24.781	24.792	24.784	12.694	12.692	12.697	12.704	12.682	12.674	12.685	12.693	3.268	3.270	3.269	3.269	5.9166	2.479E-02	1.269E-02	1.265E-04	5.54271E-08	3.07945E-06			x					1921.32	1.9213
Pre-Irradiation	AL8-02	25.377	25.377	25.373	25.382	12.733	12.741	12.738	12.730	12.738	12.738	12.737	12.733	3.162	3.162	3.167	3.172	5.9359	2.538E-02	1.274E-02	1.274E-04	5.19937E-08						3.23301E-06	-7.96954E-08	-2.465050846	1866.04	1.8660
Post-Irradiation		25.172	25.163	25.167	25.171	12.625	12.627	12.636	12.632	12.626	12.627	12.635	12.634	3.310	3.301	3.296	3.292	5.93496	2.517E-02	1.263E-02	1.253E-04	5.64657E-08					x	3.15332E-06			1916.45	1.9164
Pre-Irradiation	AL6-02	25.367	25.368	25.371	25.368	12.739	12.734	12.728	12.727	12.736	12.736	12.730	12.727	3.185	3.183	3.162	3.165	5.9218	2.537E-02	1.273E-02	1.273E-04	5.22447E-08	3.17762E-06	-1.23113E-07	-3.874						1863.59	1.8636
Post-Irradiation		24.622	24.624	24.623	24.632	12.672	12.671	12.673	12.673	12.684	12.687	12.690	12.694	3.270	3.274	3.256	3.269	5.92101	2.463E-02	1.268E-02	1.263E-04	5.53733E-08	3.05451E-06			x					1938.45	1.9384
Pre-Irradiation	AL6-01	25.372	25.366	25.366	25.370	12.738	12.736	12.730	12.737	12.738	12.737	12.729	12.729	3.175	3.172	3.162	3.162	5.9342	2.537E-02	1.273E-02	1.274E-04	5.20564E-08						3.23095E-06	-1.13952E-07	-3.526891689	1866.75	1.8667
Post-Irradiation		25.034	25.030	25.033	25.036	12.590	12.597	12.597	12.592	12.594	12.595	12.579	12.585	3.316	3.321	3.321	3.326	5.93358	2.503E-02	1.259E-02	1.245E-04	5.72069E-08					x	3.117E-06			1939.21	1.9392
SPECIMEN ORIENTATION CHANGE																																
STRESS LEVEL CHANGE																																
Pre-Irradiation	AW1-03	25.372	25.372	25.363	25.368	12.747	12.743	12.739	12.738	12.743	12.738	12.739	12.738	3.170	3.167	3.172	3.167	5.9168	2.537E-02	1.274E-02	1.275E-04	5.20979E-08	3.18224E-06	-5.97915E-08	-1.879						1859.32	1.8593
Post-Irradiation		25.055	25.061	25.064	25.063	12.711	12.701	12.704	12.712	12.704	12.705	12.709	12.705	3.261	3.269	3.269	3.269	5.91571	2.506E-02	1.271E-02	1.268E-04	5.53625E-08	3.12245E-06			x					1894.57	1.8946
Pre-Irradiation	AW2-03	25.375	25.377	25.375	25.373	12.723	12.720	12.727	12.723	12.724	12.720	12.722	12.723	3.170	3.167	3.200	3.198	5.9217	2.537E-02	1.272E-02	1.271E-04	5.25804E-08						3.22592E-06	-4.48688E-08	-1.3908824	1866.08	1.8661
Post-Irradiation		25.250	25.249	25.252	25.251	12.661	12.663	12.664	12.665	12.665	12.665	12.664	12.673	3.260	3.246	3.268	3.268	5.92098	2.525E-02	1.267E-02	1.260E-04	5.5137E-08					x	3.18106E-06			1894.16	1.8942
Pre-Irradiation	AW6-02	25.378	25.376	25.378	25.378	12.730	12.738	12.734	12.741	12.730	12.733	12.737	12.738	3.200	3.198	3.185	3.183	5.9258	2.538E-02	1.274E-02	1.274E-04	5.28315E-08	3.17982E-06	-8.85491E-08	-2.785						1863.56	1.8636
Post-Irradiation		24.920	24.918	24.914	24.918	12.689	12.679	12.673	12.676	12.688	12.680	12.676	12.678	3.260	3.265	3.265	3.260	5.92491	2.492E-02	1.268E-02	1.263E-04	5.5212E-08	3.09127E-06			x					1916.66	1.9167
Pre-Irradiation	AW7-01	25.375	25.375	25.370	25.370	12.743	12.739	12.737	12.734	12.744	12.739	12.737	12.736	3.170	3.167	3.183	3.180	5.9322	2.537E-02	1.274E-02	1.275E-04	5.22862E-08						3.2337E-06	-7.5409E-08	-2.331974473	1864.64	1.8646
Post-Irradiation		25.173	25.179	25.178	25.180	12.631	12.637	12.639	12.644	12.632	12.637	12.638	12.645	3.293	3.288	3.298	3.294	5.93151	2.518E-02	1.264E-02	1.254E-04	5.62593E-08					x	3.15829E-06			1912.14	1.9121
Pre-Irradiation	AW1-02	25.373	25.375	25.372	25.372	12.736	12.742	12.742	12.737	12.737	12.744	12.742	12.738	3.180	3.180	3.167	3.162	5.9043	2.537E-02	1.274E-02	1.275E-04	5.22027E-08	3.1821E-06	-1.17931E-07	-3.706						1855.47	1.8555
Post-Irradiation		24.827	24.825	24.830	24.827	12.653	12.652	12.652	12.645	12.650	12.650	12.648	12.640	3.274	3.275	3.266	3.274	5.90304	2.483E-02	1.265E-02	1.257E-04	5.55456E-08	3.06417E-06			x					1926.47	1.9265
Pre-Irradiation	AW2-02	25.377	25.377	25.377	25.375	12.738	12.738	12.734	12.734	12.738	12.736	12.733	12.732	3.188	3.185	3.183	3.180	5.9269	2.538E-02	1.274E-02	1.274E-04	5.25792E-08						3.23257E-06	-1.0107E-07	-3.12662392	1863.81	1.8638
Post-Irradiation		25.120	25.110	25.119	25.122	12.596	12.599	12.597	12.601	12.594	12.598	12.602	12.606	3.293	3.296	3.280	3.274	5.92573	2.512E-02	1.260E-02	1.247E-04	5.59996E-08					x	3.1315E-06			1926.75	1.9268
Pre-Irradiation	AW1-01	25.378	25.377	25.381	25.378	12.732	12.736	12.733	12.722	12.733	12.733	12.732	12.730	3.160	3.157	3.175	3.170	5.8614	2.538E-02	1.273E-02	1.273E-04	5.1973E-08	3.17879E-06	-1.36078E-07	-4.281						1843.91	1.8439
Post-Irradiation		24.740	24.749	24.760	24.747	12.632	12.620	12.615	12.624	12.628	12.623	12.624	12.635	3.274	3.274	3.270	3.274	5.85945	2.475E-02	1.263E-02	1.252E-04	5.55672E-08	3.04271E-06			x					1925.74	1.9257
Pre-Irradiation	AW2-01	25.377	25.378	25.373	25.373	12.742	12.742	12.736	12.734	12.742	12.739	12.738	12.741	3.170	3.165	3.175	3.170	5.9366	2.538E-02	1.274E-02	1.275E-04	5.21188E-08						3.23438E-06	-1.08663E-07	-3.359622888	1865.53	1.8655
Post-Irradiation		25.107	25.104	25.106	25.110	12.584	12.586	12.596	12.597	12.587	12.593	12.590	12.589	3.298	3.298	3.316	3.308	5.93583	2.511E-02	1.259E-02	1.245E-04	5.66616E-08					x	3.12572E-06			1934.09	1.9341
Pre-Irradiation	AW6-03	25.382	25.381	25.387	25.382	12.723	12.729	12.730	12.734	12.728	12.729	12.729	12.736	3.190	3.185	3.190	3.190	5.9126	2.538E-02	1.273E-02	1.273E-04	5.27471E-08	3.17785E-06	-5.13068E-08	-1.615						1860.57	1.8606
Post-Irradiation		25.097	25.100	25.101	25.101	12.716	12.706	12.698	12.698	12.715	12.702	12.700	12.694	3.249	3.254	3.249	3.255	5.91163	2.510E-02	1.270E-02	1.267E-04	5.48365E-08	3.12655E-06			x					1890.79	1.8908
Pre-Irradiation	AW7-02																		2.57E-02	1.27E-02												
Post-Irradiation		AW 7-02 not returned by INL				INL Data for means													2.53E-02	1.27E-02							x					
STRESS LEVEL CHANGE																																
Pre-Irradiation	AW4-02	25.372	25.372	25.372	25.373	12.736	12.736	12.737	12.733	12.742	12.738	12.738	12.737	3.178	3.172	3.180	3.178	5.9364	2.537E-02	1.274E-02	1.274E-04	5.23488E-08	3.1805E-06	-5.82062E-08	-1.830						1866.50	1.8665
Post-Irradiation		25.029	25.030	25.028	25.030	12.716	12.707	12.709	12.713	12.716	12.716	12.713	12.718	3.255	3.246	3.264	3.270	5.93533	2.503E-02	1.271E-02	1.269E-04	5.50834E-08	3.1223E-06			x					1900.95	1.9010
Pre-Irradiation	AW5-01	25.373	25.375	25.375	25.373	12.739	12.741	12.741	12.746	12.739	12.739	12.737	12.748	3.170	3.170	3.167	3.172	5.9411	2.537E-02	1.274E-02	1.275E-04	5.21188E-08						3.23523E-06	-4.30758E-08	-1.331461349	1866.44	1.8664
Post-Irradiation		25.259	25.261	25.261	25.256	12.683	12.686	12.685	12.685	12.684	12.686	12.685	12.685	3.279	3.293	3.283	3.285	5.93993	2.526E-02	1.268E-02	1.264E-04	5.59775E-08					x	3.19215E-06			1894.00	1.8940
Pre-Irradiation	AW4-01	25.375	25.373	25.375	25.375	12.741	12.737	12.738	12.733	12.738	12.738	12.742	12.738	3.175	3.172	3.180	3.178	5.9331	2.537E-02	1.274E-02	1.274E-04	5.23279E-08	3.18133E-06	-1.05801E-07	-3.326						1864.98	1.8650
Post-Irradiation		24.827	24.828	24.837	24.822	12.673	12.671	12.669	12.671	12.672	12.671	12.670	12.674	3.239	3.275	3.287	3.285	5.93195	2.483E-02	1.267E-02	1.261E-04	5.55135E-08	3.07553E-06			x					1928.76	1.9288
Pre-Irradiation	AW4-03	25.385	25.385	25.383	25.385	12.747	12.746	12.742	12.738	12.746	12.746	12.744	12.739	3.170	3.165	3.165	3.165	5.9319	2.538E-02	1.274E-02	1.275E-04	5.19936E-08						3.23769E-06	-8.41593E-08	-2.599359727	1862.04	1.8620
Post-Irradiation		25.161	25.164	25.164	25.163	12.623	12.632	12.634	12.639	12.623	12.634	12.632	12.639	3.306	3.301	3.298	3.308	5.93021	2.516E-02	1.263E-02	1.253E-04	5.6596E-08					x	3.15353E-06			1914.86	1.9149
Pre-Irradiation	AW9-01	25.378	25.377	25.376	25.380	12.725	12.729	12.730	12.734	12.728	12.728	12.733	12.738	3.162	3.160	3.172	3.172	5.9210	2.538E-02	1.273E-02	1.273E-04	5.20146E-08	3.17838E-06	-1.10607E-07	-3.480						1862.90	1.8629
Post-Irradiation		24.740	24.751	24.751	24.749	12.699	12.678	12.677	12.675	12.691	12.680	12.671	12.660	3.296	3.296	3.321	3.322	5.93087	2.475E-02	1.268E-02	1.263E-04	5.6782E-08	3.06777E-06			x					1933.28	1.9333
Pre-Irradiation	AW10-01	25.376	25.382	25.382	25.378	12.724	12.725	12.728	12.736	12.727	12.725	12.730	12.737	3.175	3.175	3.178	3.175	5.9287	2.538E-02	1.273E-02	1.273E-04	5.23069E-08						3.22975E-06	-1.01169E-07	-3.132423081	1865.87	1.8659
Post-Irradiation		25.121	25.123	25.126	25.125	12.596	12.598	12.588	12.591	12.596	12.596	12.586	12.583	3.231	3.259	3.274	3.279	5.93569	2.512E-02	1.259E-02	1.245E-04	5.51483E-08					x	3.12858E-06			1931.29	1.9313
Pre-Irradiation	AW7-03	25.377	25.377	25.375	25.376	12.744	12.741	12.738	12.728	12.739	12.738	12.736	12.733	3.165	3.162	3.193	3.195	5.9369	2.538E-02	1.274E-02	1.274E-04	5.24128E-08	3.181E-06	-1.16219E-07	-3.654						1866.36	1.8664
Post-Irradiation		24.690	24.697	24.681	24.681	12.682	12.686	12.686	12.704	12.681	12.686	12.687	12.680	3.280	3.259	3.293	3.297	5.91989	2.469E-02	1.269E-02	1.264E-04	5.58808E-08	3.06478E-06			x					1931.58	1.9316
Pre-Irradiation	AW9-03	25.377	25.376	25.377	25.375	12.733	12.738	12.739	12.742	12.730	12.733	12.737	12.743	3.170	3.167	3.185	3.183	5.9321	2.538E-02	1.274E-02	1.274E-04	5.23281E-08						3.23334E-06	-1.13232E-07	-3.502016151	1864.85	1.8648
Post-Irradiation		25.103	25.100	25.094	25.101	12.585	12.583	12.584	12.576	12.585	12.582	12.580	12.571	3.298	3.293	3.298	3.298	5.92697	2.510E-02	1.258E-02	1.243E-04	5.63787E-08					x	3.1201E-06			1934.56	1.9346
STRESS LEVEL CHANGE																																
Pre-Irradiation	AW5-02	25.375	25.371	25.373	25.381	12.725	12.720	12.725	12.743	12.724	12.722	12.729	12.743	3.175	3.170	3.175	3.172	5.9287	2.537E-02	1.273E-02	1.273E-04	5.22233E-08	3.17692E-06	-5.77126E-08	-1.817						1866.18	1.8662
Post-Irradiation		24.991	24.990	24.980	24.982	12.729	12.723	12.706	12.708	12.738	12.726	12.708	12.713	3.260	3.265	3.265	3.274	5.92798	2.499E-02	1.272E-02	1.271E-04	5.53303E-08	3.11921E-06			x					1900.47	1.9005
Pre-Irradiation	AW6-01	25.377	25.381	25.375	25.376	12.737	12.741	12.741	12.748	12.737	12.734	12.739	12.746	3.178	3.172	3.185	3.183	5.9383	2.538E-02	1.274E-02	1.275E-04	5.24326E-08						3.23515E-06	-4.12313E-08	-1.274479935	1865.80	1.8658
Post-Irradiation		25.269	25.268	25.265	25.263	12.687	12.686	12.686	12.680	12.690	12.689	12.686	12.689	3.264	3.274	3.283	3.274	5.93716	2.527E-02	1.269E-02	1.264E-04	5.55888E-08					x	3.19392E-06			1891.82	1.8918
Pre-Irradiation	AW12-01	25.357	25.353	25.354	25.356	12.743	12.737	12.737	12.736	12.746	12.741	12.741	12.734	3.165	3.162	3.183	3.178	5.9283	2.535E-02	1.274E-02	1.275E-04	5.21818E-08	3.17957E-06	-6.02486E-08	-1.895						1864.50	1.8645
Post-Irradiation		24.963	24.966	24.962	24.955	12.729	12.727	12.728	12.732	12.729	12.723	12.720	12.730	3.293	3.293	3.298	3.296	5.92711	2.496E-02	1.273E-02	1.272E-04	5.63135E-08	3.11932E-06			x					1900.13	1.9001
Pre-Irradiation	AW13-01	25.376	25.372	25.370	25.371	12.741	12.727	12.730	12.728	12.741	12.728	12.727	12.728	3.165	3.165	3.178	3.175	5.9277	2.537E-02	1.273E-02	1.273E-04	5.21399E-08						3.22983E-06	-3.92819E-08	-1.216222691	1865.41	1.8654
Post-Irradiation		25.250	25.252	25.258	25.256	12.676	12.683	12.679	12.696	12.671	12.684	12.681	12.694	3.269	3.269	3.289	3.288	5.92154	2.525E-02	1.268E-02	1.263E-04	5.57619E-08					x	3.19055E-06			1888.98	1.8890
Pre-Irradiation	AW13-02	25.364	25.370	25.366	25.367	12.734	12.733	12.738	12.738	12.730	12.733	12.737	12.741	3.188	3.190	3.198	3.190	5.9269	2.537E-02	1.274E-02	1.274E-04	5.28312E-08	3.17857E-06	-1.10917E-07	-3.490						1864.65	1.8646
Post-Irradiation		24.660	24.664	24.661	24.668	12.698	12.690	12.695	12.700	12.700	12.690	12.696	12.699	3.233	3.258	3.241	3.252	5.92546	2.466E-02	1.270E-02	1.266E-04	5.46542E-08	3.06765E-06			x					1931.60	1.9316
Pre-Irradiation	AW5-03	25.375	25.378	25.377	25.375	12.732	12.730	12.736	12.743	12.732	12.732	12.737	12.741	3.170	3.170	3.170	3.162	5.9198	2.538E-02	1.274E-02	1.274E-04	5.20562E-08						3.23245E-06	-9.32596E-08	-2.88510703	1861.34	1.8613
Post-Irradiation		25.142	25.143	25.147	25.138	12.609	12.611	12.610	12.607	12.612	12.610	12.604	12.604	3.282	3.303	3.260	3.265	5.91835	2.514E-02	1.261E-02	1.249E-04	5.57191E-08					x	3.13919E-06			1919.38	1.9194
Pre-Irradiation	AW10-03	25.373	25.372	25.377	25.375	12.736	12.732	12.733	12.739	12.733	12.734	12.734	12.739	3.167	3.165	3.183	3.180	5.9260	2.537E-02	1.274E-02	1.274E-04	5.22445E-08	3.17988E-06	-1.22696E-07	-3.859						1863.59	1.8636
Post-Irradiation		24.643	24.643	24.645	24.646	12.692	12.681	12.676	12.675	12.693	12.676	12.675	12.678	3.260	3.260	3.260	3.272	5.92511	2.464E-02	1.268E-02	1.263E-04	5.52227E-08	3.05719E-06			x					1938.09	1.9381
Pre-Irradiation	AW12-03	25.352	25.352	25.353	25.352	12.733	12.725	12.725	12.729	12.733	12.724	12.723	12.725	3.165	3.162	3.167	3.162	5.9277	2.535E-02	1.273E-02	1.272E-04	5.1931E-08						3.22535E-06	-9.69639E-08	-3.006303432	1867.92	1.8679
Post-Irradiation		25.102	25.100	25.104	25.103	12.588	12.599	12.594	12.601	12.601	12.594	12.596	12.601	3.274	3.273	3.239	3.250	5.92652	2.510E-02	1.260E-02	1.246E-04	5.50842E-08					x	3.12839E-06			1928.39	1.9284
Pre-Irradiation	AW10-02	25.377	25.376	25.375	25.376	12.734	12.738	12.738	12.746	12.738	12.739	12.739	12.746	3.193	3.185	3.167	3.162	5.9365	2.538E-02	1.274E-02	1.275E-04	5.23495E-08	3.1824E-06	-1.28459E-07	-4.037						1865.42	1.8654
Post-Irradiation		24.597	24.597	24.610	24.599	12.693	12.684	12.678	12.686	12.698	12.682	12.678	12.680	3.268	3.264	3.245	3.249	5.9355	2.460E-02	1.268E-02	1.264E-04	5.49978E-08	3.05394E-06			x					1943.56	1.9436
Pre-Irradiation	AW9-02																		2.54E-02	1.27E-02												
Post-Irradiation		AW 9-02 not returned by INL				INL data for means													2.51E-02	1.26E-02							x					

Table 19 Dimensional change, the creep strain, the specimen loading details, and the irradiation conditions (dose and temperature for grade NBG-17

Specimen Number	I.D. Number	Companion Specimen I.D. Number	Companion Specimen Number	Dimensional Change, ΔDIM = IRR-UNIRR: L (mm)	$\Delta L/L_0$(%)	D (mm)	$\Delta D/D_0$(%)	Specimen Type: Creep	Control	Load Details: Load lbf	Stress ksi	Stress MPa	Creep Strain (creep-control): Longitudanal (mm)	Longitudanal %	Lateral (mm)	Lateral %	Irradiation Conditions: ID No.	Temp °C	Dose DPA	channel
AL8-01	3S8	4S11	AL8-02	-0.570	-2.248	-0.036	-0.286	x		474	2.40	16.58	-0.361	-1.42	0.069	0.55	3S8	655	5.33	S5
AL8-02	4S11	3S8	AL8-01	-0.209	-0.824	-0.106	-0.831		x	0	0.00	0.00					4S11	585	4.65	U5
AL6-02	2S4	1S13	AL6-01	-0.743	-2.930	-0.052	-0.405	x		467	2.37	16.32	-0.408	-1.61	0.092	0.72	2S4	703	6.70	S2
AL6-01	1S13	2S4	AL6-02	-0.335	-1.321	-0.143	-1.124		x	0	0	0					1S13	667	6.40	U2
AW1-03	1S12	1U12	AW2-03	-0.308	-1.215	-0.034	-0.270	x		377	1.91	13.15	-0.184	-0.72	0.023	0.18	1S12	589	3.47	S1
AW2-03	1U12	1S12	AW1-03	-0.124	-0.490	-0.058	-0.454		x	0	0.00	0.00					1U12	468	2.87	U1
AW6-02	4S8	4U8	AW7-01	-0.460	-1.814	-0.055	-0.435	x		359	1.82	12.54	-0.266	-1.05	0.045	0.36	4S8	656	5.23	S4
AW7-01	4U8	4S8	AW6-02	-0.195	-0.767	-0.101	-0.792		x	0	0	0					4U8	587	4.55	U4
AW1-02	1S11	1U11	AW2-02	-0.546	-2.151	-0.091	-0.714	x		377	1.91	13.16	-0.287	-1.13	0.045	0.36	1S11	668	5.97	S1
AW2-02	1U11	1S11	AW1-02	-0.259	-1.020	-0.136	-1.070		x	0	0.00	0.00					1U11	592	5.44	U1
AW1-01	1S3	1U3	AW2-01	-0.630	-2.481	-0.106	-0.834	x		377	1.91	13.17	-0.361	-1.42	0.043	0.34	1S3	690	6.51	S1
AW2-01	1U3	1S3	AW1-01	-0.269	-1.059	-0.149	-1.169		x	0	0.00	0.00					1U3	650	6.17	U1
AW6-03	4S12	4U11	AW7-02	-0.283	-1.117	-0.026	-0.206	x		359	1.82	12.55	INL data for AW 702 not sound				4S12	594	3.32	S4
AW7-02	4U11	4S12	AW6-03	INL data for AW 702 not good					x	0	0	0					4U11	473	2.73	U4
AW4-02	2U4	2U10	AW5-01	-0.343	-1.352	-0.023	-0.184	x		467	2.36	16.30	-0.228	-0.90	0.033	0.26	2U4	592	3.49	S2
AW5-01	2U10	2U4	AW4-02	-0.115	-0.452	-0.056	-0.443		x	0	0.00	0.00					2U10	470	2.86	U2
AW4-01	2S6	2U6	AW4-03	-0.546	-2.151	-0.067	-0.524	x		467	2.36	16.30	-0.324	-1.28	0.045	0.35	2S6	653	5.47	S2
AW4-03	2U6	2S6	AW4-01	-0.221	-0.872	-0.111	-0.875		x	0	0.00	0.00					2U6	582	4.78	U2
AW9-01	5S14	5U13	AW10-01	-0.630	-2.483	-0.052	-0.408	x		474	2.40	16.56	-0.374	-1.47	0.085	0.67	5S14	677	6.09	S5
AW10-01	5U13	5S14	AW9-01	-0.256	-1.008	-0.137	-1.079		x	0							5U13	617	5.61	U5
AW7-03	5S6	5U6	AW9-03	-0.689	-2.715	-0.051	-0.398	x		474	2.40	16.55	-0.412	-1.62	0.106	0.83	5S6	712	6.56	S5
AW9-03	5U6	5S6	AW7-03	-0.277	-1.090	-0.156	-1.227		x	0	0.00	0.00					5U6	678	6.4	U5
AW5-02	3S13	3U12	AW6-01	-0.389	-1.534	-0.010	-0.080	x		565	2.86	19.75	-0.278	-1.10	0.044	0.34	3S13	594	3.42	S3
AW6-01	3U12	3S13	AW5-02	-0.111	-0.437	-0.054	-0.421		x	0	0	0					3U12	472	2.79	U3
AW12-01	6S15	6U14	AW13-01	-0.393	-1.552	-0.012	-0.094	x		558	2.82	19.47	-0.275	-1.09	0.036	0.28	6S15	593	3.51	S6
AW13-01	6U14	6S15	AW 12-01	-0.118	-0.465	-0.048	-0.378		x	0	0.00	0.00					6U14	470	2.85	U6
AW13-02	SPARE	3U8	AW5-03	-0.703	-2.773	-0.040	-0.311	x		565	2.86	19.73	-0.470	-1.85	0.087	0.69	AW13-02	674	5.92	S3
AW5-03	3U8	SPARE	AW13-02	-0.234	-0.921	-0.127	-0.996		x	0	0	0					3U8	597	5.35	U3
AW10-03	6S8	6U8	AW12-03	-0.730	-2.877	-0.054	-0.427	x		558	2.83	19.49	-0.480	-1.89	0.076	0.60	6S8	670	6	S6
AW12-03	6U8	6S8	AW10-03	-0.250	-0.985	-0.131	-1.026		x	0	0.00	0.00					6U8	594	5.43	U6
AW10-02	6S1	5U3	AW9-02	-0.775	-3.055	-0.055	-0.431	x		558	2.82	19.47	-0.509	-2.01	0.093	0.73	6S1	703	6.66	S6
AW9-02	5U3	6S1	AW10-02	-0.266	-1.047	-0.148	-1.159		x	0	0	0					5U3	667	6.36	U6

3.2 Grade NBG-18 (B)

Table 20 Specimen dimensions, mass, bulk density, and volume change for grade NBG-18

	Specimen Number	Thickness Measurements, mm. T1	T2	T3	T4	Outside Diameter Measurements, mm. D1	D2	D3	D4	$D1^{90}$	$D2^{90}$	$D3^{90}$	$D4^{90}$	Hole Diameter, mm. H1	H2	H1'	H2'	Weight g	Means: Thickness m	Diameter m	Cross-section m^2	2- hole Volume m^3	Creep specimens: Volume m^3	Volume Change m^3	Volume Change (ΔV/Vo),%	Specimen Type: Creep	Control	Control specimens: Volume m3	Volume Change m3	Volume Change (ΔV/Vo),%	Density kg/m^3	Density g/cm^3
Pre-Irradiation	BL7-01	25.368	25.368	25.367	25.366	12.743	12.738	12.738	12.741	12.743	12.742	12.739	12.742	3.241	3.246	3.246	3.249	5.9751	2.537E-02	1.274E-02	1.275E-04	5.46333E-08	3.1795E-06	-6.17444E-08	-1.942						1879.26	1.8793
Post-Irradiation		24.946	24.966	24.947	24.950	12.732	12.720	12.718	12.723	12.737	12.725	12.722	12.713	3.264	3.264	3.246	3.246	5.97459	2.495E-02	1.272E-02	1.272E-04	5.49548E-08	3.11776E-06			x					1916.31	1.9163
Pre-Irradiation	BL7-02	25.363	25.364	25.366	25.368	12.734	12.742	12.741	12.738	12.738	12.736	12.741	12.734	3.244	3.241	3.246	3.246	5.9591	2.537E-02	1.274E-02	1.274E-04	5.45905E-08						3.17785E-06	-5.32845E-08	-1.677	1875.20	1.8752
Post-Irradiation		25.218	25.218	25.219	25.219	12.665	12.670	12.675	12.672	12.670	12.676	12.674	12.669	3.294	3.293	3.269	3.246	5.95809	2.522E-02	1.267E-02	1.261E-04	5.56548E-08					x	3.12457E-06			1906.85	1.9069
Pre-Irradiation	BL6-03	25.370	25.375	25.372	25.373	12.741	12.739	12.739	12.741	12.741	12.739	12.738	12.742	3.239	3.241	3.239	3.239	5.9625	2.537E-02	1.274E-02	1.275E-04	5.44197E-08	3.17996E-06	-1.25968E-07	-3.961						1875.02	1.8750
Post-Irradiation		24.535	24.536	24.540	24.541	12.710	12.699	12.698	12.701	12.708	12.698	12.694	12.703	3.274	3.266	3.247	3.247	5.96165	2.454E-02	1.270E-02	1.267E-04	5.50838E-08	3.05399E-06			x					1952.08	1.9521
Pre-Irradiation	BL6-02	25.372	25.367	25.368	25.371	12.741	12.738	12.737	12.728	12.743	12.736	12.736	12.728	3.241	3.244	3.239	3.239	5.9668	2.537E-02	1.274E-02	1.274E-04	5.44624E-08						3.17738E-06	-1.22503E-07	-3.855	1877.90	1.8779
Post-Irradiation		25.053	25.063	25.067	25.061	12.563	12.570	12.572	12.578	12.573	12.573	12.573	12.578	3.293	3.293	3.298	3.301	5.96582	2.506E-02	1.257E-02	1.241E-04	5.6357E-08					x	3.05488E-06			1952.88	1.9529
Specimen Orientation Change																																
LOAD CHANGE																																
Pre-Irradiation	BW7-03	25.366	25.366	25.362	25.364	12.732	12.734	12.727	12.744	12.730	12.729	12.727	12.739	3.244	3.244	3.244	3.244	5.9619	2.536E-02	1.273E-02	1.273E-04	5.45692E-08	3.17518E-06	-5.22751E-08	-1.646						1877.66	1.8777
Post-Irradiation		25.061	25.063	25.069	25.068	12.717	12.712	12.704	12.698	12.718	12.707	12.702	12.689	3.255	3.261	3.272	3.265	5.96118	2.507E-02	1.271E-02	1.268E-04	5.52336E-08	3.1229E-06			x					1908.86	1.9089
Pre-Irradiation	BW8-03													INL Means					2.537E-02	1.274E-02							x					
Post-Irradiation																			2.523E-02	1.267E-02												
Pre-Irradiation	BW12-02	25.377	25.375	25.377	25.380	12.738	12.739	12.742	12.742	12.739	12.738	12.742	12.741	3.246	3.246	3.236	3.236	5.9721	2.538E-02	1.274E-02	1.275E-04	5.44839E-08	3.18059E-06	-5.95444E-08	-1.872						1877.67	1.8777
Post-Irradiation		25.045	25.050	25.050	25.048	12.708	12.705	12.707	12.700	12.712	12.711	12.703	12.703	3.259	3.261	3.254	3.259	5.97036	2.505E-02	1.271E-02	1.268E-04	5.50617E-08	3.12104E-06			x					1912.94	1.9129
Pre-Irradiation	BW1-02	25.372	25.364	25.367	25.372	12.737	12.739	12.744	12.743	12.742	12.742	12.746	12.746	3.228	3.228	3.233	3.233	5.9715	2.537E-02	1.274E-02	1.275E-04	5.41427E-08						3.181E-06	-5.37177E-08	-1.689	1877.24	1.8772
Post-Irradiation		25.222	25.222	25.221	25.221	12.676	12.675	12.674	12.675	12.673	12.677	12.676	12.674	3.269	3.255	3.255	3.263	5.97086	2.522E-02	1.268E-02	1.262E-04	5.51367E-08					x	3.12729E-06			1909.28	1.9093
Pre-Irradiation	BW12-03	25.359	25.358	25.363	25.364	12.748	12.742	12.746	12.744	12.751	12.746	12.747	12.743	3.228	3.228	3.231	3.231	5.9791	2.536E-02	1.275E-02	1.276E-04	5.41001E-08	3.18185E-06	-1.01801E-07	-3.199						1879.13	1.8791
Post-Irradiation		24.587	24.852	24.857	24.854	12.700	12.686	12.684	12.686	12.697	12.695	12.684	12.685	3.245	3.249	3.264	3.249	5.97738	2.479E-02	1.269E-02	1.265E-04	5.48365E-08	3.08005E-06			x					1940.68	1.9407
Pre-Irradiation	BW8-02	25.378	25.372	25.371	25.376	12.736	12.739	12.737	12.732	12.736	12.741	12.738	12.733	3.244	3.246	3.244	3.244	5.9649	2.537E-02	1.274E-02	1.274E-04	5.45905E-08						3.17818E-06	-7.98179E-08	-2.511	1876.83	1.8768
Post-Irradiation		25.159	25.181	25.191	25.174	12.623	12.630	12.634	12.632	12.629	12.623	12.641	12.631	3.284	3.280	3.292	3.289	5.96354	2.518E-02	1.263E-02	1.253E-04	5.6021E-08					x	3.09836E-06			1924.74	1.9247
Pre-Irradiation	BW7-02	25.375	25.375	25.375	25.373	12.738	12.738	12.741	12.741	12.739	12.738	12.739	12.741	3.246	3.246	3.233	3.236	5.9578	2.537E-02	1.274E-02	1.275E-04	5.44625E-08	3.17984E-06	-1.12411E-07	-3.535						1873.62	1.8736
Post-Irradiation		24.784	24.787	24.790	24.790	12.668	12.658	12.663	12.658	12.670	12.668	12.662	12.669	3.255	3.246	3.269	3.265	5.95707	2.479E-02	1.266E-02	1.260E-04	5.50834E-08	3.06743E-06			x					1942.04	1.9420
Pre-Irradiation	BW8-01	25.381	25.380	25.383	25.385	12.742	12.738	12.736	12.737	12.739	12.736	12.736	12.738	3.246	3.246	3.244	3.246	5.9639	2.538E-02	1.274E-02	1.274E-04	5.46333E-08						3.17979E-06	-1.11014E-07	-3.491	1875.56	1.8756
Post-Irradiation		25.097	25.102	25.096	25.101	12.590	12.586	12.592	12.593	12.590	12.589	12.595	12.590	3.291	3.292	3.288	3.292	5.96327	2.510E-02	1.259E-02	1.245E-04	5.61617E-08					x	3.06878E-06			1943.21	1.9432
Pre-Irradiation	BW3-02	25.378	25.376	25.380	25.381	12.728	12.729	12.730	12.732	12.727	12.728	12.729	12.733	3.241	3.246	3.239	3.241	5.9512	2.538E-02	1.273E-02	1.273E-04	5.45051E-08	3.17537E-06	-1.27388E-07	-4.012						1874.18	1.8742
Post-Irradiation		24.791	24.793	24.789	24.796	12.631	12.624	12.622	12.617	12.634	12.629	12.621	12.624	3.291	3.270	3.282	3.274	5.95069	2.479E-02	1.263E-02	1.252E-04	5.57719E-08	3.04798E-06			x					1952.34	1.9523
Pre-Irradiation	BW5-02	25.370	25.368	25.364	25.372	12.744	12.741	12.741	12.738	12.741	12.739	12.737	12.737	3.236	3.236	3.239	3.239	5.9594	2.537E-02	1.274E-02	1.275E-04	5.43557E-08						3.17938E-06	-1.12378E-07	-3.535	1874.39	1.8744
Post-Irradiation		25.076	25.083	25.086	25.087	12.587	12.587	12.593	12.593	12.588	12.589	12.595	12.594	3.293	3.287	3.284	3.280	5.95867	2.508E-02	1.259E-02	1.245E-04	5.60101E-08					x	3.067E-06			1942.83	1.9428
Pre-Irradiation	BW1-01	25.372	25.371	25.376	25.376	12.741	12.741	12.738	12.733	12.737	12.741	12.738	12.737	3.244	3.241	3.244	3.244	5.9653	2.537E-02	1.274E-02	1.274E-04	5.45478E-08	3.17903E-06	-1.31258E-07	-4.129						1876.45	1.8765
Post-Irradiation		24.721	24.725	24.724	24.727	12.645	12.641	12.642	12.644	12.639	12.636	12.643	12.649	3.294	3.288	3.258	3.288	5.96433	2.472E-02	1.264E-02	1.255E-04	5.58693E-08	3.04777E-06			x					1956.95	1.9569
Pre-Irradiation	BW1-03	25.367	25.368	25.373	25.367	12.728	12.732	12.734	12.737	12.729	12.733	12.737	12.734	3.236	3.233	3.246	3.249	5.9608	2.537E-02	1.273E-02	1.273E-04	5.44839E-08						3.17591E-06	-1.19343E-07	-3.758	1876.88	1.8769
Post-Irradiation		25.068	25.064	25.060	25.061	12.583	12.575	12.571	12.570	12.582	12.576	12.573	12.571	3.298	3.289	3.291	3.294	5.95953	2.506E-02	1.258E-02	1.242E-04	5.62484E-08					x	3.05656E-06			1949.75	1.9497
LOAD CHANGE																																
Pre-Irradiation	BW9-03	25.376	25.377	25.383	25.381	12.725	12.725	12.730	12.723	12.723	12.727	12.727	12.725	3.241	3.241	3.233	3.236	5.9693	2.538E-02	1.273E-02	1.272E-04	5.43771E-08	3.17364E-06	-5.80113E-08	-1.828						1880.90	1.8809
Post-Irradiation		25.008	25.013	25.015	25.018	12.713	12.700	12.701	12.698	12.711	12.706	12.700	12.701	3.242	3.242	3.260	3.266	5.96865	2.501E-02	1.270E-02	1.268E-04	5.48799E-08	3.11563E-06			x					1915.71	1.9157
Pre-Irradiation	BW11-02	25.373	25.370	25.377	25.376	12.736	12.739	12.744	12.733	12.736	12.737	12.746	12.733	3.231	3.226	3.241	3.241	5.9666	2.537E-02	1.274E-02	1.274E-04	5.42706E-08						3.17927E-06	-5.14738E-08	-1.619	1876.72	1.8767
Post-Irradiation		25.235	25.235	25.234	25.238	12.669	12.677	12.673	12.673	12.670	12.676	12.674	12.670	3.269	3.274	3.258	3.256	5.96569	2.524E-02	1.267E-02	1.261E-04	5.5266E-08					x	3.12779E-06			1907.32	1.9073
Pre-Irradiation	BW9-02	25.368	25.361	25.367	25.372	12.725	12.722	12.729	12.728	12.730	12.720	12.730	12.728	3.241	3.241	3.241	3.241	5.9530	2.537E-02	1.273E-02	1.272E-04	5.44837E-08	3.17244E-06	-9.61158E-08	-3.030						1876.47	1.8765
Post-Irradiation		24.791	24.789	24.790	24.784	12.690	12.684	12.677	12.680	12.689	12.684	12.676	12.681	3.269	3.265	3.259	3.259	5.95168	2.479E-02	1.268E-02	1.263E-04	5.52228E-08	3.07633E-06			x					1934.67	1.9347
Pre-Irradiation	BW10-02	25.375	25.373	25.377	25.377	12.737	12.718	12.727	12.736	12.737	12.715	12.727	12.736	3.246	3.246	3.236	3.236	5.9621	2.538E-02	1.273E-02	1.273E-04	5.44839E-08						3.17466E-06	-8.3032E-08	-2.615	1878.03	1.8780
Post-Irradiation		25.144	25.145	25.140	25.146	12.624	12.619	12.629	12.630	12.619	12.619	12.629	12.631	3.279	3.275	3.293	3.296	5.96113	2.514E-02	1.263E-02	1.252E-04	5.59996E-08					x	3.09163E-06			1928.15	1.9282
Pre-Irradiation	BW2-02	25.368	25.368	25.363	25.366	12.746	12.744	12.744	12.737	12.744	12.742	12.743	12.736	3.244	3.244	3.244	3.246	5.9706	2.537E-02	1.274E-02	1.275E-04	5.45905E-08	3.18007E-06	-1.16981E-07	-3.679						1877.51	1.8775
Post-Irradiation		24.761	24.769	24.764	24.770	12.662	12.662	12.660	12.664	12.666	12.662	12.661	12.660	3.261	3.277	3.274	3.274	5.97009	2.477E-02	1.266E-02	1.259E-04	5.55132E-08	3.06309E-06			x					1949.04	1.9490
Pre-Irradiation	BW3-01	25.367	25.364	25.367	25.366	12.746	12.743	12.741	12.739	12.743	12.742	12.741	12.739	3.244	3.246	3.241	3.241	5.9657	2.537E-02	1.274E-02	1.275E-04	5.45478E-08						3.17991E-06	-9.84956E-08	-3.097	1876.06	1.8761
Post-Irradiation		25.115	25.116	25.117	25.111	12.609	12.608	12.613	12.614	12.616	12.610	12.614	12.614	3.293	3.287	3.298	3.293	5.96511	2.511E-02	1.261E-02	1.249E-04	5.62376E-08					x	3.08142E-06			1935.83	1.9358
Pre-Irradiation	BW9-01	25.373	25.380	25.381	25.380	12.738	12.742	12.729	12.733	12.729	12.741	12.727	12.732	3.249	3.251	3.228	3.228	5.9733	2.538E-02	1.274E-02	1.274E-04	5.44203E-08	3.17823E-06	-1.05357E-07	-3.315						1879.44	1.8794
Post-Irradiation		24.715	24.728	24.718	24.728	12.704	12.685	12.687	12.697	12.693	12.689	12.693	12.689	3.246	3.242	3.264	3.272	5.97195	2.472E-02	1.269E-02	1.265E-04	5.49873E-08	3.07287E-06			x					1943.44	1.9434
Pre-Irradiation	BW10-01	25.382	25.376	25.378	25.382	12.742	12.741	12.741	12.742	12.741	12.739	12.738	12.742	3.244	3.244	3.244	3.246	5.9741	2.538E-02	1.274E-02	1.275E-04	5.45905E-08						3.18104E-06	-1.07461E-07	-3.378	1878.03	1.8780
Post-Irradiation		25.098	25.102	25.100	25.103	12.597	12.598	12.602	12.604	12.600	12.598	12.594	12.601	3.292	3.285	3.280	3.269	5.97249	2.510E-02	1.260E-02	1.247E-04	5.58588E-08					x	3.07358E-06			1943.17	1.9432
Pre-Irradiation	BW2-01	25.371	25.364	25.363	25.363	12.742	12.742	12.741	12.738	12.743	12.739	12.742	12.741	3.239	3.239	3.239	3.239	5.9707	2.537E-02	1.274E-02	1.275E-04	5.43984E-08	3.17958E-06	-1.35141E-07	-4.250						1877.83	1.8778
Post-Irradiation		24.611	24.630	24.631	24.614	12.669	12.654	12.654	12.660	12.672	12.659	12.656	12.662	3.254	3.266	3.275	3.265	5.96975	2.462E-02	1.266E-02	1.259E-04	5.5298E-08	3.04444E-06			x					1960.87	1.9609
Pre-Irradiation	BW2-03	25.362	25.370	25.359	25.364	12.730	12.733	12.734	12.732	12.730	12.732	12.736	12.732	3.241	3.244	3.244	3.241	5.9744	2.536E-02	1.273E-02	1.273E-04	5.45264E-08						3.1749E-06	-1.25645E-07	-3.957	1881.76	1.8818
Post-Irradiation		25.058	25.056	25.052	25.056	12.557	12.567	12.566	12.563	12.558	12.564	12.561	12.563	3.298	3.293	3.288	3.298	5.97338	2.506E-02	1.256E-02	1.239E-04	5.62918E-08					x	3.04925E-06			1958.97	1.9590
LOAD CHANGE																																
Pre-Irradiation	BW5-01	25.366	25.363	25.362	25.364	12.738	12.741	12.739	12.730	12.739	12.741	12.742	12.730	3.246	3.249	3.246	3.249	5.9693	2.536E-02	1.274E-02	1.274E-04	5.46974E-08	3.17738E-06	-1.03425E-07	-3.255						1878.68	1.8787
Post-Irradiation		24.723	24.724	24.731	24.745	12.691	12.685	12.690	12.696	12.699	12.690	12.691	12.700	3.260	3.272	3.260	3.268	5.96794	2.473E-02	1.269E-02	1.265E-04	5.52871E-08	3.07396E-06			x					1941.45	1.9415
Pre-Irradiation	BW7-01	25.371	25.370	25.366	25.370	12.739	12.737	12.738	12.737	12.739	12.738	12.738	12.737	3.246	3.246	3.228	3.228	5.9624	2.537E-02	1.274E-02	1.274E-04	5.43561E-08						3.17854E-06	-8.6211E-08	-2.712	1875.83	1.8758
Post-Irradiation		25.153	25.153	25.153	25.152	12.618	12.622	12.622	12.628	12.623	12.624	12.624	12.629	3.266	3.268	3.293	3.293	5.96184	2.515E-02	1.262E-02	1.252E-04	5.58055E-08					x	3.09233E-06			1927.95	1.9279
Pre-Irradiation	BW3-03	25.364	25.371	25.368	25.368	12.734	12.742	12.741	12.746	12.733	12.743	12.742	12.748	3.251	3.251	3.241	3.241	5.9714	2.537E-02	1.274E-02	1.275E-04	5.46548E-08	3.17972E-06	-1.18985E-07	-3.742						1877.96	1.8780
Post-Irradiation		24.639	24.641	24.638	24.633	12.689	12.687	12.684	12.702	12.689	12.688	12.680	12.699	3.260	3.269	3.260	3.268	5.97072	2.464E-02	1.269E-02	1.265E-04	5.52657E-08	3.06074E-06			x					1950.74	1.9507
Pre-Irradiation	BW5-03	25.364	25.362	25.368	25.367	12.739	12.738	12.741	12.737	12.739	12.739	12.738	12.737	3.241	3.244	3.239	3.241	5.9704	2.537E-02	1.274E-02	1.274E-04	5.44837E-08						3.17829E-06	-1.08355E-07	-3.409	1878.50	1.8785
Post-Irradiation		25.100	25.100	25.097	25.094	12.587	12.595	12.598	12.593	12.589	12.591	12.594	12.597	3.274	3.293	3.287	3.293	5.96579	2.510E-02	1.259E-02	1.246E-04	5.60315E-08					x	3.06993E-06			1943.30	1.9433
Pre-Irradiation	BW11-01	25.373	25.371	25.375	25.373	12.739	12.742	12.738	12.739	12.738	12.741	12.738	12.742	3.246	3.246	3.239	3.239	5.9612	2.537E-02	1.274E-02	1.275E-04	5.45265E-08	3.17977E-06	-1.42205E-07	-4.472						1874.72	1.8747
Post-Irradiation		24.647	24.647	24.652	24.654	12.590	12.591	12.594	12.592	12.698	12.684	12.682	12.682	3.265	3.259	3.256	3.259	5.96049	2.465E-02	1.264E-02	1.255E-04	5.51153E-08	3.03757E-06			x					1962.26	1.9623
Pre-Irradiation	BW12-01	25.372	25.368	25.371	25.372	12.737	12.743	12.742	12.736	12.738	12.741	12.741	12.738	3.241	3.241	3.241	3.241	5.9644	2.537E-02	1.274E-02	1.275E-04	5.44837E-08						3.17937E-06	-1.03179E-07	-3.245	1875.97	1.8760
Post-Irradiation		25.108	25.107	25.103	25.105	12.598	12.606	12.604	12.606	12.600	12.608	12.610	12.602	3.298	3.298	3.299	3.289	5.96324	2.511E-02	1.260E-02	1.248E-04	5.63569E-08					x	3.07619E-06			1938.51	1.9385
Pre-Irradiation	BW10-03	25.377	25.373	25.377	25.377	12.737	12.729	12.734	12.739	12.733	12.728	12.734	12.738	3.244	3.244	3.236	3.236	5.9708	2.538E-02	1.273E-02	1.274E-04	5.44411E-08	3.17744E-06	-1.26438E-07	-3.979						1879.12	1.8791
Post-Irradiation		24.560	24.565	24.578	24.564	12.700	12.680	12.678	12.683	12.704	12.681	12.685	12.691	3.246	3.260	3.265	3.259	5.96974	2.457E-02	1.269E-02	1.264E-04	5.50402E-08	3.05101E-06			x					1956.65	1.9566
Pre-Irradiation	BW11-03		Not returned by INL											INL Means					2.54E-02	1.27E-02												
Post-Irradiation																			2.51E-02	1.26E-02							x					

Table 21 Dimensional change, the creep strain, the specimen loading details, and the irradiation conditions (dose and temperature) for grade NBG-18

Specimen Number	I.D. Number	Companion Specimen Number	Companion Specimen I.D. Number	Dimensional Change, ΔDIM = IRR-UNIRR L (mm)	$\Delta L/L_0$(%)	D (mm)	$\Delta D/D_0$(%)	Specimen Type Creep	Control	Load Details Load lbf	Stress ksi	Stress MPa	Creep Strain (creep-control) Longitudanal (mm)	Longitudanal %	Lateral (mm)	Lateral %	Irradiation Conditions ID No.	Temp °C	Dose DPA	channel
BL7-01	4S7	BL7-02	5S5	-0.415	-1.636	-0.01705	-0.13381	x		558	2.82	19.47	-0.268	-1.06	0.049518	0.39	4S7	559	3.96	S6
BL7-02	5S5	BL7-01	4S7	-0.147	-0.579	-0.06657	-0.52258		x	0	0	0					5S2	505	3.39	U6
BL6-03	3S12	BL6-02	2S12	-0.834	-3.289	-0.03863	-0.30322	x		565	2.86	19.72	-0.526	-2.07	0.124589	0.98	3S12	714	6.76	S3
BL6-02	2S12	BL6-03	3S12	-0.309	-1.216	-0.16322	-1.28158		x	0	0	0					2S12	678	6.56	U3
BW7-03	4S14	BW8-03	4U13	-0.299	-1.180	-0.02699	-0.21194	x		359	1.82	12.54	-0.158	-0.62	0.041414	0.33	4S14	603	3.76	S4
BW8-03	4U13	BW7-03	4S14	-0.141	-0.556	-0.0684	-0.53706		x	0	0	0					4U13	509	3.24	U4
BW12-02	SPARE 1W	BW1-02	1U1	-0.329	-1.296	-0.03404	-0.26718	x		377	1.91	13.15	-0.182	-0.72	0.033348	0.26	BW12-02	597	3.93	S1
BW1-02	1U1	BW12-02	SPARE 1W	-0.147	-0.581	-0.06739	-0.52884		x	0	0	0					1U1	504	3.41	U1
BW12-03	SPARE 2W	BW8-02	4U7	-0.574	-2.262	-0.05625	-0.44135	x		359	1.82	12.52	-0.376	-1.48	0.049725	0.39	BW12-03	675	5.76	S4
BW8-02	4U7	BW12-03	SPARE 2W	-0.198	-0.780	-0.10598	-0.8321		x	0	0	0					4U7	599	5.22	U4
BW7-02	4S5	BW8-01	4U5	-0.587	-2.312	-0.07487	-0.58771	x		359	1.82	12.53	-0.303	-1.20	0.072129	0.57	4S5	698	6.3	S4
BW8-01	4U5	BW7-02	4S5	-0.283	-1.116	-0.147	-1.15405		x	0	0	0					4U5	658	5.95	U4
BW3-02	3S2	BW5-02	3U3	-0.586	-2.311	-0.10428	-0.81918	x		377	1.91	13.18	-0.301	-1.19	0.04466	0.35	3S2	671	6.19	S1
BW5-02	3U2	BW3-02	3S2	-0.286	-1.126	-0.14894	-1.16908		x	0	0	0					3U2	611	5.72	U1
BW1-01	1S4	BW1-03	1U4	-0.649	-2.559	-0.09572	-0.75149	x		377	1.91	13.16	-0.344	-1.35	0.06217	0.49	1S4	700	6.63	S1
BW1-03	1U4	BW1-01	1S4	-0.306	-1.205	-0.15789	-1.24004		x	0	0	0					1U4	664	6.34	U1
BW9-03	5U5	BW11-02	6U3	-0.366	-1.442	-0.02197	-0.17262	x		467	2.37	16.33	-0.227	-0.90	0.043224	0.34	5U5	599	3.95	S2
BW11-02	6U3	BW9-03	5U5	-0.138	-0.546	-0.06519	-0.51179		x	0	0	0					6U3	505	3.41	U2
BW9-02	5S15	BW10-02	5U14	-0.578	-2.280	-0.04404	-0.34608	x		474	2.40	16.57	-0.347	-1.37	0.059847	0.47	5S15	668	5.62	S5
BW10-02	5U14	BW9-02	5S15	-0.232	-0.913	-0.10389	-0.81619		x	0	0	0					5U14	585	5.01	U5
BW2-02	2S11	BW3-01	2U11	-0.600	-2.367	-0.07994	-0.6274	x		467	2.36	16.29	-0.349	-1.38	0.049557	0.39	2S11	665	5.76	S2
BW3-01	2U11	BW2-02	2S11	-0.251	-0.991	-0.1295	-1.01635		x	0	0	0					2U11	582	5.15	U2
BW9-01	5S8	BW10-01	5U8	-0.656	-2.586	-0.04296	-0.33733	x		474	2.40	16.55	-0.377	-1.49	0.098431	0.77	5S8	686	6.28	S5
BW10-01	5U8	BW9-01	5S8	-0.279	-1.099	-0.14139	-1.10976		x	0	0	0					5U8	638	5.85	U5
BW2-01	2S2	BW2-03	2U2	-0.744	-2.933	-0.08021	-0.62952	x		467	2.36	16.29	-0.436	-1.72	0.089802	0.70	2S2	709	6.8	S5
BW2-03	2U2	BW2-01	2S2	-0.308	-1.216	-0.17001	-1.33526		x	0	0	0					2U2	675	6.55	U5
BW5-01	3S14	BW7-01	3U13	-0.633	-2.496	-0.04487	-0.35229	x		565	2.86	19.72	-0.417	-1.64	0.06933	0.54	3S14	656	5.38	S3
BW7-01	3U13	BW5-01	3S14	-0.216	-0.852	-0.1142	-0.89656		x	0	0	0					3U13	585	4.66	U3
BW3-03	3S11	BW5-03	3U11	-0.730	-2.878	-0.05137	-0.40315	x		565	2.86	19.71	-0.463	-1.82	0.094223	0.74	3S11	678	6.13	S3
BW5-03	3U11	BW3-03	3S11	-0.268	-1.055	-0.14559	-1.1429		x	0	0	0					3U11	617	5.63	U3
BW11-01	6S13	BW12-01	6U12	-0.723	-2.850	-0.10056	-0.78936	x		558	2.82	19.47	-0.458	-1.80	0.034557	0.27	6S13	674	6.21	S6
BW12-01	6U12	BW11-01	6S13	-0.265	-1.045	-0.13512	-1.06065		x	0	0	0					6U12	613	5.72	U6
BW10-03	6S6	BW11-03	6U6	-0.809	-3.190	-0.04638	-0.36423	x		558	2.83	19.49	-0.514	-2.03	0.103519	0.81	6S6	709	6.76	S6
BW11-03	6U6	BW10-03	6S6	-0.295	-1.163	-0.1499	-1.17707		x	0	0	0					6U6	674	6.51	U6

3.3. Grade H-451 (Code C)

Table 22 Specimen dimensions, mass, bulk density, and volume change for grade H-451

	Specimen Number	Thickness Measurements, mm. T1	T2	T3	T4	Outside Diameter Measurements,mm. D1	D2	D3	D4	$D1^{90}$	$D2^{90}$	$D3^{90}$	$D4^{90}$	Hole Diameter ,mm. H1	H2	H1'	H2'	Weight g	Means Thickness m	Means Diameter m	Means Cross-section m^2	2- hole Volume m^3	Creep specimens Volume m^3	Creep specimens Volume Change m^3	Creep specimens Volume Change (ΔV/Vo),%	Specimen Type Creep	Specimen Type Control	Control specimens Volume m3	Control specimens Volume Change m3	Control specimens Volume Change (ΔV/Vo),%	Density kg/m^3	Density g/cm^3
Pre-Irradiation	CW11-01	25.357	25.357	25.357	25.368	12.717	12.719	12.720	12.722	12.722	12.715	12.715	12.709	3.246	3.246	3.249	3.254	5.4335	2.536E-02	1.272E-02	1.270E-04	5.47402E-08	3.167E-06	-9.66626E-08	-3.053	x					1715.93	1.7159
Post-Irradiation		24.781	24.790	24.790	24.801	12.675	12.676	12.676	12.670	12.665	12.665	12.664	12.663	3.266	3.274	3.261	3.265	5.43215	2.479E-02	1.267E-02	1.261E-04	5.53518E-08	3.07E-06								1769.52	1.7695
Pre-Irradiation	CW12-01	not returned from INL																	2.537E-02	1.274E-02							x					
Post-Irradiation																			2.511E-02	1.263E-02												
Pre-Irradiation	CW11-02	25.364	25.354	25.362	25.367	12.727	12.733	12.733	12.729	12.734	12.730	12.729	12.724	3.249	3.249	3.254	3.256	5.4356	2.536E-02	1.273E-02	1.273E-04	5.48473E-08				x					1713.01	1.7130
Post-Irradiation		24.798	24.811	24.797	24.791	12.685	12.686	12.684	12.684	12.674	12.679	12.680	12.683	3.278	3.265	3.259	3.269	5.43396	2.480E-02	1.268E-02	1.263E-04	5.5384E-08	3.077E-06	-3.07715E-06	-100.000						1765.90	1.7659
																							0									
Pre-Irradiation	CW12-01	Not returned from INL				Not Returned by INL													2.54E-02	1.274E-02							x					
Post-Irradiation																			2.51E-02	1.263E-02												
Pre-Irradiation	CW7-03	25.361	25.358	25.363	25.366	12.718	12.725	12.720	12.718	12.719	12.727	12.723	12.725	3.244	3.244	3.236	3.233	5.4328	2.536E-02	1.272E-02	1.271E-04	5.44198E-08	3.169E-06	-1.15244E-07	-3.636	x					1714.12	1.7141
Post-Irradiation		24.704	24.692	24.718	24.715	12.669	12.658	12.666	12.654	12.648	12.657	12.660	12.651	3.236	3.250	3.261	3.268	5.4316	2.471E-02	1.266E-02	1.258E-04	5.4912E-08	3.054E-06								1778.40	1.7784
Pre-Irradiation	CW8-03	25.344	25.370	25.363	25.362	12.720	12.725	12.723	12.723	12.728	12.728	12.724	12.720	3.251	3.254	3.246	3.246	5.4286	2.536E-02	1.272E-02	1.272E-04	5.47617E-08					x	3.16987E-06	-9.71149E-08	-3.064	1712.56	1.7126
Post-Irradiation		25.045	25.052	25.050	25.045	12.598	12.609	12.616	12.615	12.605	12.616	12.615	12.623	3.302	3.308	3.289	3.302	5.42704	2.505E-02	1.261E-02	1.249E-04	5.64982E-08						3.07275E-06			1766.18	1.7662
Pre-Irradiation	CW7-01	25.348	25.373	25.361	25.339	12.713	12.709	12.709	12.711	12.718	12.717	12.717	12.713	3.251	3.251	3.256	3.259	5.4271	2.536E-02	1.271E-02	1.269E-04	5.4933E-08	3.164E-06	-1.59664E-07	-5.047	x					1715.45	1.7154
Post-Irradiation		24.398	24.409	24.410	24.433	12.630	12.632	12.631	12.630	12.629	12.631	12.646	12.634	3.274	3.283	3.298	3.277	5.42503	2.441E-02	1.263E-02	1.253E-04	5.59016E-08	3.004E-06								1805.94	1.8059
Pre-Irradiation	CW8-02	25.361	25.368	25.340	25.367	12.719	12.725	12.722	12.711	12.715	12.724	12.718	12.722	3.251	3.249	3.256	3.254	5.4300	2.536E-02	1.272E-02	1.271E-04	5.48687E-08					x	3.16743E-06	-1.38046E-07	-4.358	1714.32	1.7143
Post-Irradiation		24.894	24.899	24.892	24.902	12.557	12.563	12.570	12.559	12.561	12.566	12.565	12.554	3.301	3.293	3.293	3.284	5.42857	2.490E-02	1.256E-02	1.239E-04	5.62376E-08						3.02938E-06			1791.97	1.7920
STRESS CHANGE																																
Pre-Irradiation	CW14-01	25.352	25.348	25.347	25.354	12.717	12.723	12.725	12.729	12.729	12.732	12.733	12.736	3.246	3.246	3.241	3.241	5.4557	2.535E-02	1.273E-02	1.272E-04	5.45692E-08	3.171E-06	-9.59281E-08	-3.025	x					1720.57	1.7206
Post-Irradiation		24.737	24.735	24.722	24.736	12.703	12.690	12.687	12.681	12.708	12.695	12.694	12.691	3.244	3.241	3.269	3.268	5.45483	2.473E-02	1.269E-02	1.266E-04	5.4966E-08	3.075E-06								1773.97	1.7740
Pre-Irradiation	CW13-01	25.359	25.357	25.333	25.354	12.727	12.725	12.713	12.723	12.723	12.723	12.710	12.718	3.259	3.256	3.251	3.251	5.4562	2.535E-02	1.272E-02	1.271E-04	5.4933E-08					x	3.16664E-06	-8.2742E-08	-2.613	1723.03	1.7230
Post-Irradiation		25.086	25.099	25.098	25.094	12.614	12.620	12.627	12.623	12.617	12.621	12.627	12.628	3.297	3.298	3.285	3.275	5.45485	2.509E-02	1.262E-02	1.251E-04	5.61078E-08						3.0839E-06			1768.82	1.7688
Pre-Irradiation	CW12-02	25.352	25.367	25.359	25.359	12.703	12.713	12.715	12.715	12.695	12.705	12.708	12.708	3.244	3.246	3.256	3.256	5.4069	2.536E-02	1.271E-02	1.268E-04	5.48046E-08	3.162E-06	-1.07753E-07	-3.408	x					1710.23	1.7102
Post-Irradiation		24.644	24.650	24.646	24.651	12.682	12.673	12.673	12.674	12.678	12.674	12.665	12.664	3.261	3.256	3.260	3.275	5.40484	2.465E-02	1.267E-02	1.261E-04	5.52334E-08	3.054E-06								1769.90	1.7699
Pre-Irradiation	CW13-01	25.359	25.357	25.333	25.354	12.727	12.725	12.713	12.723	12.723	12.723	12.710	12.718	3.259	3.256	3.251	3.251	5.4562	2.535E-02	1.272E-02	1.271E-04	5.4933E-08					x	3.16664E-06	-8.2742E-08	-2.613	1723.03	1.7230
Post-Irradiation		25.086	25.099	25.098	25.094	12.614	12.620	12.627	12.623	12.617	12.621	12.627	12.628	3.297	3.298	3.285	3.275	5.45485	2.509E-02	1.262E-02	1.251E-04	5.61078E-08						3.0839E-06			1768.82	1.7688
Pre-Irradiation	CW9-01	25.368	25.367	25.368	25.368	12.700	12.717	12.723	12.727	12.718	12.720	12.720	12.722	3.259	3.261	3.256	3.251	5.4090	2.537E-02	1.272E-02	1.270E-04	5.50188E-08	3.168E-06	-1.56094E-07	-4.928	x					1707.51	1.7075
Post-Irradiation		24.354	24.377	24.368	24.361	12.675	12.656	12.660	12.642	12.670	12.662	12.658	12.660	3.266	3.274	3.280	3.274	5.40747	2.437E-02	1.266E-02	1.259E-04	5.55888E-08	3.012E-06								1795.50	1.7955
	CW9-02	Not returned, specimen lost in hot cells																									x					
Pre-Irradiation	CW13-02	25.363	25.361	25.352	25.364	12.718	12.725	12.728	12.728	12.720	12.729	12.727	12.727	3.261	3.261	3.246	3.244	5.4695	2.536E-02	1.273E-02	1.272E-04	5.48905E-08	3.17E-06	-1.57279E-07	-4.961	x					1725.16	1.7252
Post-Irradiation		24.344	24.343	24.363	24.347	12.675	12.659	12.666	12.657	12.676	12.668	12.672	12.668	3.266	3.277	3.275	3.283	5.46742	2.435E-02	1.267E-02	1.260E-04	5.56427E-08	3.013E-06								1814.52	1.8145
Pre-Irradiation	CW11-03	Not returned				INL Data for ave dimensions													2.537E-02	1.274E-02							x					
Post-Irradiation																			2.511E-02	1.256E-02												
STRESS CHANGE																																
Pre-Irradiation	CW13-03	25.354	25.364	25.363	25.370	12.722	12.722	12.717	12.715	12.720	12.715	12.714	12.704	3.246	3.246	3.249	3.249	5.4530	2.536E-02	1.272E-02	1.270E-04	5.46974E-08	3.166E-06	-1.3085E-07	-4.133	x					1722.19	1.7222
Post-Irradiation		24.495	24.495	24.490	24.496	12.683	12.665	12.662	12.674	12.673	12.675	12.676	12.693	3.269	3.269	3.259	3.255	5.45086	2.449E-02	1.268E-02	1.262E-04	5.52229E-08	3.035E-06								1795.73	1.7957
Pre-Irradiation	CW14-02	25.353	25.348	25.349	25.353	12.730	12.727	12.722	12.713	12.725	12.725	12.724	12.723	3.241	3.239	3.251	3.249	5.4374	2.535E-02	1.272E-02	1.271E-04	5.4612E-08					x	3.16873E-06	-9.52277E-08	-3.005	1715.96	1.7160
Post-Irradiation		25.047	25.055	25.052	25.056	12.596	12.614	12.621	12.618	12.608	12.611	12.608	12.610	3.287	3.269	3.279	3.265	5.4353	2.505E-02	1.261E-02	1.249E-04	5.56316E-08						3.0735E-06			1768.44	1.7684
Pre-Irradiation	CW10-01	25.366	25.356	25.372	25.363	12.700	12.705	12.711	12.699	12.723	12.719	12.715	12.706	3.254	3.254	3.256	3.259	5.4191	2.536E-02	1.271E-02	1.269E-04	5.49759E-08	3.163E-06	-1.47359E-07	-4.659	x					1713.25	1.7132
Post-Irradiation		24.269	24.295	24.283	24.269	12.689	12.677	12.684	12.687	12.697	12.692	12.692	12.710	3.282	3.282	3.260	3.265	5.41762	2.428E-02	1.269E-02	1.265E-04	5.55353E-08	3.016E-06								1796.47	1.7965
Pre-Irradiation	CW10-03	25.353	25.362	25.358	25.354	12.725	12.724	12.715	12.713	12.725	12.724	12.723	12.710	3.261	3.261	3.259	3.251	5.4368	2.536E-02	1.272E-02	1.271E-04	5.50617E-08					x	3.1672E-06	-1.34962E-07	-4.261	1716.60	1.7166
Post-Irradiation		24.929	24.931	24.933	24.938	12.558	12.569	12.564	12.563	12.551	12.555	12.559	12.562	3.321	3.298	3.316	3.324	5.43593	2.493E-02	1.256E-02	1.239E-04	5.69882E-08						3.03223E-06			1792.72	1.7927
Pre-Irradiation	CW9-03	25.354	25.349	25.354	25.349	12.720	12.732	12.722	12.725	12.717	12.730	12.725	12.720	3.246	3.246	3.254	3.254	5.4137	2.535E-02	1.272E-02	1.272E-04	5.47831E-08	3.169E-06	-1.63911E-07	-5.173	x					1708.42	1.7084
Post-Irradiation		24.120	24.118	24.114	24.113	12.714	12.720	12.709	12.714	12.713	12.708	12.708	12.700	3.278	3.283	3.236	3.255	5.41216	2.412E-02	1.271E-02	1.269E-04	5.52241E-08	3.005E-06								1801.09	1.8011
Pre-Irradiation	CW10-02	25.367	25.359	25.358	25.354	12.713	12.720	12.724	12.720	12.722	12.723	12.724	12.710	3.261	3.261	3.254	3.254	5.4214	2.536E-02	1.272E-02	1.271E-04	5.50403E-08					x	3.16734E-06	-1.40922E-07	-4.449	1711.66	1.7117
Post-Irradiation		24.909	24.903	24.905	24.912	12.563	12.563	12.556	12.550	12.542	12.556	12.561	12.551	3.320	3.325	3.321	3.324	5.41927	2.491E-02	1.256E-02	1.238E-04	5.72507E-08						3.02642E-06			1790.66	1.7907

Table 23 Dimensional change, the creep strain, the specimen loading details, and the irradiation conditions (dose and temperature) for grade H-451

Specimen Number	I.D. Number	Companion Specimen Number	Companion Specimen I.D. Number		Dimensional Change, ΔDIM = IRR-UNIRR: L (mm)	$\Delta L/L_0$ (%)	D (mm)	$\Delta D/D_0$ (%)	Specimen Type: Creep	Specimen Type: Control	Load Details: Load (lbf)	Stress (ksi)	Stress (MPa)	Creep Strain (creep-control): Longitudanal (mm)	Longitudanal %	Lateral (mm)	Lateral %	Irradiation Conditions: ID No.	Temp (°C)	Dose (DPA)	channel
CW11-01	4S2	CW12-01	4U12		-0.569	-2.244	-0.04805	-0.37786	x		359	1.82	12.57					4S2	642	4.91	S4
CW12-01	4U12	CW11-01	4S2		-0.261	-1.030	-0.1131	-0.88782		x	0	0	0	-0.308	-1.21	0.065046	0.51	4U12	568	4.16	U4
CW11-02	4S13	CW12-01	4U12		-0.563	-2.218	-0.04813	-0.37807	x		359	1.82	12.55					4S13	628	4.56	S4
CW12-01	4U12	CW11-02	4S13		-0.261	-1.030	-0.1131	-0.88782		x	0	0	0	-0.301	-1.19	0.064971	0.51	4U12	568	4.16	U4
CW7-03	1S15	CW8-03	1U14		-0.655	-2.581	-0.06403	-0.50332	x		377	1.91	13.19					1S15	649	5.44	S1
CW8-03	1U14	CW7-03	1S15		-0.312	-1.229	-0.11185	-0.87902		x	0	0	0	-0.343	-1.35	0.047814	0.38	1U14	580	4.76	U1
CW7-01	1S8	CW8-02	1U8		-0.943	-3.718	-0.0803	-0.63164	x		377	1.92	13.21					1S8	706	6.84	S1
CW8-02	1U8	CW7-01	1S8		-0.462	-1.823	-0.15765	-1.23944		x	0	0	0	-0.480	-1.89	0.07735	0.61	1U8	674	6.7	U1
CW14-01	6U5	CW13-01	5U7	shared Control	-0.618	-2.436	-0.03432	-0.2696	x		474	2.40	16.57					6U5	627	4.64	S5
														-0.361	-1.42	0.063721	0.50				
CW13-01	5U7	CW14-01	6U5		-0.257	-1.012	-0.09804	-0.77072		x	0	0	0					5U7	567	4.24	U5
CW12-02	5S7	CW 13-01	5U7	shared Control	-0.712	-2.806	-0.03474	-0.27342	x		474	2.41	16.62					5S7	641	5	S5
														-0.455	-1.79	0.063291	0.50				
CW13-01	5U7	CW 12-02	5S7		-0.257	-1.012	-0.09804	-0.77072		x	0	0	0					5U7	567	4.24	U5
CW9-01	2S13	CW9-02	2U12		-1.003	-3.954	-0.05788	-0.4551	x		467	2.37	16.35					2S13	683	6.42	S2
CW9-02	2U12				Not returned from INL					x	0	0	0	Not returned by INL				2U12	635	6	U2
CW13-02	6S5	CW11-03	4U2		-1.011	-3.986	-0.05762	-0.45277	x		467	2.37	16.33					6S5	708	6.92	S2
CW11-03	4U2	CW13-02	6S5		-0.261	-1.030	-0.1843	-1.44662		x	0	0	0	-0.750	-2.96	0.126684	1.00	4U2	677	6.77	U2
CW13-03	6S9	CW14-02	6U9		-0.869	-3.426	-0.04091	-0.32171	x		558	2.83	19.54					6S9	653	5.46	S6
CW14-02	6U9	CW13-03	6S9		-0.298	-1.177	-0.1129	-0.88735		x	0	0	0	-0.571	-2.25	0.071995	0.57	6U9	582	4.74	U6
CW10-01	3S10	CW10-03	3U10		-1.085	-4.278	-0.01884	-0.14825	x		565	2.87	19.81					3S10	697	6.47	S3
CW10-03	3U10	CW10-01	3S10		-0.424	-1.672	-0.15988	-1.2569		x	0	0	0	-0.661	-2.61	0.141035	1.11	3U10	657	6.09	U3
CW9-03	3S1	CW10-02	3U1		-1.235	-4.873	-0.01322	-0.10391	x		565	2.87	19.77					3S1	712	6.81	S3
CW10-02	3U1	CW9-03	3S1		-0.452	-1.784	-0.16428	-1.29153		x	0	0	0	-0.783	-3.09	0.151055	1.19	3U1	681	6.66	U3

3.4 Grade PCEA (D)

Table 24 Specimen dimensions, mass, bulk density, and volume change for grade PCEA

	Specimen	Thickness Measurements, mm.				Outside Diameter Measurements,mm.								Hole Diameter ,mm.				Weight	Means				Creep specimens			Specimen Type		Control specimens			DOSE	Density	Density
	Number	T1	T2	T3	T4	D1	D2	D3	D4	$D1^{90}$	$D2^{90}$	$D3^{90}$	$D4^{90}$	H1	H2	H1'	H2'	g	Thickness m	Diameter m	Cross-section m^2	2- hole Volume m^3	Volume m^3	Volume Change m^3	(ΔV/Vo),%	Creep	Control	Volume m3	Volume Change m3	(ΔV/Vo),%	DPA	kg/m^3	g/cm^3
Pre-Irradiation	DA701	25.391	25.390	25.387	25.389	12.725	12.725	12.728	12.733	12.728	12.728	12.730	12.733	3.198	3.195	3.185	3.185	5.6448	2.539E-02	1.273E-02	1.273E-04	5.28103E-08	3.17807E-06	-9.08312E-08	-2.858						4.17	1776.17	1.7762
Post-Irradiation		24.884	24.887	24.886	24.891	12.689	12.679	12.675	12.671	12.692	12.671	12.668	12.667	3.216	3.222	3.218	3.217	5.6439	2.489E-02	1.268E-02	1.262E-04	5.37178E-08	3.08724E-06			X						1828.14	1.8281
Pre-Irradiation	DA702	25.375	25.372	25.373	25.375	12.751	12.743	12.734	12.730	12.751	12.746	12.736	12.732	3.239	3.226	3.195	3.198	5.7624	2.537E-02	1.274E-02	1.275E-04	5.35923E-08						3.18111E-06	-6.89339E-08	-2.167	3.72	1811.44	1.8114
Post-Irradiation		25.163	25.170	25.171	25.168	12.642	12.651	12.665	12.668	12.644	12.658	12.663	12.669	3.230	3.241	3.266	3.256	5.76233	2.517E-02	1.266E-02	1.258E-04	5.47302E-08					X	3.11218E-06				1851.54	1.8515
Pre-Irradiation	DA602	25.389	25.390	25.390	25.385	12.732	12.727	12.727	12.727	12.736	12.729	12.728	12.728	3.200	3.195	3.198	3.193	5.6454	2.539E-02	1.273E-02	1.273E-04	5.29995E-08	3.17784E-06	-1.7127E-07	-5.389						6.37	1776.49	1.7765
Post-Irradiation		24.522	24.523	24.527	24.523	12.613	12.594	12.591	12.612	12.619	12.600	12.601	12.619	3.242	3.244	3.218	3.235	5.64458	2.452E-02	1.261E-02	1.248E-04	5.42706E-08	3.00657E-06			X						1877.41	1.8774
Pre-Irradiation	DA601	25.387	25.391	25.391	25.389	12.722	12.727	12.729	12.734	12.725	12.727	12.730	12.734	3.195	3.195	3.195	3.195	5.6611	2.539E-02	1.273E-02	1.272E-04	5.29574E-08						3.17781E-06	-1.43944E-07	-4.530	5.96	1781.45	1.7814
Post-Irradiation		24.997	25.002	25.003	25.005	12.538	12.538	12.536	12.531	12.550	12.541	12.542	12.563	3.254	3.258	3.259	3.274	5.65962	2.500E-02	1.254E-02	1.236E-04	5.51583E-08					X	3.03386E-06				1865.48	1.8655
ORIENTATION CHANGE																																	
Pre-Irradiation	DW1-03	25.382	25.383	25.383	25.383	12.715	12.724	12.730	12.736	12.719	12.728	12.728	12.739	3.205	3.211	3.200	3.195	5.7604	2.538E-02	1.273E-02	1.272E-04	5.32104E-08	3.17618E-06	-8.91086E-08	-2.806						4.36	1813.62	1.8136
Post-Irradiation		24.912	24.902	24.901	24.902	12.688	12.674	12.665	12.657	12.693	12.672	12.668	12.659	3.230	3.226	3.218	3.213	5.75981	2.490E-02	1.267E-02	1.261E-04	5.38347E-08	3.08707E-06			X						1865.78	1.8658
Pre-Irradiation	DW2-03	25.375	25.376	25.376	25.375	12.737	12.728	12.727	12.724	12.737	12.725	12.722	12.719	3.198	3.200	3.195	3.195	5.7447	2.538E-02	1.273E-02	1.272E-04	5.30206E-08						3.17528E-06	-7.81407E-08	-2.461	3.91	1809.19	1.8092
Post-Irradiation		25.136	25.140	25.139	25.138	12.621	12.630	12.635	12.652	12.616	12.629	12.644	12.646	3.233	3.239	3.235	3.242	5.74467	2.514E-02	1.263E-02	1.254E-04	5.43557E-08					X	3.09714E-06				1854.83	1.8548
Pre-Irradiation	DW6-02	25.377	25.377	25.378	25.378	12.741	12.734	12.727	12.723	12.743	12.736	12.728	12.724	3.200	3.200	3.205	3.195	5.7631	2.538E-02	1.273E-02	1.273E-04	5.31259E-08	3.17783E-06	-1.42792E-07	-4.493						5.97	1813.53	1.8135
Post-Irradiation		24.644	24.646	24.651	24.645	12.628	12.617	12.623	12.635	12.643	12.625	12.633	12.657	3.226	3.230	3.218	3.241	5.76255	2.465E-02	1.263E-02	1.253E-04	5.40679E-08	3.03504E-06			X						1898.67	1.8987
Pre-Irradiation	DW7-02	25.380	25.378	25.380	25.380	12.724	12.728	12.732	12.738	12.724	12.724	12.730	12.741	3.200	3.198	3.203	3.195	5.7628	2.538E-02	1.273E-02	1.273E-04	5.30837E-08						3.17719E-06	-1.13996E-07	-3.588	5.5	1813.80	1.8138
Post-Irradiation		25.026	25.061	25.077	25.061	12.592	12.587	12.585	12.580	12.595	12.589	12.587	12.583	3.244	3.269	3.233	3.250	5.76287	2.506E-02	1.259E-02	1.244E-04	5.47506E-08					X	3.0632E-06				1881.33	1.8813
Pre-Irradiation	DW6-03	25.376	25.377	25.377	25.378	12.746	12.741	12.733	12.725	12.746	12.741	12.733	12.725	3.195	3.198	3.198	3.195	5.7397	2.538E-02	1.274E-02	1.274E-04	5.29995E-08	3.18006E-06	-1.6787E-07	-5.279						6.52	1804.91	1.8049
Post-Irradiation		24.503	24.510	24.515	24.506	12.622	12.606	12.606	12.625	12.618	12.608	12.620	12.665	3.237	3.216	3.230	3.236	5.73902	2.451E-02	1.262E-02	1.251E-04	5.40998E-08	3.01219E-06			X						1905.27	1.9053
Pre-Irradiation	DW7-01	25.378	25.381	25.380	25.377	12.723	12.728	12.733	12.742	12.724	12.724	12.734	12.742	3.205	3.203	3.200	3.200	5.7650	2.538E-02	1.273E-02	1.273E-04	5.31892E-08						3.17761E-06	-1.53883E-07	-4.843	6.27	1814.26	1.8143
Post-Irradiation		24.926	24.928	24.940	24.934	12.554	12.550	12.535	12.537	12.546	12.537	12.532	12.525	3.265	3.261	3.283	3.247	5.7644	2.493E-02	1.254E-02	1.235E-04	5.52649E-08					X	3.02373E-06				1906.39	1.9064
Pre-Irradiation	DW1-01	25.383	25.383	25.385	25.386	12.719	12.723	12.729	12.737	12.719	12.723	12.728	12.733	3.203	3.205	3.200	3.200	5.7468	2.538E-02	1.273E-02	1.272E-04	5.31892E-08	3.1758E-06	-1.82111E-07	-5.734						6.73	1809.56	1.8096
Post-Irradiation		24.478	24.485	24.487	24.487	12.601	12.586	12.578	12.574	12.617	12.591	12.582	12.589	3.239	3.233	3.237	3.232	5.7457	2.448E-02	1.259E-02	1.245E-04	5.42917E-08	2.99369E-06			X						1919.27	1.9193
Pre-Irradiation	DW2-01	25.377	25.377	25.376	25.376	12.719	12.722	12.727	12.733	12.719	12.723	12.729	12.737	3.195	3.195	3.203	3.198	5.7565	2.538E-02	1.273E-02	1.272E-04	5.30416E-08						3.17478E-06	-1.64033E-07	-5.167	6.49	1813.20	1.8132
Post-Irradiation		24.893	24.894	24.890	24.882	12.529	12.520	12.517	12.512	12.534	12.533	12.523	12.517	3.246	3.260	3.260	3.260	5.75572	2.489E-02	1.252E-02	1.232E-04	5.5008E-08					X	3.01074E-06				1911.73	1.9117
STRESS LEVEL CHANGE																																	
Pre-Irradiation	DW8-02	25.381	25.382	25.381	25.382	12.722	12.725	12.734	12.744	12.725	12.728	12.736	12.747	3.195	3.198	3.198	3.195	5.7745	2.538E-02	1.273E-02	1.273E-04	5.29995E-08	3.17885E-06	-8.99573E-08	-2.830						4.25	1816.54	1.8165
Post-Irradiation		24.836	24.850	24.845	24.855	12.707	12.694	12.683	12.678	12.715	12.695	12.681	12.672	3.226	3.219	3.213	3.242	5.77386	2.485E-02	1.269E-02	1.265E-04	5.39507E-08	3.08889E-06			X						1869.23	1.8692
Pre-Irradiation	DW9-02	Not retuurned by INL				Using INL mean dim data													2.539E-02	1.273E-02											3.8		
Post-Irradiation																			2.517E-02	1.264E-02							X						
Pre-Irradiation	DW3-03	25.378	25.378	25.378	25.377	12.717	12.723	12.728	12.738	12.719	12.722	12.729	12.738	3.205	3.195	3.205	3.200	5.7625	2.538E-02	1.273E-02	1.272E-04	5.3168E-08	3.17517E-06	-9.47273E-08	-2.983						4.38	1814.86	1.8149
Post-Irradiation		24.813	24.811	24.818	24.808	12.705	12.686	12.677	12.673	12.701	12.681	12.670	12.666	3.223	3.226	3.227	3.232	5.76176	2.481E-02	1.268E-02	1.263E-04	5.40151E-08	3.08045E-06			X						1870.43	1.8704
Pre-Irradiation	DW5-01	25.382	25.382	25.383	25.382	12.713	12.720	12.723	12.734	12.720	12.722	12.728	12.736	3.198	3.203	3.200	3.195	5.6963	2.538E-02	1.272E-02	1.272E-04	5.30837E-08						3.1747E-06	-7.83845E-08	-2.469	3.91	1794.28	1.7943
Post-Irradiation		25.146	25.155	25.156	25.152	12.634	12.630	12.626	12.623	12.638	12.629	12.627	12.626	3.239	3.241	3.244	3.236	5.69586	2.515E-02	1.263E-02	1.253E-04	5.4441E-08					X	3.09631E-06				1839.56	1.8396
Pre-Irradiation	DW8-01	25.381	25.382	25.382	25.382	12.722	12.728	12.733	12.743	12.724	12.729	12.733	12.742	3.205	3.203	3.198	3.193	5.7662	2.538E-02	1.273E-02	1.273E-04	5.31049E-08	3.1783E-06	-1.40275E-07	-4.414						5.87	1814.24	1.8142
Post-Irradiation		24.564	24.580	24.586	24.574	12.684	12.656	12.641	12.657	12.674	12.650	12.639	12.650	3.226	3.209	3.227	3.226	5.76539	2.458E-02	1.266E-02	1.258E-04	5.3845E-08	3.03803E-06			X						1897.74	1.8977
Pre-Irradiation	DW9-01	25.385	25.385	25.383	25.385	12.728	12.730	12.734	12.746	12.728	12.730	12.734	12.743	3.200	3.200	3.198	3.198	5.7479	2.538E-02	1.273E-02	1.274E-04	5.30838E-08						3.17993E-06	-1.17448E-07	-3.693	5.33	1807.55	1.8076
Post-Irradiation		25.038	25.052	25.056	25.045	12.596	12.583	12.584	12.583	12.598	12.592	12.585	12.584	3.250	3.246	3.250	3.260	5.74695	2.505E-02	1.259E-02	1.245E-04	5.48365E-08					X	3.06249E-06				1876.56	1.8766
Pre-Irradiation	DW3-02	25.378	25.378	25.377	25.381	12.739	12.730	12.723	12.718	12.742	12.732	12.724	12.722	3.200	3.195	3.200	3.200	5.7597	2.538E-02	1.273E-02	1.273E-04	5.30838E-08	3.17639E-06	-1.50199E-07	-4.729						6.02	1813.29	1.8133
Post-Irradiation		24.562	24.558	24.560	24.561	12.623	12.629	12.627	12.655	12.643	12.627	12.636	12.655	3.232	3.226	3.236	3.235	5.75979	2.456E-02	1.264E-02	1.254E-04	5.41853E-08	3.02619E-06			X						1903.32	1.9033
Pre-Irradiation	DW4-01	25.389	25.390	25.390	25.391	12.719	12.722	12.730	12.739	12.719	12.719	12.725	12.736	3.205	3.198	3.200	3.200	5.7407	2.539E-02	1.273E-02	1.272E-04	5.3147E-08						3.17645E-06	-1.26965E-07	-3.997	5.47	1807.27	1.8073
Post-Irradiation		25.015	25.016	25.013	25.015	12.578	12.573	12.567	12.565	12.575	12.575	12.566	12.566	3.266	3.260	3.250	3.259	5.74024	2.501E-02	1.257E-02	1.241E-04	5.50832E-08					X	3.04948E-06				1882.37	1.8824
Pre-Irradiation	DW7-03	25.381	25.381	25.382	25.382	12.723	12.728	12.732	12.739	12.724	12.727	12.732	12.743	3.198	3.198	3.203	3.198	5.7567	2.538E-02	1.273E-02	1.273E-04	5.30838E-08	3.17788E-06	-1.69522E-07	-5.334						6.55	1811.49	1.8115
Post-Irradiation		24.422	24.437	24.407	24.417	12.661	12.630	12.623	12.631	12.663	12.636	12.624	12.623	3.227	3.259	3.232	3.222	5.75683	2.442E-02	1.264E-02	1.254E-04	5.42807E-08	3.00836E-06			X						1913.61	1.9136
Pre-Irradiation	DW8-03	25.383	25.382	25.385	25.383	12.742	12.734	12.725	12.727	12.742	12.736	12.732	12.727	3.203	3.198	3.205	3.198	5.7800	2.538E-02	1.273E-02	1.273E-04	5.3147E-08						3.1791E-06	-1.52009E-07	-4.781	6.24	1818.12	1.8181
Post-Irradiation		24.929	24.939	24.952	24.942	12.532	12.538	12.547	12.554	12.530	12.543	12.551	12.557	3.274	3.249	3.250	3.272	5.77973	2.494E-02	1.254E-02	1.236E-04	5.51576E-08					X	3.0271E-06				1909.33	1.9093
Pre-Irradiation	DW3-01	25.380	25.380	25.377	25.378	12.719	12.722	12.730	12.736	12.717	12.722	12.727	12.730	3.228	3.228	3.233	3.231	5.7568	2.538E-02	1.273E-02	1.272E-04	5.41214E-08	3.17358E-06	-1.84085E-07	-5.801						6.8	1813.98	1.8140
Post-Irradiation		24.340	24.364	24.371	24.363	12.649	12.609	12.604	12.608	12.642	12.611	12.596	12.604	3.261	3.258	3.275	3.269	5.75586	2.436E-02	1.262E-02	1.250E-04	5.53197E-08	2.98949E-06			X						1925.36	1.9254
Pre-Irradiation	DW4-03	25.382	25.383	25.383	25.383	12.718	12.719	12.725	12.733	12.715	12.718	12.720	12.730	3.205	3.203	3.205	3.198	5.7429	2.538E-02	1.272E-02	1.271E-04	5.32102E-08						3.1736E-06	-1.69496E-07	-5.341	6.68	1809.58	1.8096
Post-Irradiation		24.886	24.882	24.880	24.882	12.526	12.512	12.510	12.509	12.524	12.512	12.505	12.501	3.275	3.268	3.265	3.275	5.74246	2.488E-02	1.251E-02	1.230E-04	5.54917E-08					X	3.00411E-06				1911.54	1.9115
STRESS LEVEL CHANGE																																	
Pre-Irradiation	DW10-01	25.383	25.385	25.385	25.383	12.718	12.717	12.717	12.724	12.715	12.717	12.715	12.722	3.193	3.203	3.200	3.203	5.7473	2.538E-02	1.272E-02	1.270E-04	5.31048E-08	3.17157E-06	-9.92906E-08	-3.131						4.39	1812.13	1.8121
Post-Irradiation		24.753	24.753	24.752	24.764	12.699	12.675	12.675	12.671	12.694	12.677	12.672	12.678	3.218	3.219	3.231	3.222	5.74659	2.476E-02	1.268E-02	1.263E-04	5.38664E-08	3.07228E-06			X						1870.46	1.8705
Pre-Irradiation	DW10-02	25.382	25.385	25.387	25.382	12.717	12.715	12.718	12.723	12.717	12.714	12.717	12.720	3.200	3.198	3.200	3.200	5.7395	2.538E-02	1.272E-02	1.270E-04	5.31048E-08						3.17133E-06	-7.65821E-08	-2.415	3.88	1809.81	1.8098
Post-Irradiation		25.156	25.159	25.160	25.163	12.622	12.619	12.621	12.627	12.626	12.625	12.627	12.629	3.251	3.249	3.236	3.242	5.73852	2.516E-02	1.262E-02	1.252E-04	5.46013E-08					X	3.09475E-06				1854.28	1.8543
Pre-Irradiation	DW5-02	25.381	25.381	25.378	25.382	12.718	12.723	12.723	12.737	12.723	12.725	12.729	12.738	3.203	3.200	3.198	3.198	5.7316	2.538E-02	1.273E-02	1.272E-04	5.31049E-08	3.17572E-06	-1.44979E-07	-4.565						5.66	1804.82	1.8048
Post-Irradiation		24.465	24.463	24.475	24.478	12.697	12.665	12.660	12.649	12.693	12.668	12.655	12.664	3.211	3.232	3.218	3.235	5.73131	2.447E-02	1.267E-02	1.261E-04	5.39084E-08	3.03074E-06			X						1891.06	1.8911
Pre-Irradiation	DW6-01	25.381	25.380	25.381	25.381	12.720	12.722	12.728	12.739	12.724	12.725	12.734	12.743	3.203	3.198	3.195	3.200	5.7612	2.538E-02	1.273E-02	1.273E-04	5.30837E-08						3.17703E-06	-1.04558E-07	-3.291	5.02	1813.39	1.8134
Post-Irradiation		25.088	25.095	25.080	25.078	12.604	12.603	12.590	12.592	12.607	12.608	12.597	12.591	3.273	3.265	3.232	3.245	5.76032	2.509E-02	1.260E-02	1.247E-04	5.49126E-08					X	3.07247E-06				1874.81	1.8748
Pre-Irradiation	DW11-01	25.383	25.385	25.383	25.385	12.724	12.715	12.717	12.715	12.724	12.717	12.717	12.717	3.195	3.198	3.195	3.195	5.7456	2.538E-02	1.272E-02	1.270E-04	5.29785E-08	3.17178E-06	-1.66141E-07	-5.238						6.32	1811.47	1.8115
Post-Irradiation		24.339	24.357	24.352	24.359	12.652	12.626	12.625	12.664	12.668	12.643	12.643	12.673	3.232	3.255	3.237	3.250	5.74273	2.435E-02	1.265E-02	1.257E-04	5.45687E-08	3.00564E-06			X						1910.65	1.9107
Pre-Irradiation	DW5-03	25.381	25.380	25.380	25.382	12.722	12.724	12.730	12.744	12.722	12.725	12.729	12.743	3.200	3.200	3.200	3.200	5.7596	2.538E-02	1.273E-02	1.273E-04	5.31259E-08						3.17723E-06	-1.39475E-07	-4.390	5.88	1812.77	1.8128
Post-Irradiation		24.988	25.003	24.995	24.984	12.561	12.550	12.544	12.546	12.561	12.556	12.554	12.542	3.244	3.251	3.251	3.249	5.75881	2.499E-02	1.255E-02	1.237E-04	5.47402E-08					X	3.03776E-06				1895.74	1.8957
Pre-Irradiation	DW1-02	25.382	25.382	25.383	25.381	12.719	12.725	12.729	12.736	12.719	12.723	12.730	12.734	3.200	3.198	3.205	3.198	5.7516	2.538E-02	1.273E-02	1.272E-04	5.31259E-08	3.1759E-06	-1.73369E-07	-5.459						6.39	1811.01	1.8110
Post-Irradiation		24.347	24.350	24.356	24.368	12.637	12.640	12.636	12.638	12.674	12.637	12.627	12.639	3.227	3.218	3.250	3.226	5.75084	2.436E-02	1.264E-02	1.255E-04	5.41213E-08	3.00253E-06			X						1915.33	1.9153
Pre-Irradiation	DW2-02	25.376	25.375	25.376	25.377	12.723	12.725	12.727	12.736	12.718	12.723	12.730	12.738	3.200	3.198	3.203	3.198	5.7443	2.538E-02	1.273E-02	1.272E-04	5.31048E-08						3.17536E-06	-1.43996E-07	-4.535	5.96	1809.02	1.8090
Post-Irradiation		24.956	24.958	24.961	24.957	12.560	12.553	12.545	12.546	12.556	12.546	12.537	12.538	3.261	3.256	3.242	3.246	5.74423	2.496E-02	1.255E-02	1.237E-04	5.48368E-08					X	3.03136E-06				1894.93	1.8949
Pre-Irradiation	DW9-03	25.385	25.385	25.385	25.385	12.725	12.725	12.724	12.728	12.725	12.723	12.725	12.728	3.195	3.205	3.198	3.195	5.7734	2.538E-02	1.273E-02	1.272E-04	5.30626E-08	3.17556E-06	-1.83591E-07	-5.781						6.83	1818.07	1.8181
Post-Irradiation		24.312	24.270	24.267	24.261	12.657	12.634	12.628	12.660	12.661	12.621	12.620	12.625	3.207	3.211	3.214	3.227	5.77266	2.428E-02	1.264E-02	1.254E-04	5.36014E-08	2.99197E-06			X						1929.38	1.9294
Pre-Irradiation	DW10-03	NOT RETURNED BY INL				Using INL mean dimesions data													2.539E-02	1.272E-02											6.63		
Post-Irradiation																			2.49E-02	1.25E-02							X						

Table 25 Dimensional change, the creep strain, the specimen loading details, and the irradiation conditions (dose and temperature) for grade PCEA

Specimen Number	I.D.	Companion Specimen Number	Number	Dimensional Change, L (mm)	$\Delta L/L_0$ (%)	D (mm)	$\Delta D/D_0$ (%)	Specimen Type: Creep	Control	Load Details: Load (lbf)	Stress (ksi)	(MPa)	Creep Strain (creep-control): Longitudanal (mm)	%	Lateral (mm)	%	Irradiation Conditions: ID No.	Temp (°C)	Dose (DPA)	channel
				ΔDIM = IRR-UNIRR																
DA701	4S6	DA702	5S11	-0.502	-1.978	-0.0523925	-0.41	X		359	1.82	12.55	-0.297	-1.168	0.030	0.239	4S6	612	4.17	S4
DA702	5S11	DA701	4S6	-0.206	-0.810	-0.0828225	-0.65		X	0	0	0					5S11	538	3.72	U4
DA602	4S1	DA601	3S6	-0.865	-3.405	-0.1229262	-0.97	X		377	1.91	13.18	-0.477	-1.878	0.063	0.497	4S1	680	6.37	S1
DA601	3S6	DA602	4S1	-0.388	-1.527	-0.1862	-1.46		X	0	0	0					3S6	632	5.96	U1
DW1-03	1S14	DW2-03	1U13	-0.479	-1.887	-0.0554637	-0.44	X		377	1.91	13.18	-0.242	-0.953	0.038	0.296	1S14	606	4.36	S1
DW2-03	1U13	DW1-03	1S14	-0.237	-0.934	-0.09318	-0.73		X	0	0	0					1U13	533	3.91	U1
DW6-02	4S15	DW7-02	4U14	-0.731	-2.882	-0.0992837	-0.78	X		359	1.85	12.74	-0.408	-1.608	0.044	0.343	4S15	679	5.97	S4
DW7-02	4U14	DW6-02	4S15	-0.323	-1.273	-0.1429125	-1.12		X	0	0	0					4U14	618	5.5	U4
DW6-03	4U1	DW7-01	4U6	-0.869	-3.423	-0.114945	-0.90	X		359	1.85	12.76	-0.422	-1.661	0.077	0.603	4U1	714	6.52	S4
DW7-01	4U6	DW6-03	4U1	-0.447	-1.761	-0.1917738	-1.51		X	0	0	0	.				4U6	679	6.27	U4
DW1-01	1S2	DW2-01	1U2	-0.900	-3.546	-0.1366025	-1.07	X		377	1.95	13.47	-0.413	-1.629	0.066	0.521	1S2	706	6.73	S1
DW2-01	1U2	DW1-01	1S2	-0.487	-1.918	-0.20291	-1.59		X	0	0	0					1U2	672	6.49	S1
DW8-02	5S12	**DW902**	5U11	-0.535	-2.108	-0.0420775	-0.33	X		474	2.42	16.67	-0.316	-1.245	0.052	0.408	5S12	611	4.25	S5
DW902	5U11	**DW8-02**	5S12	-0.219	-0.863	-0.094	-0.74		X	0	0	0					5Ull	537	3.8	U5
DW3-03	2S14	**DW5-01**	2U13	-0.566	-2.229	-0.044295	-0.35	X		467	2.39	16.44	-0.335	-1.321	0.051	0.401	4S14	609	4.38	S2
DW5-01	2U13	**DW3-03**	2S14	-0.230	-0.907	-0.0953225	-0.75		X	0	0	0					2U13	534	3.91	U2
DW8-01	5S9	**DW9-01**	5U9	-0.806	-3.175	-0.075375	-0.59	X		474	2.43	16.76	-0.469	-1.849	0.071	0.556	5S9	674	5.87	S5
DW9-01	5U9	**DW8-01**	5S9	-0.337	-1.326	-0.146165	-1.15		X	0	0	0					5U9	597	5.33	U5
DW3-02	2S8	**DW4-01**	2U8	-0.818	-3.225	-0.0918587	-0.72	X		467	2.40	16.56	-0.443	-1.747	0.064	0.501	2S8	670	6.02	S2
DW4-01	2U8	**DW3-02**	2S8	-0.375	-1.477	-0.1555688	-1.22		X	0	0	0					2U8	594	5.47	U2
DW7-03	5S4	**DW8-03**	5U4	-0.961	-3.786	-0.0945812	-0.74	X		474	2.44	16.81	-0.518	-2.040	0.094	0.742	5S4	706	6.55	S5
DW8-03	5U4	**DW7-03**	5S4	-0.443	-1.745	-0.18902	-1.48		X	0	0	0					5U4	670	6.24	U5
DW3-01	2S1	**DW4-03**	2U1	-1.019	-4.016	-0.1098663	-0.86	X		467	2.41	16.62	-0.519	-2.043	0.100	0.787	2S1	711	6.8	S2
DW4-03	2U1	**DW3-01**	2S1	-0.501	-1.972	-0.2100087	-1.65		X	0	0	0					2U1	674	6.68	U2
DW10-01	6S11	**DW10-02**	6U11	-0.629	-2.476	-0.0378137	-0.30	X		558	2.85	19.66	-0.404	-1.592	0.055	0.434	6S11	610	4.39	S6
DW10-02	6U11	**DW10-01**	6S11	-0.225	-0.885	-0.0929625	-0.73		X	0	0	0					6U11	534	3.88	U6
DW5-02	3S15	**DW6-01**	3U14	-0.910	-3.587	-0.0581125	-0.46	X		565	2.89	19.94	-0.615	-2.423	0.072	0.569	3S15	669	5.66	S3
DW6-01	3U14	**DW5-02**	3S15	-0.295	-1.164	-0.1305275	-1.03		X	0	0	0					3U14	585	5.02	U3
DW11-01	Spare 1W	**DW5-03**	3U6	-1.032	-4.067	-0.0688475	-0.54	X		565	2.90	20.00	-0.644	-2.538	0.109	0.860	DW1101	687	6.32	S3
DW5-03	3U6	**DW11-01**	Spare 1W	-0.388	-1.529	-0.1782537	-1.40		X	0	0	0					3U6	638	5.88	U3
DW1-02	1S6	**DW2-02**	1U6	-1.027	-4.046	-0.0859875	-0.68	X		558	2.87	19.78	-0.609	-2.400	0.094	0.737	1S6	683	6.39	S6
DW2-02	1U6	**DW1-02**	1S6	-0.418	-1.647	-0.1798387	-1.41		X	0	0	0					1U6	634	5.96	U6
DW9-03	6S4	**DW10-03**	6U4	-1.107	-4.362	-0.0873087	-0.69	X		558	2.87	19.79	-0.615	-2.423	0.122	0.963	6S4	710	6.83	S6
DW10-03	6U4	**DW9-03**	6S4	-0.492	-1.939	-0.2098	-1.65		X	0	0	0					6U4	674	6.63	U6

3.5. Grade IG-110 (Code E)

Table 26 Specimen dimensions, mass, bulk density, and volume change for grade IG-110

	Specimen Number	Thickness Measurements, mm. T1	T2	T3	T4	Outside Diameter Measurements,mm. D1	D2	D3	D4	$D1^{90}$	$D2^{90}$	$D3^{90}$	$D4^{90}$	Hole Diameter ,mm. H1	H2	H1'	H2'	Weight g
Pre-Irradiation	**EW2-02**	25.387	25.389	25.383	25.378	12.718	12.725	12.730	12.724	12.720	12.723	12.727	12.730	3.205	3.205	3.205	3.205	5.5901
Post-Irradiation		24.842	24.854	24.851	24.868	12.658	12.663	12.661	12.658	12.675	12.663	12.659	12.663	3.249	3.240	3.227	3.233	5.58771
Pre-Irradiation	**EW2-03**	25.386	25.386	25.383	25.385	12.730	12.727	12.725	12.717	12.725	12.727	12.724	12.720	3.208	3.211	3.203	3.205	5.5930
Post-Irradiation		25.163	25.161	25.161	25.161	12.594	12.605	12.609	12.609	12.597	12.608	12.610	12.610	3.249	3.237	3.246	3.242	5.5899
Pre-Irradiation	**EW2-01**	25.381	25.381	25.361	25.385	12.725	12.727	12.730	12.725	12.722	12.725	12.728	12.717	3.200	3.216	3.211	3.213	5.5838
Post-Irradiation		24.826	24.813	24.806	24.825	12.654	12.646	12.646	12.646	12.646	12.651	12.652	12.649	3.233	3.246	3.252	3.263	5.57996
Pre-Irradiation	**EW2-03**	25.386	25.386	25.383	25.385	12.730	12.727	12.725	12.717	12.725	12.727	12.724	12.720	3.208	3.211	3.203	3.205	5.5930
Post-Irradiation		25.163	25.161	25.161	25.161	12.594	12.605	12.609	12.609	12.597	12.608	12.610	12.610	3.249	3.237	3.246	3.242	5.5899
Pre-Irradiation	**EW7-01**	25.368	25.376	25.378	25.380	12.715	12.715	12.715	12.701	12.701	12.718	12.720	12.709	3.208	3.203	3.205	3.205	5.5902
Post-Irradiation		24.622	24.632	24.619	24.630	12.628	12.623	12.624	12.622	12.622	12.631	12.641	12.633	3.213	3.227	3.250	3.228	5.58736
Pre-Irradiation	**EW8-01**	25.380	25.378	25.378	25.371	12.687	12.703	12.697	12.708	12.701	12.705	12.705	12.706	3.205	3.203	3.203	3.200	5.5829
Post-Irradiation		25.088	25.091	25.091	25.088	12.520	12.522	12.516	12.513	12.530	12.531	12.528	12.526	3.269	3.259	3.265	3.255	5.58098
Pre-Irradiation	**EW6-03**	25.373	25.372	25.376	25.377	12.701	12.710	12.711	12.709	12.706	12.710	12.713	12.713	3.203	3.200	3.205	3.203	5.6009
Post-Irradiation		24.576	24.579	24.573	24.584	12.601	12.606	12.607	12.608	12.629	12.635	12.628	12.615	3.231	3.235	3.244	3.227	5.59804
Pre-Irradiation	**EW7-03**	Not returned by INL, use INL data for mean length and diameter changes																
Post-Irradiation																		
STRESS LEVEL CHANGE																		
Pre-Irradiation	**EW5-01**	25.370	25.368	25.368	25.373	12.713	12.717	12.720	12.710	12.715	12.720	12.722	12.720	3.203	3.203	3.203	3.203	5.5756
Post-Irradiation		24.528	24.546	24.536	24.552	12.630	12.630	12.622	12.634	12.645	12.637	12.636	12.643	3.231	3.225	3.237	3.231	5.57224
Pre-Irradiation	**EW5-03**	25.382	25.375	25.373	25.376	12.706	12.701	12.706	12.703	12.720	12.718	12.718	12.713	3.205	3.203	3.203	3.200	5.5845
Post-Irradiation		25.080	25.086	25.086	25.088	12.545	12.545	12.550	12.555	12.529	12.542	12.553	12.553	3.265	3.251	3.246	3.266	5.5815
Pre-Irradiation	**EW8-03**	25.373	25.377	25.376	25.385	12.695	12.695	12.701	12.709	12.666	12.700	12.703	12.710	3.198	3.203	3.208	3.203	5.5817
Post-Irradiation		24.871	24.887	24.881	24.881	12.676	12.671	12.677	12.672	12.678	12.668	12.663	12.656	3.207	3.227	3.222	3.217	5.57956
Pre-Irradiation	**EW9-02**	25.368	25.386	25.386	25.370	12.710	12.714	12.705	12.704	12.711	12.713	12.710	12.703	3.203	3.200	3.203	3.203	5.5911
Post-Irradiation		25.213	25.210	25.213	25.215	12.614	12.624	12.623	12.614	12.614	12.620	12.632	12.624	3.235	3.236	3.225	3.226	5.58796
Pre-Irradiation	**EW8-02**	25.373	25.366	25.370	25.371	12.713	12.710	12.708	12.704	12.710	12.708	12.708	12.699	3.198	3.198	3.193	3.193	5.5862
Post-Irradiation		24.403	24.425	24.401	24.424	12.622	12.620	12.634	12.641	12.634	12.654	12.671	12.689	3.209	3.214	3.213	3.202	5.55367
Pre-Irradiation	**EW9-01**	25.364	25.378	25.381	25.381	12.605	12.705	12.703	12.709	12.709	12.709	12.703	12.700	3.203	3.198	3.200	3.198	5.5981
Post-Irradiation		25.055	25.061	25.062	25.064	12.525	12.530	12.528	12.536	12.494	12.511	12.520	12.518	3.241	3.245	3.252	3.255	5.59619
STRESS LEVEL CHANGE																		
Pre-Irradiation	**EW4-01**	25.370	25.377	25.358	25.366	12.695	12.710	12.718	12.722	12.708	12.711	12.706	12.715	3.205	3.208	3.208	3.203	5.5908
Post-Irradiation		24.657	24.669	24.667	24.667	12.686	12.685	12.681	12.679	12.689	12.638	12.688	12.688	3.211	3.223	3.227	3.228	5.58784
Pre-Irradiation	**EW6-02**	Not returned by INL, use INL data for mean length and diameter changes																
Post-Irradiation																		
Pre-Irradiation	**EW6-01**	25.368	25.375	25.378	25.372	12.706	12.706	12.706	12.708	12.703	12.711	12.709	12.710	3.203	3.200	3.200	3.198	5.5918
Post-Irradiation		24.605	24.601	24.613	24.609	12.690	12.687	12.682	12.675	12.675	12.686	12.686	12.684	3.203	3.208	3.223	3.208	5.58862
Pre-Irradiation	**EW6-02**	Not returned by INL, use INL data for mean length and diameter changes																
Post-Irradiation																		
Pre-Irradiation	**EW9-03**	25.375	25.371	25.377	25.376	12.678	12.700	12.697	12.700	12.699	12.705	12.709	12.710	3.205	3.203	3.203	3.203	5.5902
Post-Irradiation		24.519	24.525	24.535	24.537	12.644	12.634	12.640	12.643	12.663	12.671	12.668	12.663	3.222	3.236	3.236	3.228	5.58822
Pre-Irradiation	**EW10-01**	25.381	25.376	25.376	25.378	12.691	12.696	12.692	12.678	12.696	12.703	12.711	12.713	3.205	3.205	3.200	3.198	5.5822
Post-Irradiation		25.117	25.118	25.117	25.119	12.559	12.554	12.548	12.542	12.562	12.570	12.572	12.566	3.265	3.241	3.241	3.260	5.57855
Pre-Irradiation	**EW10-02**	25.377	25.377	25.377	25.377	12.703	12.705	12.703	12.689	12.700	12.705	12.711	12.701	3.198	3.200	3.203	3.208	5.5845
Post-Irradiation		24.324	24.331	24.353	24.354	12.674	12.665	12.673	12.662	12.677	12.667	12.652	12.667	3.227	3.228	3.225	3.213	5.58141
Pre-Irradiation	**EW10-03**	25.375	25.376	25.376	25.376	12.713	12.703	12.699	12.699	12.691	12.701	12.697	12.704	3.203	3.200	3.203	3.200	5.5923
Post-Irradiation		25.039	25.038	25.036	25.040	12.507	12.530	12.541	12.540	12.502	12.522	12.527	12.515	3.249	3.275	3.255	3.275	5.58907
Pre-Irradiation	**EW4-02**	25.371	25.378	25.370	25.376	12.724	12.720	12.718	12.700	12.723	12.722	12.715	12.714	3.200	3.205	3.205	3.208	5.5921
Post-Irradiation		24.353	24.361	24.362	24.365	12.676	12.656	12.656	12.675	12.659	12.656	12.646	12.650	3.232	3.223	3.225	3.233	5.58979
Pre-Irradiation	**EW5-02**	25.377	25.372	25.359	25.372	12.718	12.713	12.710	12.717	12.701	12.709	12.713	12.699	3.200	3.205	3.205	3.205	5.5834
Post-Irradiation		25.061	25.058	25.064	25.064	12.531	12.554	12.563	12.559	12.538	12.536	12.525	12.519	3.258	3.237	3.254	3.244	5.58045

	Specimen Number	Means: Thickness m	Diameter m	Cross-section m^2	2- hole Volume m^3	Creep specimens: Volume m^3	Volume Change m^3	Volume Change (ΔV/Vo),%	Specimen Type: Creep	Control	Control specimens: Volume m3	Volume Change m3	Volume Change (ΔV/Vo),%	Density kg/m^3	Density g/cm^3
Pre-Irradiation	EW2-02	2.538E-02	1.272E-02	1.272E-04	5.32947E-08	3.17489E-06	-9.94069E-08	-3.131036185	X					1760.72	1.7607
Post-Irradiation		2.485E-02	1.266E-02	1.259E-04	5.43559E-08	3.07548E-06								1816.86	1.8169
Pre-Irradiation	EW2-03	2.539E-02	1.272E-02	1.272E-04	5.3337E-08					X	3.17477E-06	-8.93287E-08	-2.81370891	1761.71	1.7617
Post-Irradiation		2.516E-02	1.261E-02	1.248E-04	5.45691E-08						3.08544E-06			1811.70	1.8117
Pre-Irradiation	EW2-01	2.538E-02	1.272E-02	1.272E-04	5.34425E-08	3.17385E-06	-1.10104E-07	-3.469084208	X					1759.31	1.7593
Post-Irradiation		2.482E-02	1.265E-02	1.257E-04	5.47405E-08	3.06375E-06								1821.29	1.8213
Pre-Irradiation	EW2-03	2.539E-02	1.272E-02	1.272E-04	5.3337E-08					X	3.17477E-06	-8.93287E-08	-2.81370891	1761.71	1.7617
Post-Irradiation		2.516E-02	1.261E-02	1.248E-04	5.45691E-08						3.08544E-06			1811.70	1.8117
Pre-Irradiation	EW7-01	2.538E-02	1.271E-02	1.269E-04	5.32947E-08	3.16724E-06	-1.3709E-07	-4.328366422	X					1765.01	1.7650
Post-Irradiation		2.463E-02	1.263E-02	1.252E-04	5.41001E-08	3.03015E-06								1843.92	1.8439
Pre-Irradiation	EW8-01	2.538E-02	1.270E-02	1.267E-04	5.32103E-08					X	3.16226E-06	-1.27032E-07	-4.01712843	1765.48	1.7655
Post-Irradiation		2.509E-02	1.252E-02	1.232E-04	5.51904E-08						3.03523E-06			1838.74	1.8387
Pre-Irradiation	EW6-03	2.537E-02	1.271E-02	1.269E-04	5.32103E-08	3.16583E-06	-1.47604E-07	-4.66239492	X					1769.17	1.7692
Post-Irradiation		2.458E-02	1.262E-02	1.250E-04	5.4249E-08	3.01823E-06								1854.74	1.8547
Pre-Irradiation	EW7-03	2.538E-02	1.272E-02							X					
Post-Irradiation		2.508E-02	1.252E-02												
Pre-Irradiation	EW5-01	2.537E-02	1.272E-02	1.270E-04	5.32103E-08	3.16925E-06	-1.46597E-07	-4.625593665	X					1759.28	1.7593
Post-Irradiation		2.454E-02	1.263E-02	1.254E-04	5.41427E-08	3.02266E-06								1843.49	1.8435
Pre-Irradiation	EW5-03	2.538E-02	1.271E-02	1.269E-04	5.32103E-08					X	3.1668E-06	-1.20482E-07	-3.80454285	1763.45	1.7635
Post-Irradiation		2.509E-02	1.255E-02	1.236E-04	5.50291E-08						3.04632E-06			1832.21	1.8322
Pre-Irradiation	EW8-03	2.538E-02	1.270E-02	1.266E-04	5.32103E-08	3.16021E-06	-7.70098E-08	-2.436857227	X					1766.24	1.7662
Post-Irradiation		2.488E-02	1.267E-02	1.261E-04	5.37176E-08	3.0832E-06								1809.67	1.8097
Pre-Irradiation	EW9-02	2.538E-02	1.271E-02	1.269E-04	5.31892E-08					X	3.16598E-06	-6.60176E-08	-2.08521893	1766.00	1.7660
Post-Irradiation		2.521E-02	1.262E-02	1.251E-04	5.41215E-08						3.09996E-06			1802.59	1.8026
Pre-Irradiation	EW8-02	2.537E-02	1.271E-02	1.268E-04	5.29574E-08	3.16452E-06	-1.51777E-07	-4.79620424	X					1765.26	1.7653
Post-Irradiation		2.441E-02	1.265E-02	1.256E-04	5.3432E-08	3.01274E-06								1843.39	1.8434
Pre-Irradiation	EW9-01	2.538E-02	1.269E-02	1.265E-04	5.31048E-08					X	3.15778E-06	-1.27143E-07	-4.02635251	1772.80	1.7728
Post-Irradiation		2.506E-02	1.252E-02	1.231E-04	5.47297E-08						3.03063E-06			1846.54	1.8465
Pre-Irradiation	EW4-01	2.537E-02	1.271E-02	1.269E-04	5.33158E-08	3.16557E-06	-1.05133E-07	-3.321137169	X		3.16557E-06	-1.05133E-07	-3.32113717	1766.13	1.7661
Post-Irradiation		2.467E-02	1.268E-02	1.263E-04	5.38558E-08	3.06043E-06					3.06043E-06			1825.83	1.8258
Pre-Irradiation	EW6-02	2.539E-02	1.272E-02							X					
Post-Irradiation		2.517E-02	1.260E-02												
Pre-Irradiation	EW6-01	2.537E-02	1.271E-02	1.268E-04	5.31259E-08	3.16487E-06	-1.09471E-07	-3.458926799	X		3.16487E-06	-1.09471E-07	-3.4589268	1766.83	1.7668
Post-Irradiation		2.461E-02	1.268E-02	1.263E-04	5.34637E-08	3.0554E-06					3.0554E-06			1829.09	1.8291
Pre-Irradiation	EW6-02	2.539E-02	1.272E-02							X					
Post-Irradiation		2.517E-02	1.260E-02												
Pre-Irradiation	EW9-03	2.537E-02	1.270E-02	1.267E-04	5.32314E-08	3.16107E-06	-1.30776E-07	-4.13708176	X		3.16107E-06	-1.30776E-07	-4.13708176	1768.45	1.7685
Post-Irradiation		2.453E-02	1.265E-02	1.257E-04	5.41319E-08	3.03029E-06					3.03029E-06			1844.12	1.8441
Pre-Irradiation	EW10-01	2.538E-02	1.270E-02	1.266E-04	5.31892E-08					X	3.16039E-06	-1.03589E-07	-3.27772562	1766.30	1.7663
Post-Irradiation		2.512E-02	1.256E-02	1.239E-04	5.48467E-08						3.0568E-06			1824.96	1.8250
Pre-Irradiation	EW10-02	2.538E-02	1.270E-02	1.267E-04	5.31892E-08	3.16256E-06	-1.49005E-07	-4.711518689	X					1765.82	1.7658
Post-Irradiation		2.434E-02	1.267E-02	1.260E-04	5.38876E-08	3.01356E-06								1852.10	1.8521
Pre-Irradiation	EW10-03	2.538E-02	1.270E-02	1.267E-04	5.31681E-08					X	3.16174E-06	-1.32998E-07	-4.2064845	1768.74	1.7687
Post-Irradiation		2.504E-02	1.252E-02	1.232E-04	5.52435E-08						3.02874E-06			1845.35	1.8453
Pre-Irradiation	EW4-02	2.537E-02	1.272E-02	1.270E-04	5.32736E-08	3.16959E-06	-1.57534E-07	-4.970179916	X					1764.30	1.7643
Post-Irradiation		2.436E-02	1.266E-02	1.259E-04	5.40575E-08	3.01206E-06								1855.80	1.8558
Pre-Irradiation	EW5-02	2.537E-02	1.271E-02	1.269E-04	5.32525E-08					X	3.16555E-06	-1.24702E-07	-3.93933684	1763.80	1.7638
Post-Irradiation		2.506E-02	1.254E-02	1.235E-04	5.47185E-08						3.04085E-06			1835.16	1.8352

Table 27 Dimensional change, the creep strain, the specimen loading details, and the irradiation conditions (dose and temperature) for grade IG-110

Specimen Number	Specimen I.D. Number	Companion Specimen Number	Companion Specimen I.D. Number	Dimensional Change, L (mm)	$\Delta L/L_0$ (%)	D (mm)	$\Delta D/D_0$ (%)	Specimen Type: Creep	Specimen Type: Control	Load Details: Load lbf	Stress ksi	Stress MPa	Creep Strain (creep-control) Longitudanal (mm)	Longitudanal %	Lateral (mm)	Lateral %	Irradiation Conditions ID No.	Temp °C	Dose DPA	channel
				ΔDIM = IRR-UNIRR																
EW2-02	1S9	**EW2-03**	1U7	-0.531	-2.091	-0.06226	-0.49	X		377	1.91	13.19	-0.307	-1.21	0.056933	0.45	1S9	621	4.75	S1
EW2-03	1U7	**EW2-02**	1S9	-0.224	-0.881	-0.1192	-0.94		X	0	0	0					1U7	562	4.36	U1
EW2-01	1S7	**EW2-02**	1S9	-0.559	-2.204	-0.07617	-0.60	X		377	1.91	13.19	-0.336	-1.32	0.043024	0.34	1S7	635	5.11	S1
EW2-03	1U7	**EW2-01**	1S7	-0.224	-0.881	-0.1192	-0.94		X	0	0	0					1U7	562	4.36	U1
EW7-01	4S9	**EW8-01**	4U9	-0.750	-2.955	-0.08391	-0.66	X		359	1.82	12.58	-0.462	-1.82	0.094431	0.74	4S9	708	6.42	S4
EW8-01	4U9	**EW7-01**	4S9	-0.287	-1.132	-0.17834	-1.40		X	0	0	0					4U9	671	6.13	U4
EW6-03	4S4	**EW7-03**	4U4	-0.797	-3.139	-0.09308	-0.73	X		359	1.83	12.59	-0.492	-1.94	0.108918	0.86	4S4	713	6.63	S4
EW7-03	4U4	**EW6-03**	4S4	-0.305	-1.202	-0.202	-1.59		X	0	0	0					4U4	682	6.49	U4
EW5-01	2S7	**EW5-03**	2U7	-0.829	-3.269	-0.08252	-0.65	X		467	2.37	16.35	-0.538	-2.12	0.081616	0.64	2S7	674	6.24	S2
EW5-03	2U7	**EW5-01**	2S7	-0.292	-1.149	-0.16414	-1.29		X	0	0	0					2U7	613	5.76	U2
EW8-03	5S13	**EW9-02**	5U12	-0.498	-1.961	-0.02718	-0.21	X		474	2.42	16.65	-0.333	-1.31	0.06093	0.48	5S13	601	3.82	S5
EW9-02	5U12	**EW8-03**	5S13	-0.165	-0.649	-0.08811	-0.69		X	0	0						5U12	507	3.31	U5
EW8-02	5S1	**EW9-01**	5U1	-0.957	-3.771	-0.06168	-0.49	X		474	2.41	16.63	-0.641	-2.53	0.11077	0.87	5S1	712	6.77	S5
EW9-01	5U1	**EW8-02**	5S1	-0.316	-1.244	-0.17245	-1.36		X	0	0	0					5U1	681	6.62	U5
EW4-01	1U9	**EW6-02**	3U9	-0.703	-2.770	-0.03139	-0.25	X		565	2.87	19.81	-0.487	-1.92	0.088614	0.70	1U9	628	4.69	S3
EW6-02	3U9	**EW4-01**	1U9	-0.216	-0.850	-0.12	-0.94		X	0	0	0					3U9	567	4.25	U3
EW6-01	3S9	**EW6-02**	3U9	-0.766	-3.020	-0.02434	-0.19	X		565	2.87	19.82	-0.551	-2.17	0.095664	0.75	3S9	642	5.05	S3
EW6-02	3U9	**EW6-01**	3S9	-0.216	-0.850	-0.12	-0.94		X	0	0	0					3U9	567	4.25	U3
EW9-03	6S14	**EW10-01**	6U13	-0.846	-3.332	-0.04659	-0.37	X		558	2.84	19.59	-0.586	-2.31	0.091903	0.72	6S14	666	5.75	S6
EW10-01	6U13	**EW9-03**	6S14	-0.260	-1.025	-0.13849	-1.09		X	0	0	0					6U13	582	5.11	U6
EW10-02	SPARE1	**EW10-03**	SPARE 2	-1.037	-4.085	-0.03494	-0.28	X		565	2.88	19.83	-0.699	-2.76	0.142855	1.12	SPARE1	713	6.69	S3
EW10-03	SPARE 2	**EW10-02**	SPARE1	-0.337	-1.329	-0.17779	-1.40		X	0	0	0					SPARE 2	678	6.43	U3
EW4-02	2S5	**EW5-02**	2U5	-1.013	-3.994	-0.05774	-0.45	X		558	2.83	19.54	-0.705	-2.78	0.111481	0.88	2S5	693	6.54	S6
EW5-02	2U5	**EW4-02**	2S5	-0.308	-1.216	-0.16922	-1.33		X	0	0	0					2U5	653	6.18	U6

3.6. Grade 1G-430 (Code F)

Table 28 Specimen dimensions, mass, bulk density, and volume change for grade IG-430

	Specimen Number	Thickness Measurements, mm. T1	T2	T3	T4	Outside Diameter Measurements,mm. D1	D2	D3	D4	$D1^{90}$	$D2^{90}$	$D3^{90}$	$D4^{90}$	Hole Diameter ,mm. H1	H2	H1'	H2'	Weight g	Means Thickness m	Means Diameter m	Means Cross-section m^2	2- hole Volume m^3	Creep specimens Volume m^3	Creep specimens Volume Change m^3	Creep specimens Volume Change (ΔV/Vo),%	Specimen Type Creep	Specimen Type Control	Control specimens Volume m3	Control specimens Volume Change m3	Control specimens Volume Change (ΔV/Vo),%	Density kg/m^3	Density g/cm^3
Pre-Irradiation	FW8-02	25.380	25.383	25.381	25.383	12.709	12.708	12.710	12.717	12.713	12.713	12.713	12.720	3.205	3.208	3.208	3.205	5.7571	2.538E-02	1.271E-02	1.269E-04	5.33369E-08	3.1684E-06	-8.2462E-08	-2.603						1817.03	1.8170
Post-Irradiation		24.944	24.954	24.952	24.950	12.666	12.657	12.643	12.656	12.669	12.658	12.660	12.656	3.232	3.217	3.226	3.213	5.75462	2.495E-02	1.266E-02	1.258E-04	5.38449E-08	3.08594E-06			X					1864.79	1.8648
Pre-Irradiation	FW9-01	25.387	25.392	25.390	25.386	12.719	12.718	12.717	12.717	12.723	12.718	12.718	12.718	3.211	3.203	3.205	3.200	5.7732	2.539E-02	1.272E-02	1.270E-04	5.32736E-08						3.17217E-06	-8.35144E-08	-2.633	1819.95	1.8200
Post-Irradiation		25.193	25.202	25.199	25.197	12.596	12.600	12.602	12.606	12.602	12.599	12.608	12.610	3.246	3.247	3.252	3.242	5.77081	2.520E-02	1.260E-02	1.247E-04	5.46867E-08					X	3.08866E-06			1868.39	1.8684
Pre-Irradiation	FW4-02	25.382	25.373	25.382	25.377	12.717	12.699	12.699	12.710	12.713	12.714	12.715	12.711	3.203	3.208	3.203	3.200	5.7458	2.538E-02	1.271E-02	1.269E-04	5.32314E-08	3.16658E-06	-9.35758E-08	-2.955						1814.51	1.8145
Post-Irradiation		24.875	24.882	24.876	24.876	12.656	12.651	12.642	12.658	12.656	12.652	12.651	12.645	3.235	3.240	3.231	3.236	5.74276	2.488E-02	1.265E-02	1.257E-04	5.42917E-08	3.073E-06			X					1868.78	1.8688
Pre-Irradiation	FW5-03	25.386	25.380	25.386	25.383	12.728	12.728	12.738	12.733	12.730	12.729	12.729	12.734	3.203	3.205	3.198	3.200	5.7923	2.538E-02	1.273E-02	1.273E-04	5.31681E-08						3.17824E-06	-1.03102E-07	-3.244	1822.49	1.8225
Post-Irradiation		25.183	25.179	25.185	25.183	12.588	12.575	12.580	12.578	12.585	12.579	12.578	12.578	3.247	3.252	3.264	3.259	5.78984	2.518E-02	1.258E-02	1.243E-04	5.4976E-08					X	3.07513E-06			1882.79	1.8828
Pre-Irradiation	FW13-01	25.385	25.381	25.381	25.383	12.730	12.728	12.730	12.730	12.725	12.724	12.725	12.727	3.205	3.208	3.200	3.205	5.7910	2.538E-02	1.273E-02	1.272E-04	5.32736E-08	3.17612E-06	-1.00755E-07	-3.172						1823.30	1.8233
Post-Irradiation		24.909	24.904	24.911	24.920	12.651	12.647	12.653	12.651	12.650	12.644	12.640	12.643	3.213	3.241	3.230	3.246	5.78689	2.491E-02	1.265E-02	1.256E-04	5.41954E-08	3.07536E-06			X					1881.69	1.8817
Pre-Irradiation	FW2-01	25.373	25.376	25.376	25.375	12.706	12.703	12.697	12.697	12.695	12.695	12.705	12.706	3.211	3.208	3.211	3.208	5.7255	2.537E-02	1.270E-02	1.267E-04	5.34215E-08						3.16132E-06	-9.30121E-08	-2.942	1811.11	1.8111
Post-Irradiation		25.175	25.183	25.179	25.184	12.557	12.571	12.576	12.573	12.566	12.572	12.560	12.559	3.258	3.254	3.259	3.240	5.72318	2.518E-02	1.257E-02	1.240E-04	5.48685E-08					X	3.06831E-06			1865.25	1.8653
Pre-Irradiation	FW8-01	25.383	25.377	25.381	25.377	12.709	12.708	12.713	12.718	12.710	12.710	12.714	12.717	3.205	3.203	3.208	3.205	5.7551	2.538E-02	1.271E-02	1.269E-04	5.32947E-08	3.16792E-06	-9.78478E-08	-3.089						1816.68	1.8167
Post-Irradiation		24.826	24.842	24.850	24.829	12.660	12.646	12.635	12.642	12.668	12.658	12.671	12.668	3.227	3.240	3.261	3.227	5.75263	2.484E-02	1.266E-02	1.258E-04	5.44083E-08	3.07008E-06			X					1873.77	1.8738
Pre-Irradiation	FW8-03	Not returned by INL													INL dimensional data used				2.54E-02	1.27E-02												
Post-Irradiation																			2.52E-02	1.255E-02							X					
Pre-Irradiation	FW1-01	25.371	25.372	25.371	25.370	12.710	12.717	12.711	12.692	12.710	12.705	12.705	12.701	3.208	3.205	3.208	3.213	5.7233	2.537E-02	1.271E-02	1.268E-04	5.34003E-08	3.16379E-06	-1.18105E-07	-3.733						1809.00	1.8090
Post-Irradiation		24.786	24.797	24.782	24.808	12.618	12.609	12.614	12.622	12.625	12.616	12.620	12.620	3.258	3.239	3.240	3.245	5.71889	2.479E-02	1.262E-02	1.250E-04	5.46224E-08	3.04569E-06			X					1877.70	1.8777
Pre-Irradiation	FW1-03	25.376	25.368	25.381	25.375	12.717	12.714	12.715	12.715	12.717	12.715	12.715	12.713	3.208	3.211	3.208	3.203	5.7574	2.537E-02	1.272E-02	1.270E-04	5.33581E-08						3.1687E-06	-9.83586E-08	-3.104	1816.96	1.8170
Post-Irradiation		25.230	25.227	25.226	25.229	12.561	12.556	12.549	12.538	12.556	12.566	12.574	12.570	3.250	3.247	3.242	3.259	5.76253	2.523E-02	1.256E-02	1.239E-04	5.47721E-08					X	3.07034E-06			1876.83	1.8768
Stress level change																																
Pre-Irradiation	FW12-01	25.387	25.389	25.385	25.389	12.729	12.728	12.727	12.725	12.729	12.725	12.725	12.724	3.200	3.198	3.200	3.203	5.7506	2.539E-02	1.273E-02	1.272E-04	5.31259E-08	3.17639E-06	-5.8831E-08	-1.852						1810.42	1.8104
Post-Irradiation		25.037	25.050	25.047	25.045	12.692	12.697	12.703	12.701	12.703	12.695	12.691	12.699	3.226	3.208	3.237	3.218	5.74748	2.504E-02	1.270E-02	1.266E-04	5.38554E-08	3.11756E-06			X					1843.59	1.8436
Pre-Irradiation	FW4-01	25.380	25.381	25.382	25.380	12.718	12.713	12.714	12.710	12.713	12.710	12.713	12.709	3.203	3.203	3.203	3.205	5.7339	2.538E-02	1.271E-02	1.269E-04	5.32314E-08						3.16819E-06	-4.73916E-08	-1.496	1809.84	1.8098
Post-Irradiation		25.264	25.269	25.276	25.273	12.642	12.646	12.651	12.651	12.645	12.651	12.651	12.647	3.240	3.225	3.235	3.236	5.73115	2.527E-02	1.265E-02	1.256E-04	5.42383E-08					X	3.1208E-06			1836.44	1.8364
Pre-Irradiation	FW3-01	25.380	25.378	25.377	25.371	12.699	12.695	12.695	12.700	12.703	12.703	12.703	12.696	3.200	3.205	3.211	3.211	5.7337	2.538E-02	1.270E-02	1.267E-04	5.3337E-08	3.1608E-06	-8.77338E-08	-2.776						1814.00	1.8140
Post-Irradiation		24.873	24.883	24.880	24.883	12.646	12.642	12.644	12.650	12.655	12.655	12.659	12.655	3.244	3.240	3.225	3.226	5.73113	2.488E-02	1.265E-02	1.257E-04	5.42282E-08	3.07307E-06			X					1864.95	1.8650
Pre-Irradiation	FW3-03	25.381	25.370	25.372	25.378	12.717	12.713	12.715	12.706	12.713	12.714	12.714	12.706	3.203	3.205	3.208	3.208	5.7546	2.538E-02	1.271E-02	1.269E-04	5.33158E-08						3.16734E-06	-7.71977E-08	-2.437	1816.86	1.8169
Post-Irradiation		25.219	25.220	25.219	25.216	12.592	12.601	12.600	12.604	12.595	12.606	12.602	12.601	3.236	3.242	3.236	3.242	5.7514	2.522E-02	1.260E-02	1.247E-04	5.44196E-08					X	3.09014E-06			1861.21	1.8612
Pre-Irradiation	FW2-03	25.373	25.380	25.366	25.380	12.708	12.705	12.709	12.711	12.699	12.705	12.703	12.699	3.211	3.208	3.213	3.205	5.7428	2.537E-02	1.270E-02	1.268E-04	5.34214E-08	3.16337E-06	-9.33605E-08	-2.951						1815.40	1.8154
Post-Irradiation		24.891	24.890	24.887	24.909	12.661	12.652	12.643	12.650	12.643	12.633	12.621	12.623	3.218	3.222	3.252	3.233	5.73952	2.489E-02	1.264E-02	1.255E-04	5.41644E-08	3.07001E-06			X					1869.54	1.8695
Pre-Irradiation	FW3-03	25.381	25.370	25.372	25.378	12.717	12.713	12.715	12.706	12.713	12.714	12.714	12.706	3.203	3.205	3.208	3.208	5.7546	2.538E-02	1.271E-02	1.269E-04	5.33158E-08						3.16734E-06	-7.71977E-08	-2.437	1816.86	1.8169
Post-Irradiation		25.219	25.220	25.219	25.216	12.592	12.601	12.600	12.604	12.595	12.606	12.602	12.601	3.236	3.242	3.236	3.242	5.7514	2.522E-02	1.260E-02	1.247E-04	5.44196E-08					X	3.09014E-06			1861.21	1.8612
Pre-Irradiation	FW9-03	25.382	25.380	25.381	25.381	12.717	12.714	12.711	12.718	12.718	12.718	12.715	12.719	3.203	3.203	3.203	3.203	5.7710	2.538E-02	1.272E-02	1.270E-04	5.32103E-08	3.17018E-06	-1.02293E-07	-3.227						1820.40	1.8204
Post-Irradiation		24.767	24.765	24.769	24.770	12.678	12.662	12.662	12.678	12.671	12.664	12.659	12.673	3.226	3.230	3.225	3.228	5.76706	2.477E-02	1.267E-02	1.260E-04	5.4015E-08	3.06789E-06			X					1879.81	1.8798
Pre-Irradiation	FW10-02	25.390	25.390	25.390	25.387	12.722	12.723	12.724	12.723	12.723	12.725	12.722	12.720	3.208	3.208	3.208	3.208	5.7841	2.539E-02	1.272E-02	1.271E-04	5.33792E-08						3.17436E-06	-1.04661E-07	-3.297	1822.13	1.8221
Post-Irradiation		25.171	25.167	25.168	25.168	12.566	12.562	12.563	12.567	12.583	12.584	12.580	12.574	3.245	3.264	3.245	3.250	5.7814	2.517E-02	1.257E-02	1.241E-04	5.48149E-08					X	3.0697E-06			1883.38	1.8834
Pre-Irradiation	FW9-02	25.386	25.389	25.386	25.387	12.725	12.717	12.717	12.718	12.724	12.715	12.715	12.713	3.211	3.208	3.208	3.208	5.7547	2.539E-02	1.272E-02	1.270E-04	5.34003E-08	3.17164E-06	-1.06896E-07	-3.370						1814.42	1.8144
Post-Irradiation		24.738	24.733	24.738	24.740	12.661	12.671	12.685	12.704	12.669	12.645	12.655	12.670	3.246	3.226	3.233	3.214	5.75206	2.474E-02	1.267E-02	1.261E-04	5.41104E-08	3.06475E-06			X					1876.85	1.8768
Pre-Irradiation	FW10-01	25.394	25.394	25.392	25.392	12.723	12.723	12.723	12.723	12.722	12.719	12.718	12.722	3.205	3.205	3.200	3.205	5.7745	2.539E-02	1.272E-02	1.271E-04	5.32525E-08						3.17433E-06	-1.01887E-07	-3.210	1819.13	1.8191
Post-Irradiation		25.184	25.188	25.187	25.188	12.565	12.570	12.570	12.572	12.573	12.577	12.579	12.582	3.250	3.256	3.252	3.255	5.77124	2.519E-02	1.257E-02	1.242E-04	5.49008E-08					X	3.07244E-06			1878.39	1.8784
Pre-Irradiation	FW2-02	25.362	25.363	25.376	25.375	12.705	12.709	12.711	12.710	12.694	12.695	12.701	12.696	3.216	3.208	3.205	3.211	5.7308	2.537E-02	1.270E-02	1.267E-04	5.34426E-08	3.16158E-06	-1.16258E-07	-3.677						1812.64	1.8126
Post-Irradiation		24.713	24.723	24.715	24.724	12.648	12.651	12.646	12.649	12.622	12.624	12.623	12.621	3.236	3.231	3.237	3.232	5.7283	2.472E-02	1.264E-02	1.254E-04	5.42491E-08	3.04532E-06			X					1881.02	1.8810
Pre-Irradiation	FW3-02	25.373	25.375	25.378	25.377	12.713	12.714	12.704	12.700	12.717	12.715	12.715	12.658	3.205	3.203	3.200	3.205	5.7257	2.538E-02	1.270E-02	1.268E-04	5.32314E-08						3.16356E-06	-1.02512E-07	-3.240	1809.89	1.8099
Post-Irradiation		25.176	25.196	25.196	25.194	12.538	12.553	12.548	12.547	12.545	12.558	12.563	12.549	3.269	3.269	3.251	3.252	5.72258	2.519E-02	1.255E-02	1.237E-04	5.51372E-08					X	3.06105E-06			1869.48	1.8695
Stress level change																																
Pre-Irradiation	FW5-02	25.385	25.385	25.385	25.385	12.728	12.727	12.725	12.728	12.730	12.732	12.727	12.729	3.205	3.208	3.200	3.205	5.7849	2.538E-02	1.273E-02	1.272E-04	5.32736E-08	3.17672E-06	-6.41581E-08	-2.020						1821.03	1.8210
Post-Irradiation		24.962	24.964	24.964	24.962	12.711	12.702	12.703	12.706	12.710	12.705	12.708	12.718	3.204	3.208	3.218	3.228	5.77683	2.496E-02	1.271E-02	1.268E-04	5.36016E-08	3.11256E-06			X					1855.97	1.8560
Pre-Irradiation	FW7-03	25.387	25.386	25.387	25.382	12.736	12.733	12.736	12.734	12.738	12.734	12.736	12.736	3.203	3.198	3.200	3.205	5.7559	2.539E-02	1.274E-02	1.274E-04	5.31681E-08						3.18049E-06	-5.89561E-08	-1.854	1809.75	1.8098
Post-Irradiation		25.269	25.281	25.272	25.267	12.647	12.646	12.650	12.653	12.651	12.645	12.646	12.655	3.241	3.230	3.236	3.233	5.75341	2.527E-02	1.265E-02	1.257E-04	5.4281E-08					X	3.12154E-06			1843.13	1.8431
Pre-Irradiation	FW5-01	25.378	25.381	25.363	25.366	12.718	12.720	12.711	12.717	12.723	12.719	12.714	12.713	3.203	3.200	3.200	3.205	5.7637	2.537E-02	1.272E-02	1.270E-04	5.31892E-08	3.16939E-06	-7.59441E-08	-2.396						1818.55	1.8185
Post-Irradiation		24.891	24.896	24.903	24.892	12.696	12.689	12.691	12.690	12.677	12.679	12.684	12.694	3.240	3.222	3.241	3.208	5.76041	2.490E-02	1.269E-02	1.264E-04	5.40354E-08	3.09345E-06			X					1862.13	1.8621
Pre-Irradiation	FW7-02	25.381	25.380	25.377	25.377	12.734	12.734	12.736	12.738	12.733	12.732	12.733	12.737	3.198	3.200	3.205	3.203	5.7693	2.538E-02	1.273E-02	1.274E-04	5.31681E-08						3.17928E-06	-6.71756E-08	-2.113	1814.65	1.8147
Post-Irradiation		25.245	25.245	25.246	25.246	12.638	12.635	12.636	12.637	12.635	12.641	12.642	12.633	3.245	3.241	3.226	3.235	5.76571	2.525E-02	1.264E-02	1.254E-04	5.43345E-08					X	3.11211E-06			1852.67	1.8527
Pre-Irradiation	FW11-02	25.389	25.383	25.383	25.385	12.727	12.723	12.722	12.723	12.729	12.725	12.719	12.729	3.205	3.203	3.205	3.203	5.7712	2.539E-02	1.272E-02	1.272E-04	5.32525E-08	3.17493E-06	-9.0809E-08	-2.860						1817.74	1.8177
Post-Irradiation		24.826	24.826	24.834	24.830	12.683	12.675	12.678	12.696	12.692	12.692	12.681	12.690	3.217	3.227	3.245	3.236	5.76812	2.483E-02	1.269E-02	1.264E-04	5.41536E-08	3.08412E-06			X					1870.26	1.8703
Pre-Irradiation	FW12-02	Not returned by INL													INL dimensional data used				2.54E-02	1.27E-02												
Post-Irradiation																			2.52E-02	1.262E-02							X					
Pre-Irradiation	FW11-01	25.383	25.383	25.382	25.383	12.724	12.718	12.720	12.722	12.725	12.720	12.724	12.724	3.203	3.205	3.205	3.205	5.7770	2.538E-02	1.272E-02	1.271E-04	5.32736E-08	3.17346E-06	-9.30043E-08	-2.931						1820.41	1.8204
Post-Irradiation		24.837	24.829	24.820	24.825	12.700	12.673	12.670	12.677	12.691	12.666	12.673	12.679	3.221	3.245	3.219	3.231	5.77438	2.483E-02	1.268E-02	1.263E-04	5.40784E-08	3.08045E-06			X					1874.52	1.8745
Pre-Irradiation	FW12-02	Not returned by INL													INL dimensional data used				2.54E-02	1.27E-02												
Post-Irradiation																			2.52E-02	1.262E-02							X					
Pre-Irradiation	FW4-03	25.370	25.373	25.376	25.357	12.717	12.717	12.717	12.709	12.706	12.713	12.718	12.718	3.203	3.203	3.203	3.200	5.7692	2.537E-02	1.271E-02	1.270E-04	5.31892E-08	3.16762E-06	-1.0584E-07	-3.341						1821.30	1.8213
Post-Irradiation		24.647	24.667	24.674	24.667	12.670	12.692	12.693	12.684	12.694	12.676	12.677	12.676	3.219	3.237	3.236	3.222	5.76617	2.466E-02	1.268E-02	1.263E-04	5.40679E-08	3.06178E-06			X					1883.27	1.8833
Pre-Irradiation	FW7-01	25.387	25.382	25.385	25.386	12.738	12.733	12.738	12.738	12.738	12.732	12.738	12.736	3.205	3.203	3.203	3.208	5.7641	2.539E-02	1.274E-02	1.274E-04	5.32736E-08						3.18087E-06	-1.13371E-07	-3.564	1812.11	1.8121
Post-Irradiation		25.199	25.190	25.197	25.201	12.560	12.571	12.563	12.570	12.568	12.555	12.552	12.552	3.255	3.251	3.255	3.270	5.7619	2.520E-02	1.256E-02	1.239E-04	5.50509E-08					X	3.0675E-06			1878.37	1.8784
Pre-Irradiation	FW10-03	25.382	25.382	25.382	25.383	12.720	12.719	12.719	12.722	12.723	12.723	12.722	12.724	3.208	3.208	3.203	3.208	5.7886	2.538E-02	1.272E-02	1.271E-04	5.33369E-08	3.17291E-06	-1.12937E-07	-3.559						1824.38	1.8244
Post-Irradiation		24.605	24.609	24.612	24.616	12.704	12.687	12.687	12.705	12.699	12.671	12.676	12.708	3.232	3.227	3.208	3.209	5.78597	2.461E-02	1.269E-02	1.265E-04	5.37502E-08	3.05998E-06			X					1890.86	1.8909
Pre-Irradiation	FW11-03	25.386	25.386	25.386	25.385	12.729	12.722	12.724	12.729	12.725	12.719	12.720	12.725	3.205	3.200	3.200	3.205	5.7713	2.539E-02	1.272E-02	1.272E-04	5.32102E-08						3.17489E-06	-1.02659E-07	-3.233	1817.79	1.8178
Post-Irradiation		25.262	25.255	25.268	25.269	12.555	12.557	12.555	12.551	12.551	12.560	12.555	12.551	3.266	3.258	3.240	3.274	5.76861	2.526E-02	1.255E-02	1.238E-04	5.51038E-08					X	3.07223E-06			1877.66	1.8777

Table 29 Dimensional change, the creep strain, the specimen loading details, and the irradiation conditions (dose and temperature) for grade IG-430

Specimen Number	Specimen I.D. Number	Companion Specimen Number	Companion Specimen I.D. Number	Dimensional Change, L (mm)	ΔL/L₀(%)	D (mm)	ΔD/D₀(%)	Specimen Type: Creep	Control	Load Details: Load (lbf)	Stress (ksi)	Stress (MPa)	Creep Strain (creep-control): Longitudanal (mm)	Longitudanal %	Lateral (mm)	Lateral %	Irradiation Conditions: ID No.	Temp (°C)	Dose (DPA)	channel
				ΔDIM = IRR-UNIRR																
FW8-02	4S10	FW9-01	4U10	-0.4319	-1.70	-0.05458	-0.43	X		359	1.82	12.58	-0.24076	-1.89	0.060806	0.478	4S10	669	5.51	S4
FW9-01	4U10	FW8-02	4S10	-0.19114	-0.75	-0.11538	-0.91		X	0	0	0					4U10	587	4.91	U4
FW4-02	3S3	FW5-03	3U3	-0.50148	-1.98	-0.05831	-0.46	X		359	1.83	12.59	-0.30017	-2.36	0.09284	0.730	3S3	688	6.15	S4
FW5-03	3U3	FW4-02	3S3	-0.20131	-0.79	-0.15115	-1.19		X	0	0	0					3U3	639	5.74	U4
FW13-01	Spare1	FW2-01	1U10	-0.47154	-1.86	-0.08025	-0.63	X		377	1.91	13.18	-0.27687	-2.18	0.053638	0.421	FW 13-01	662	5.72	S1
FW2-01	1U10	FW13-01	Spare1	-0.19467	-0.77	-0.13389	-1.05		X	0	0	0					1U10	580	5.12	U1
FW8-01	4S3	FW8-03	4U3	-0.54293	-2.14	-0.05622	-0.44	X		359	1.82	12.58	-0.36863	-2.90	0.111376	0.876	4S3	716	6.59	S4
FW8-03	4U3	FW8-01	4S3	-0.1743	-0.69	-0.1676	-1.32		X	0	0	0					4U3	679	6.4	U4
FW1-01	1S5	FW1-03	1U5	-0.57754	-2.28	-0.08851	-0.70	X		377	1.92	13.22	-0.43062	-3.39	0.067823	0.534	1S5	708	6.79	S1
FW1-03	1U5	FW1-01	1S5	-0.14692	-0.58	-0.15633	-1.23		X	0	0	0					1U5	672	6.61	U1
FW12-01	6U7	FW4-01	2U14	-0.34255	-1.35	-0.02905	-0.23	X		474	2.40	16.57	-0.23242	-1.83	0.035337	0.278	6U7	593	3.37	S5
FW4-01	2U14	FW12-01	6U7	-0.11013	-0.43	-0.06438	-0.51		X	0	0	0					2U14	472	2.78	U2
FW3-01	2S14	FW3-03	2U9	-0.49675	-1.96	-0.0483	-0.38	X		467	2.38	16.40	-0.34002	-2.68	0.063801	0.502	2S14	609	4.38	S2
FW3-03	2U9	FW3-01	2S14	-0.15673	-0.62	-0.1121	-0.88		X	0	0	0					2U9	564	4.37	U2
FW2-03	2S9	FW3-03	2U9	-0.48035	-1.89	-0.06401	-0.50	X		467	2.38	16.39	-0.32361	-2.55	0.048086	0.378	2S9	639	5.15	S2
FW3-03	2U9	FW2-03	2S9	-0.15673	-0.62	-0.1121	-0.88		X	0	0	0					2U9	564	4.37	U2
FW9-03	5S10	FW10-02	5U10	-0.6132	-2.42	-0.04782	-0.38	X		474	2.41	16.60	-0.3925	-3.09	0.102509	0.806	5S10	697	6.43	S5
FW10-02	5U10	FW9-03	5S10	-0.2207	-0.87	-0.15033	-1.18		X	0	0	0					5U10	656	6.06	U5
FW9-02	5S2	FW10-01	5U2	-0.64973	-2.56	-0.04794	-0.38	X		474	2.41	16.60	-0.44347	-3.49	0.099993	0.786	5S2	714	6.72	S5
FW10-01	5U2	FW9-02	5S2	-0.20627	-0.81	-0.14793	-1.16		X	0	0	0					5U2	678	6.52	U5
FW2-02	2S3	FW3-02	2U3	-0.65014	-2.56	-0.0672	-0.53	X		467	2.38	16.39	-0.46477	-3.66	0.087121	0.686	2S3	693	6.58	S2
FW3-02	2U3	FW2-02	2S3	-0.18537	-0.73	-0.15432	-1.21		X	0	0	0					2U3	653	6.22	U5
FW5-02	3S7	FW7-03	3U7	-0.42176	-1.66	-0.02038	-0.16	X		565	2.86	19.75	-0.3083	-2.42	0.065735	0.516	3S7	602	3.87	S3
FW7-03	3U7	FW5-02	3S7	-0.11346	-0.45	-0.08612	-0.68		X	0	0	0					3U7	508	3.32	U3
FW5-01	3S5	FW7-02	3U5	-0.47656	-1.88	-0.02933	-0.23	X		565	2.87	19.79	-0.34333	-2.70	0.068155	0.536	3S5	612	4.3	S3
FW7-02	3U5	FW5-01	3S5	-0.13323	-0.52	-0.09748	-0.77		X	0	0	0					3U5	537	3.8	S3
FW11-02	6S10	FW12-02	6U10	-0.55608	-2.19	-0.03873	-0.30	X		558	2.83	19.52	-0.39208	-3.08	0.069169	0.544	6S10	626	4.78	S6
FW12-02	6U10	FW11-02	6S10	-0.164	-0.65	-0.1079	-0.85		X	0	0	0					6U10	564	4.34	U6
FW11-01	6S7	FW12-02	6U10	-0.55542	-2.19	-0.0436	-0.34	X		558	2.83	19.53	-0.39142	-3.08	0.0643	0.505	6S7	639	5.14	S6
FW12-02	6U10	FW11-01	6S7	-0.164	-0.65	-0.1079	-0.85		X	0	0	0					6U10	564	4.34	U6
FW4-03	3S4	FW7-01	3U4	-0.70513	-2.78	-0.03138	-0.25	X		565	2.87	19.80	-0.51681	-4.06	0.1436	1.129	3S4	707	6.59	S3
FW7-01	3U4	FW4-03	3S4	-0.18833	-0.74	-0.17498	-1.37		X	0	0	0					3U4	670	6.28	U3
FW10-03	6S2	FW11-03	6U2	-0.77204	-3.04	-0.02931	-0.23	X		558	2.83	19.53	-0.64983	-5.11	0.140608	1.105	6S2	708	6.87	S6
FW11-03	6U2	FW10-03	6S2	-0.12221	-0.48	-0.16991	-1.34		X	0	0	0					6U2	677	6.73	U6

4. Analysis Methodology

4.1. Methodology steps

The methodology for calculating the creep strain within the AGC-1 specimens is outlined below. While the calculation is not complex, gathering and sorting the contributing data for all matched pairs within an AGC irradiation capsule is complicated. Assuring accuracy within the calculations required a methodical approach to correctly identify the matching pairs, calculate the before and after dimensional and elastic modulus changes, and apply the appropriate stress for each matched pair. The resulting methodology was used for each matched pair.

1.	**Calculate the dimensional change for each specimen**
	Both creep and control specimens
	Both length and diametral directions should be calculated.
	Calculate the volume change from length and diametral data
2.	**Determine the appropriate creep and control specimen pair**
	Pairing based upon graphite grade and core axial position
	Calculate the mean dose received between the pair
3.	**Sort dimensional change data**
	Arrange data in order of ascending applied stress
	Then sort by each applied stress
	Then sort by ascending dose received
4.	**Calculate the longitudinal and diametral creep strain (mm)**
	Subtract the dimensional change of the control specimens from the creep specimen dimensional change
5.	**Calculate the creep strain as a % of the unirradiated creep specimen dimensions.**
6.	**Plot lateral and longitudinal creep strain against the mean dose**
	The mean values for both creep and control specimen
7.	**Calculate the Primary Creep as σ_{app}/E_0**
	E_0 is the Pre-IE elastic modulus measured by Fundamental Frequency method.
	σ_{app} is the measured applied stress to the specimen during irradiation
	Lateral stress is calculated using the measured pre-IE Poisson's Ratio Value
8.	**Subtract the primary creep assumed to be σ/E_0.**
9.	**Normalize creep strain**
	Multiply the creep strain by the ratio of the maximum stress (3 ksi) to the applied stress on the specimen
	This should collapse all data onto a single line
10.	**Determine creep constant/coefficient (gradient) of secondary creep strain.**
	Fit line to normalized data plot
11.	**Assuming Linear creep law: Creep Ɛ(Total) = Ɛ(Primary) + Ɛ(Secondary)**
	Applying Equation 1 and Equation 2 give K in the correct units of %/dpa.MPa

To illustrate the results from this creep strain calculation methodology the data from H-451 is presented in Figures 6-14. Dimensional changes results (steps 1-3 of the analysis methodology) are plotted for H-451 in Figure 6 to Figure 8. The calculated creep strains (steps 4-6 of the analysis methodology) are presented in Figure 9 to Figure 11. Finally, the secondary creep constant is determined from the normalized data plot (steps 7-11) for all applied stress levels in Figure 11 & 12.

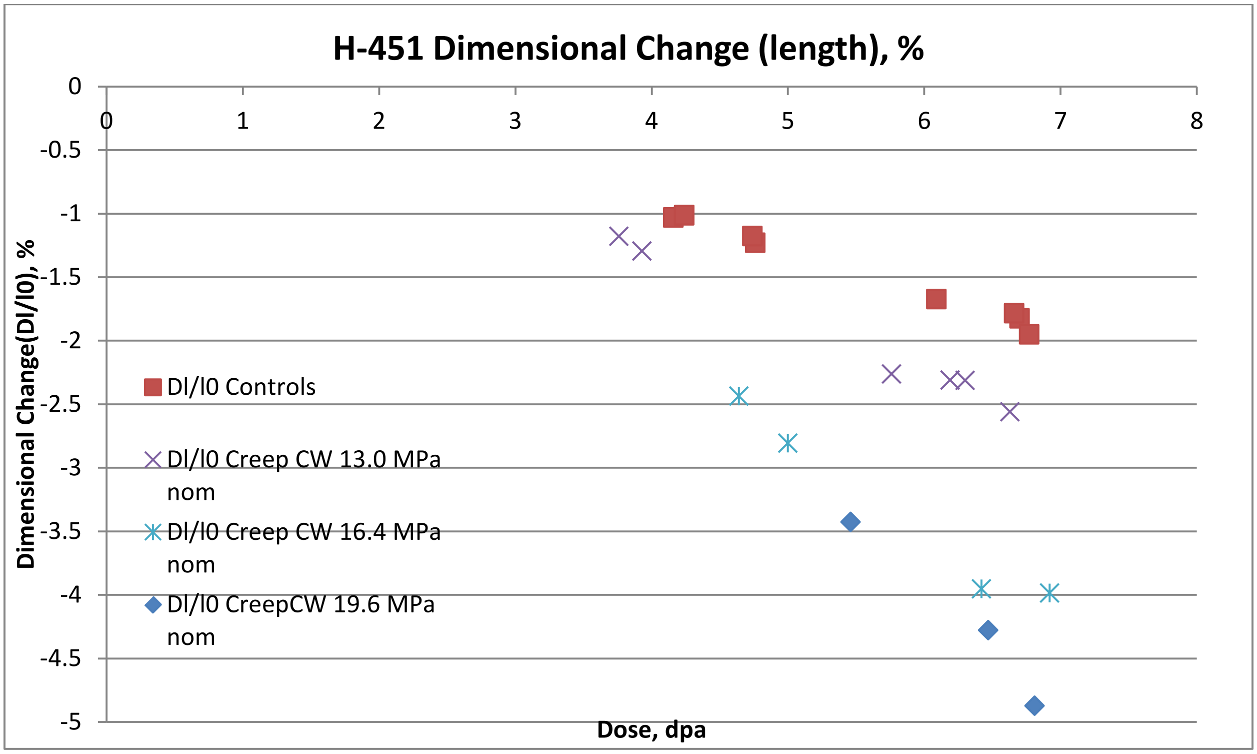

Figure 6 Dimensional changes (length) for H-451 graphite creep and control specimens

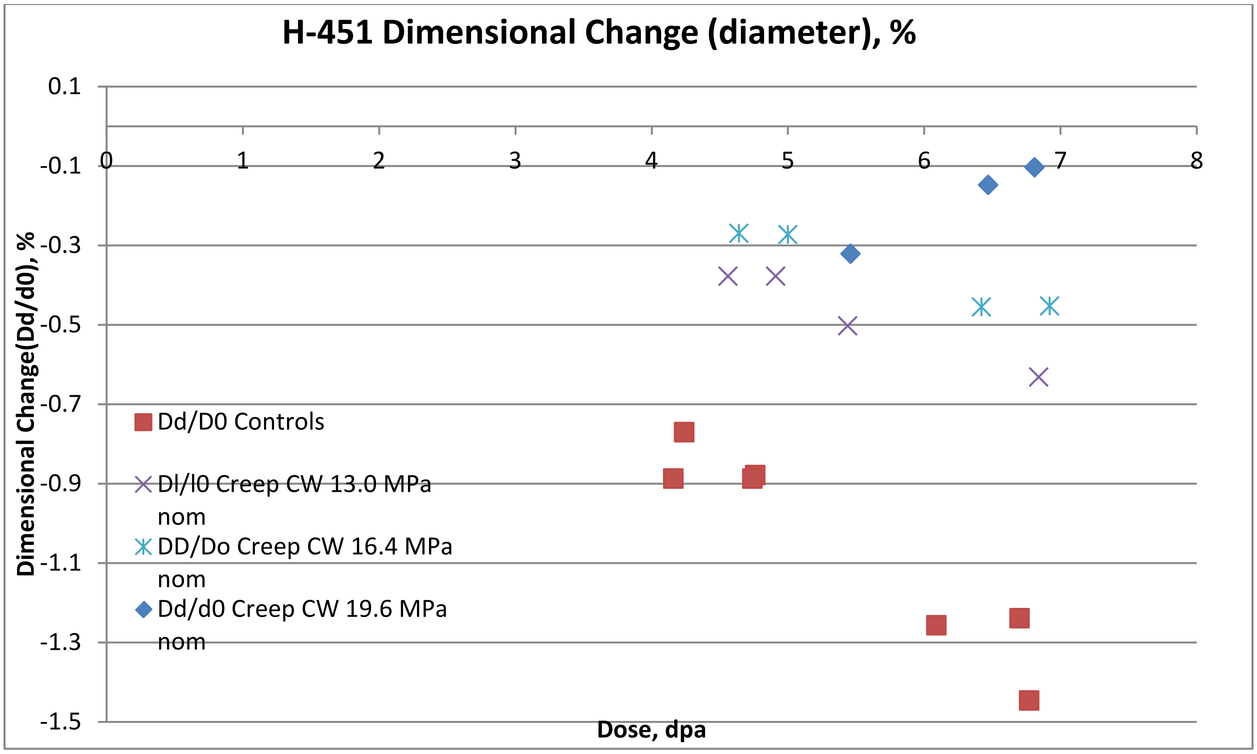

Figure 7 Dimensional change (Diameter) for H-451 graphite creep and control specimens

Considering the dimensional change of the AGC-1 H-451 controls (Figure 8) we see that for a given dose the longitudinal dimensional change exceeds the diametral dimensional change. This behavior is consistent with observed behavior of extruded graphite grades when considering (i) the orientation of filler particles on extrusion along the length direction, (ii) the c-axis crystal structure being predominantly aligned along the length of the filler particles, (iii) the expansion of the c-axis due to displacement damage being initially accommodated by aligned thermal shrinkage cracks, thus the length direction suffers more a-axis shrinkage on average even though the crystallites are simultaneously expanding (c-axis) and shrinking (a-axis). Since the initial shrinkage behavior and anisotropy is dependent upon the amount of available thermal induced microcrack accommodation, higher temperatures are deleterious to the graphite behavior because of thermal closure of the accommodation cracks.

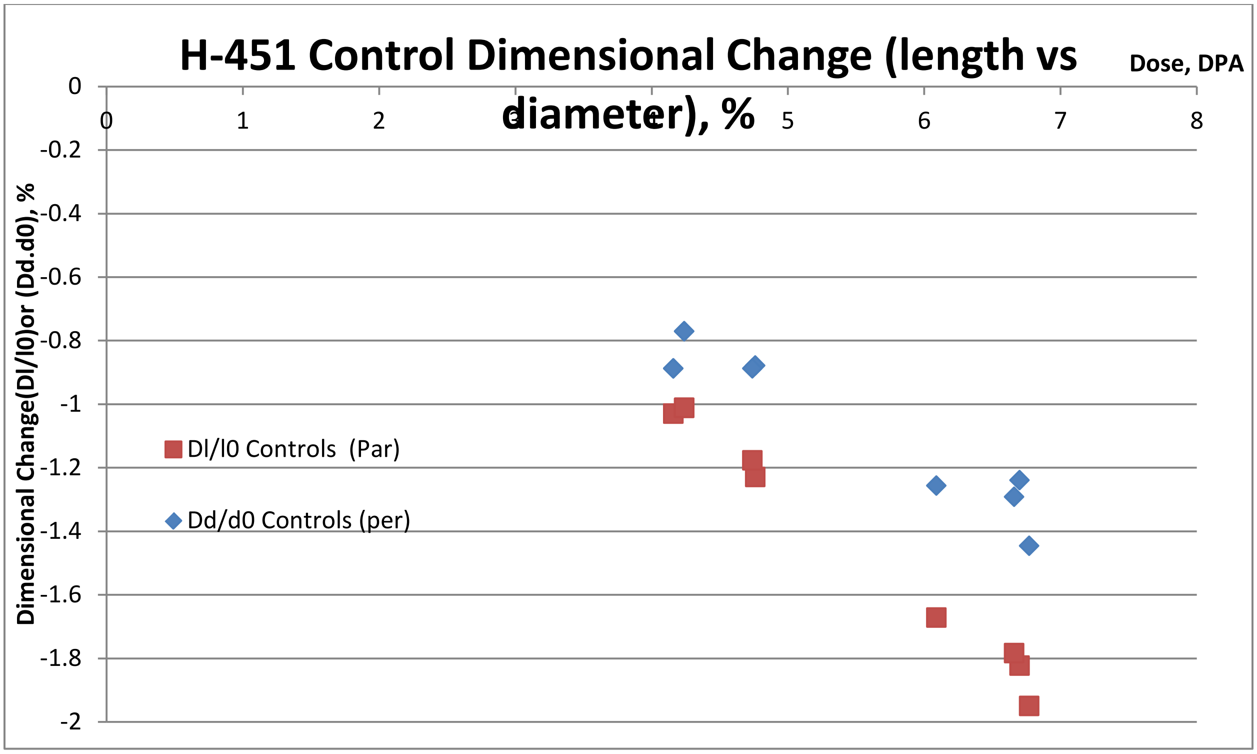

Figure 8 H-451 dimensional change (control only) showing the anisotropic behavior of extruded graphite

The longitudinal creep strain can now be calculated by determining the difference between the creep and control specimen length (step 4, 5 and 6). The creep line should be proportional to the stress, i.e., larger stress - steeper line – more strain (Figure 9 and Figure 10). The longitudinal strain is calculated from the specimen length change and for these lower doses is linear. The creep stain is negative because the creep specimens are subjected to a compressive stress. The magnitude of the strain is proportional to the applied stress. Figure 10 shows the induced lateral creep strain (from specimen diameters). This strain should be positive since it results from the Poisson's Stress which producing an outward tensile force which pushes the sides of the specimen laterally. For the Primary Creep, a point at zero dose with creep strain magnitude equal to $\sigma_{Max}/E(0)$, is shown in both Figure 9 and Figure 10.

The creep strain for both the longitudinal and lateral directions are plotted at the mean dose of the creep and control specimen. Ideally the creep and control specimen will have been irradiated under identical conditions (i.e. at the same temperature and to the same dose). Regrettably, the temperature control was not ideal in AGC-1 and the specimen pairs were as much as ~180°C apart for some of the creep specimens. Moreover, there was a very large temperature difference between the capsule mid plane and the capsule periphery (as much as 300°C).

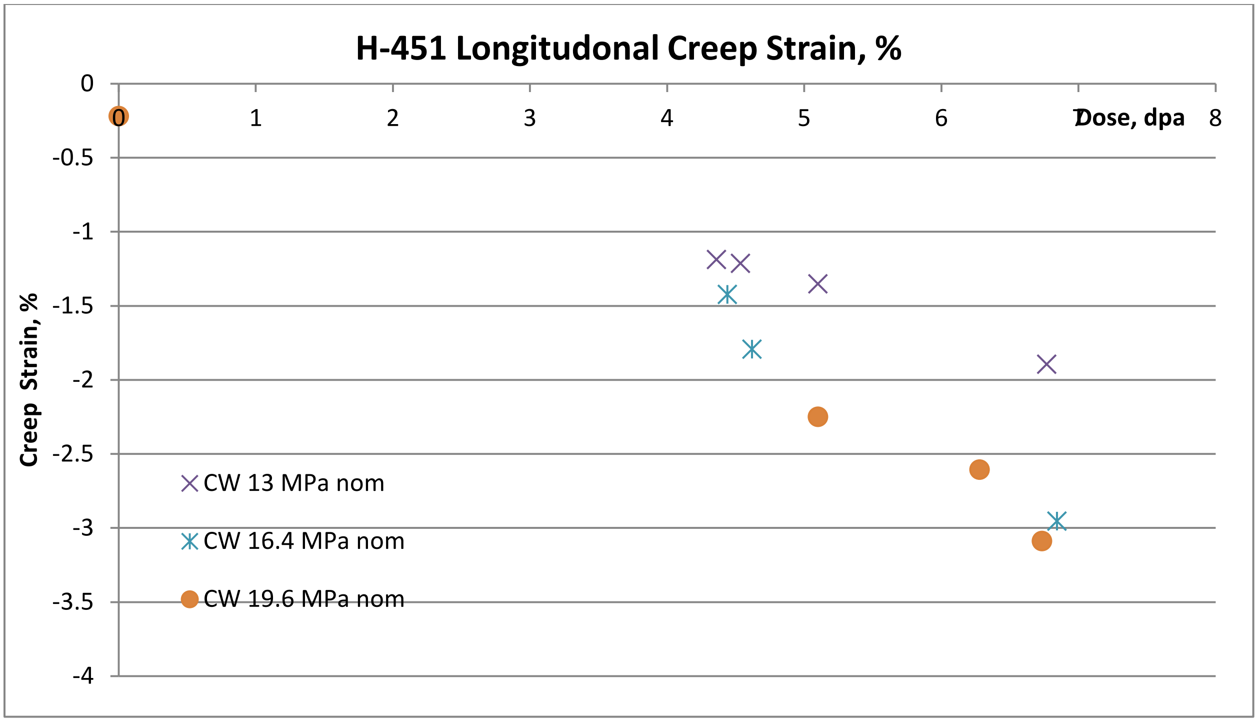

Figure 9 H-451 Longitudinal creep strain

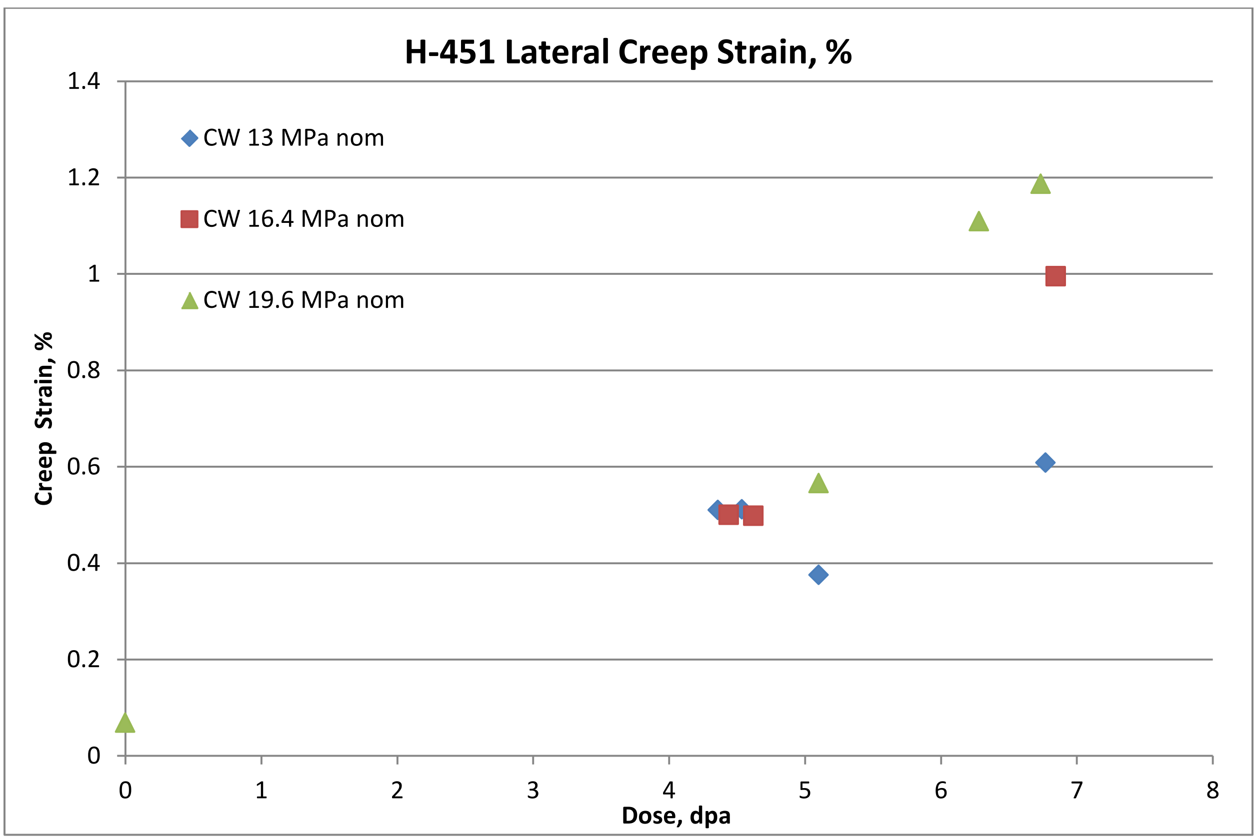

Figure 10 H-451 Lateral creep strain

The secondary creep strain is now calculated by subtracting the primary creep component (σ/E_0), and the data normalized to the stress level by multiplying each data point by the ratio of the maximum stress to the maximum applied stress. All the secondary creep strain data should now collapse to a single straight line from which the secondary creep constant K can be determined (steps 7, 8 and 9). Note for this analysis we use the mean elastic modulus, E_0, measured and reported as flexural dynamic modulus in ORNL/TM-210/285 table 34.[6] This results in a small and assumed negligible, difference in the magnitude of the calculated primary creep strain. In further analysis of the AGC-1 creep data we have the option of using the actual E_0 measured for the individual unirradiated specimens.

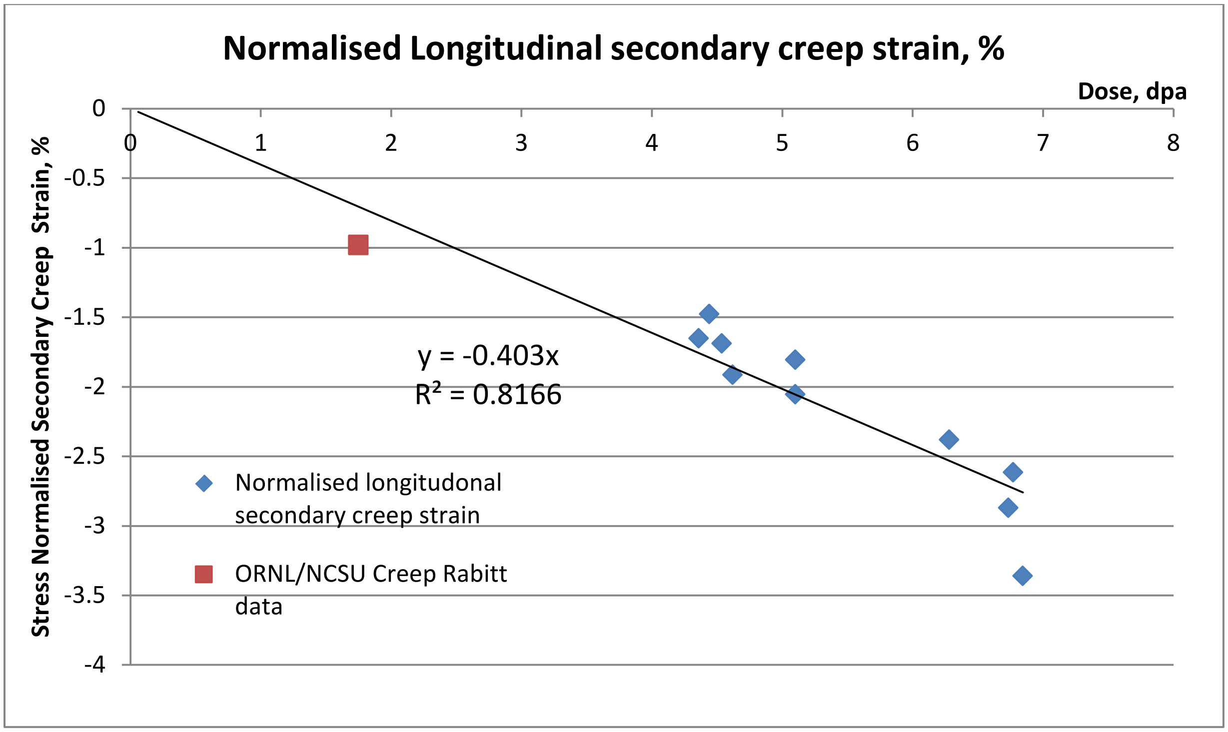

Figure 11 Stress Normalized longitudinal secondary creep strain for H-451

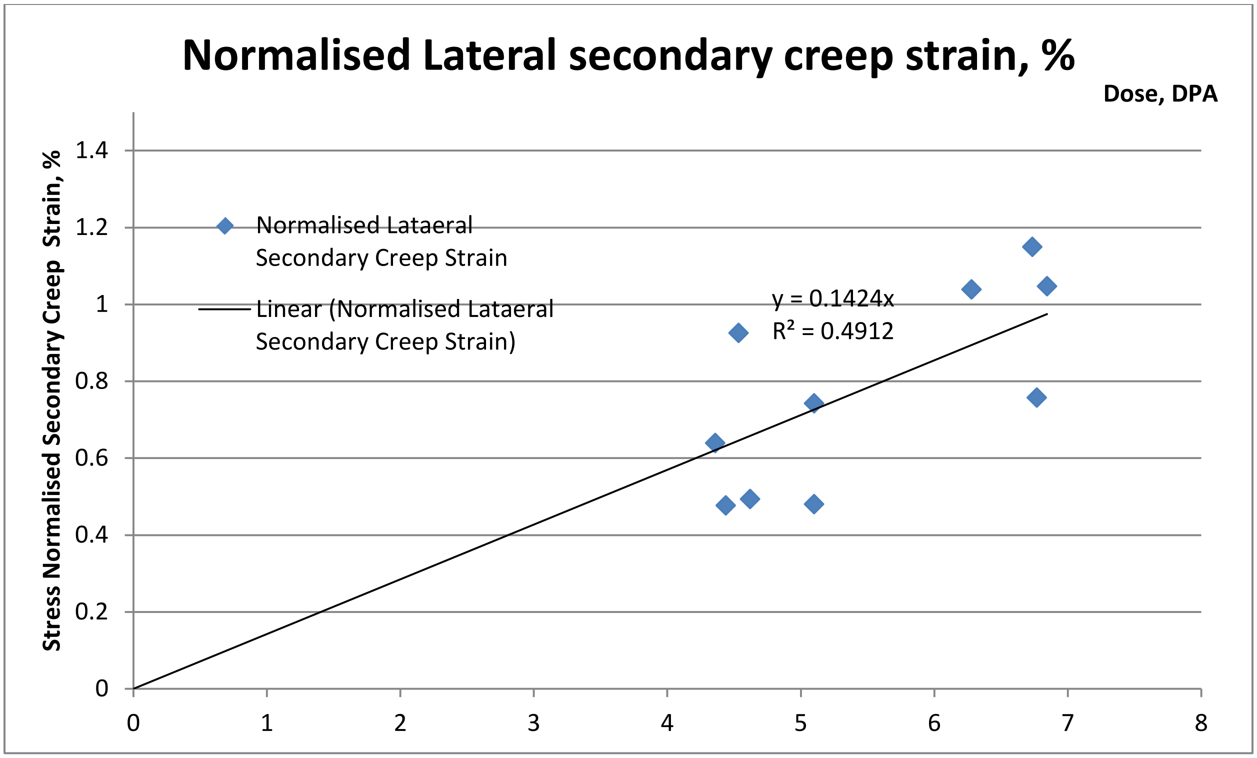

Figure 12 Normalized lateral secondary creep strain for H-451

The normalized lateral and longitudinal secondary creep data are both linear indicating there are no structure effects at these doses. Thus we may apply the linear viscoelastic creep law:

$$\varepsilon_{(TOTAL)} = \varepsilon_{PRIMARY} + \varepsilon_{SECONDARY} \ (\%)$$

$$\varepsilon_{PRIMARY} = \frac{\sigma}{E_0}(\%)$$

$$\boldsymbol{\varepsilon_{SECONDARY} = K\sigma\gamma} \ (\%)$$

Equation 1

Where

K = K'/σ(max) = secondary creep constant %/DDA.MPa

Equation 2

σ = Applied Stress (MPa)

Y = neutron dose, dpa

From Figure 11 the longitudinal creep constant K = (-0.403/19.809) = -0.0203 and from Figure 12 the lateral creep constant is estimated at K = (0.1424/5.49) = 0.0259 (analysis steps 10 and 11). Note the later value for K from the diametral data is not as reliable since the lateral strain on the creep specimens is not uniform; rather the specimen tends to take up a barrel shape due to frictional restraint of the specimens at the ends. None the less, it is satisfying that both creep strains give similar creep constants! Similar creep constants indicate near isotropic graphite behavior for the nuclear grade H-451.

Finally, in Figure 13 and Figure 14, the creep strain ratio can be obtained by plotting the best fit line gradients of the total strain (in microns) induced in the longitudinal and in the diametral direction. For H-451, the Creep Strain Ratio = lateral creep strain/longitudinal creep strain. Thus, using the gradients calculated for each direction yields a strain ratio = 18.11/-102.18 = -0.18.

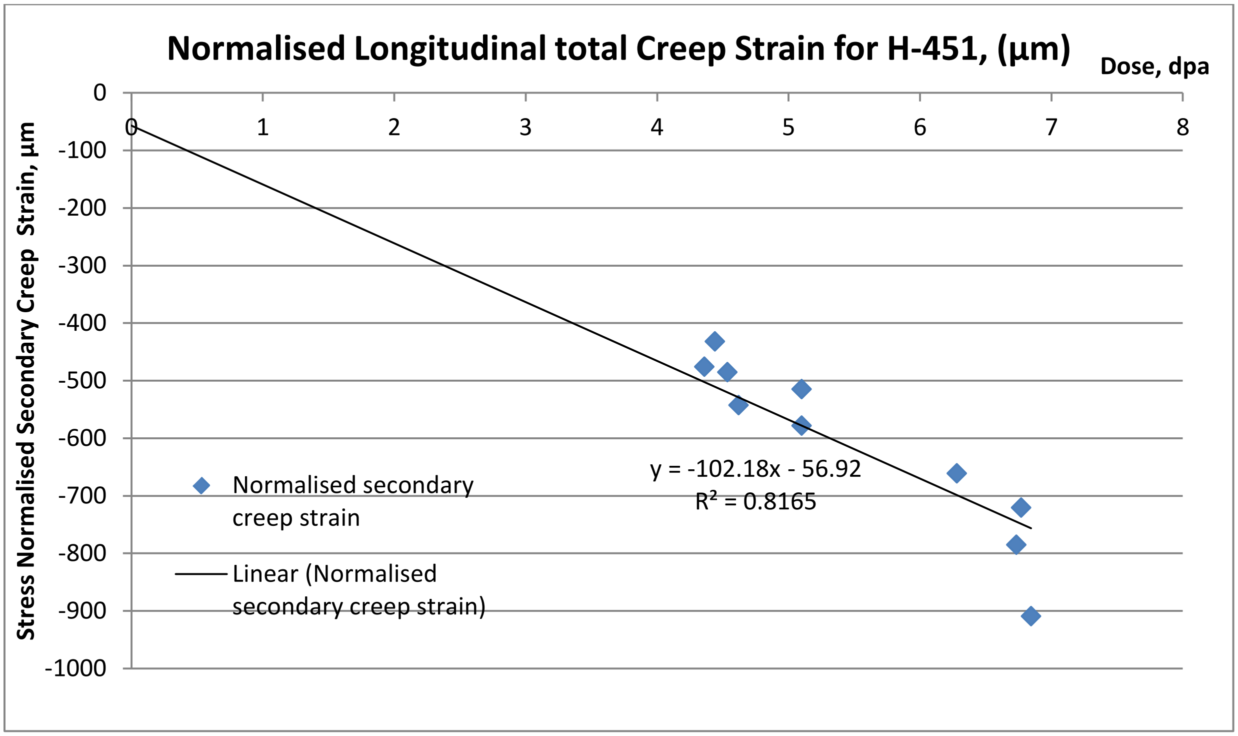

Figure 13 Stress normalized creep strain (microns) in longitudinal direction

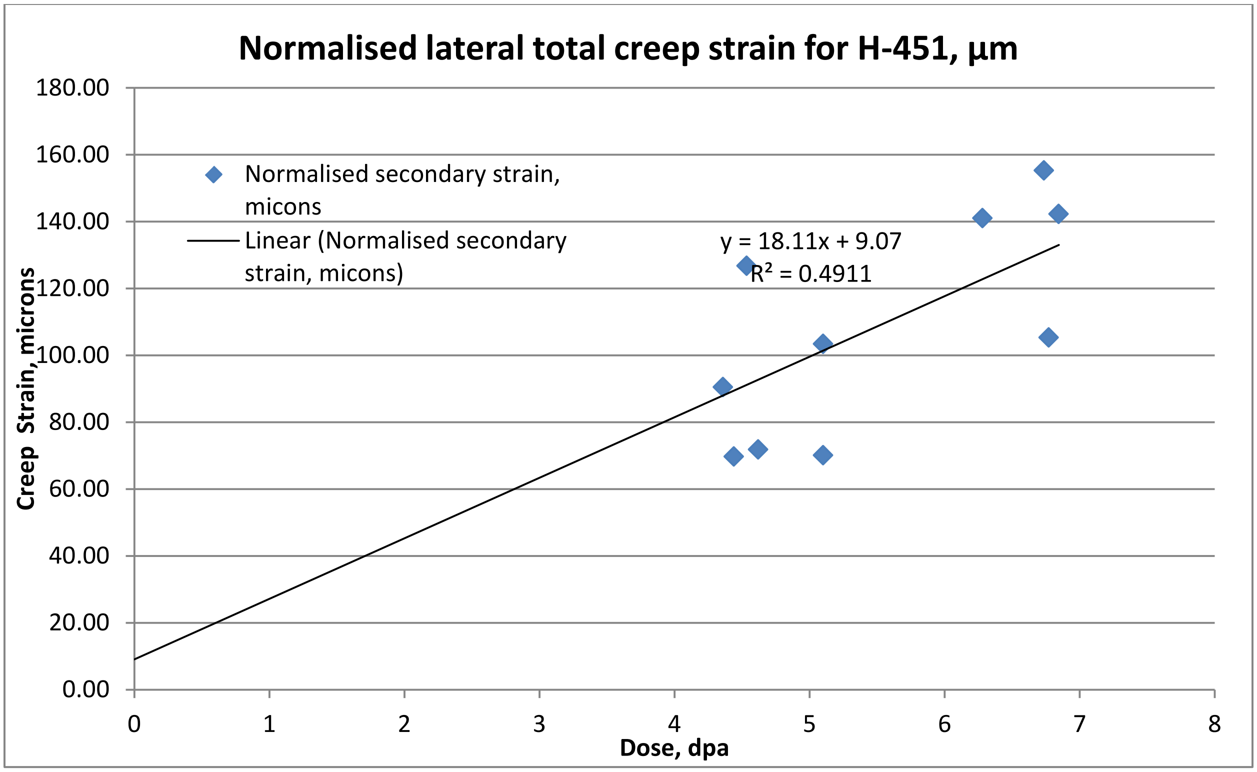

Figure 14 Stress normalized creep strain (microns) in diametral direction

The initial assessment of the creep strain calculation methodology appears to produce reasonable results. Creep strains, data trends, and the calculated results are well within expectations for the AGC experiment. A more detailed analysis of the results comparing the data to previous studies of irradiated nuclear graphite is discussed in the following section.

4.2. Analysis, Observations and Discussion of analysis method

Since the AGC-1 irradiation test train had never been built before and was considered a first-build, prototype it was considered prudent to verify the creep strain values obtained from the irradiated test. Historical grade H-451 was selected for this first irradiation capsule because of the extensive experience with this graphite grade and its large irradiation history (prior data) which could be used to compare with the AGC-1 results. To assess the validity of the creep strain methodology, the H-451 irradiation behavior trends seen in AGC-1 analysis were compared to data and trends from previous studies. The H-451 data from the current study should be very similar to these past studies as the specimens came from the same billet material.

Taking the dimensional change of the AGC-1 H-451 control specimens (Figure 8) and comparing it to previous unstressed H-451 irradiation studies it can be seen that for the AGC-1 dose range the magnitude of the AGC-1 dimensional changes is of the correct order compared to previous H-451 dimensional changes data as shown in Figure 15. Moreover, the AGC-1 data shows no signs of the onset of turnaround. This indicates (i) insufficient dose at the irradiation temperature, or (ii) the average irradiation temperature was below that of HTF-2 (875°C). Note the evidence of turnaround in the HTF-2 data in Figure 15. The control dimensional data suggest the irradiation temperature did not exceed 875°C but may in some instances been less than 600°C.

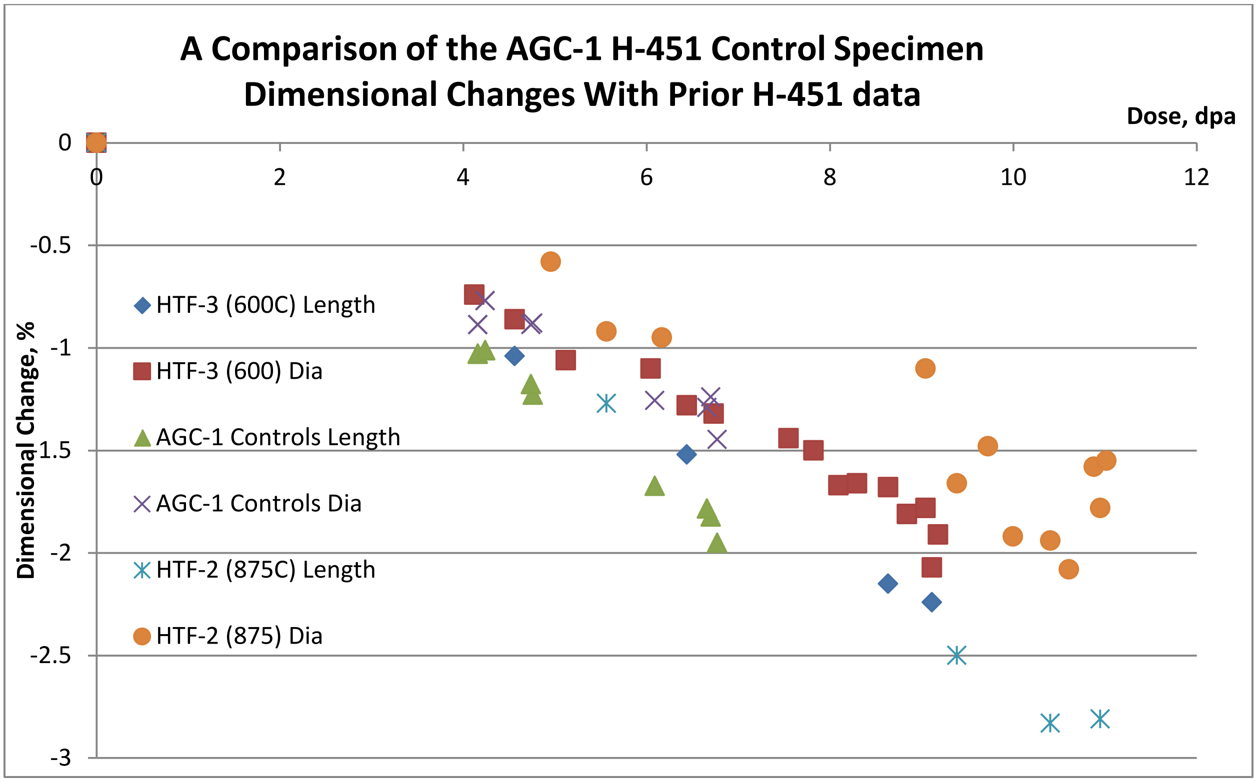

Figure 15 H-451 dimensional change data from various experiments

These results for the H-451 graphite grade are reasonable and expected from previous experience. The results match well with negative measured strains in the longitudinal direction and positive strains in the lateral direction. The secondary creep strain is linear allowing a constant creep strain rate constant to be calculated. Additionally, the strain increases as the applied stress is increased over the range of neutron dose received.

While the measured response is as expected there remains the issue of varying temperatures though the irradiation capsule. AGC-1 was designed to have a constant temperature across the entire axial length of the capsule with no more than a ±50°C variation from capsule end to core mid-plane position. These creep strain measurements are designed to have as little variation as possible across the entire capsule but keeping the temperature differences between matched pairs is critical for determining an accurate creep strain measurements. It remains to be seen how much the temperature variations will affect the strain rate calculation. This will be discussed in more detail in the following sections.

5. Dimensional and Volume Changes Analysis by Grade

Before determining the creep constants and creep ratios for the AGC-1 major graphite grades the dimensional and volume changes for the remaining major AGC-1 graphite grades will be determined. Analysis and comparisons will be made between the two historic grades of graphite (H-451 & IG-110), the two vibrationally molded grades (NBG-18 & NBG-17), the extruded graphite grades (H-451 & PCEA), and the two isostatically molded grades (IG-110 & IG-430).

As seen with the previous verification calculations for H-451, the dimensional change exhibited by the stressed samples in the longitudinal (WG) and diameter (AG) direction are markedly different. Not only is the underlying behavior different as seen in Figure 8 but the direction and sign of the stress matters, The Longitudinal direction is under a compressive stress while the diametral direction is under an induced tensile stress (Poisson's effect). The diametral data is somewhat more scattered as the specimens tend to adopt a barrel shape due to end face friction.

5.1. Dimensional and Volume Changes for Grade H-451 (Code C)

Dimensional changes have been determined previously in section 4.1 and illustrated in Figure 6 through Figure 8. The volume change behavior of the H-451 Creep and Control AGC-1 specimens are calculated from the pre-IE and PIE dimensional measurements and shown in Figure 16. Significantly, the volume change behavior is similar for the creep and control specimens, despite the creep specimens being irradiated under stress.

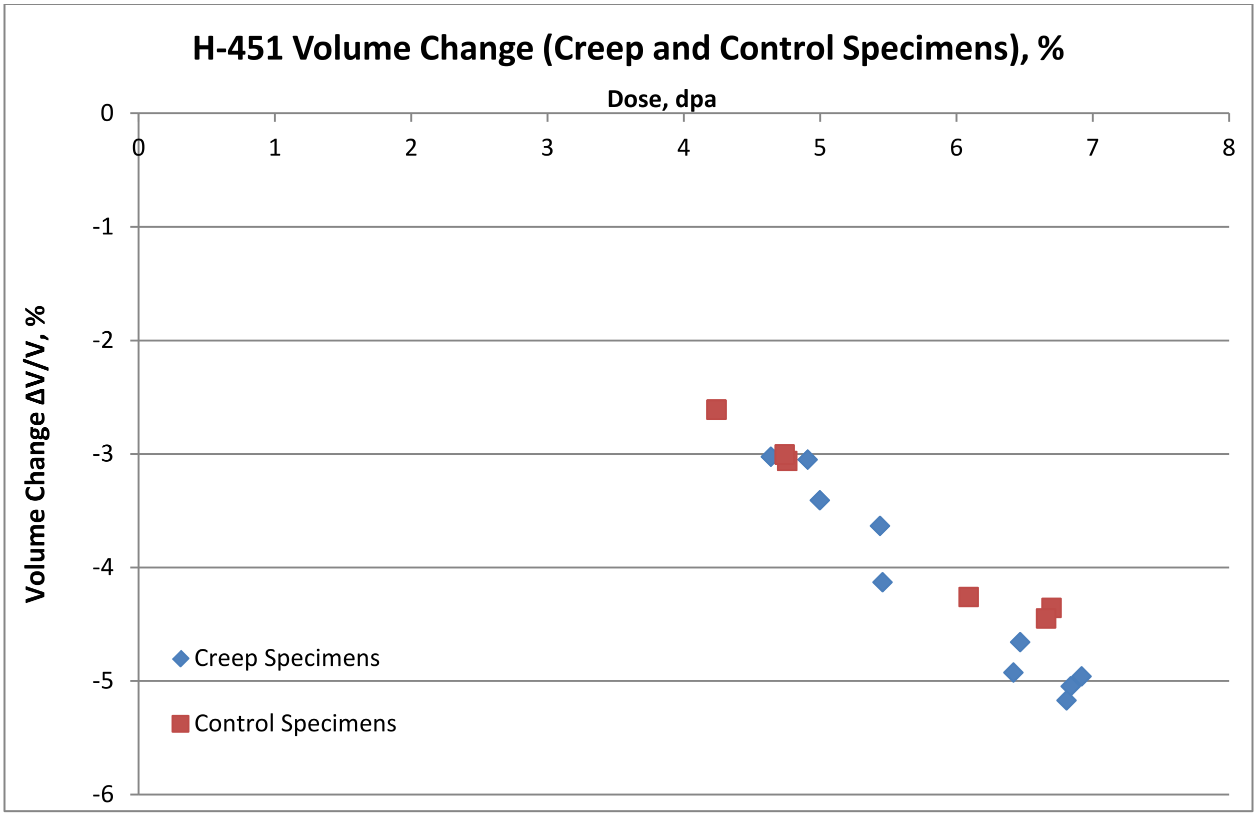

Figure 16 Volume change data for H-451 from the AGC-1 capsule

This type of volume behavior suggests that creep is volume conserving which has been seen and reported in the past.[11,12] This topic is discussed further in Section 7.1.

5.2. Dimensional and Volume Changes for Grade IG-110 (Code E)

The dimensional changes observed from AGC-1 for grade IG-110 are shown in Figure 17, Figure 18 and Figure 19. There is only minimal anisotropy shown in the irradiation induced dimensional changes of iso-molded grade IG-110 controls (Figure 19) compared to the extruded grade H-451.

Data also exists for grade IG-110 from a previous high dose experiment (HTK-7) at ORNL. These data for dimensional changes are plotted along with the AGC-1 data in Figure 20. The new AGC data form a continuous curve with the previous high dose IG-110 dimensional change data from HFIR experiment HTK-7. This implies that the irradiation temperature for AGC-1 was reasonably close to HTK-7, say ± 150°C, of HTK-7, which was a 600°C irradiation.

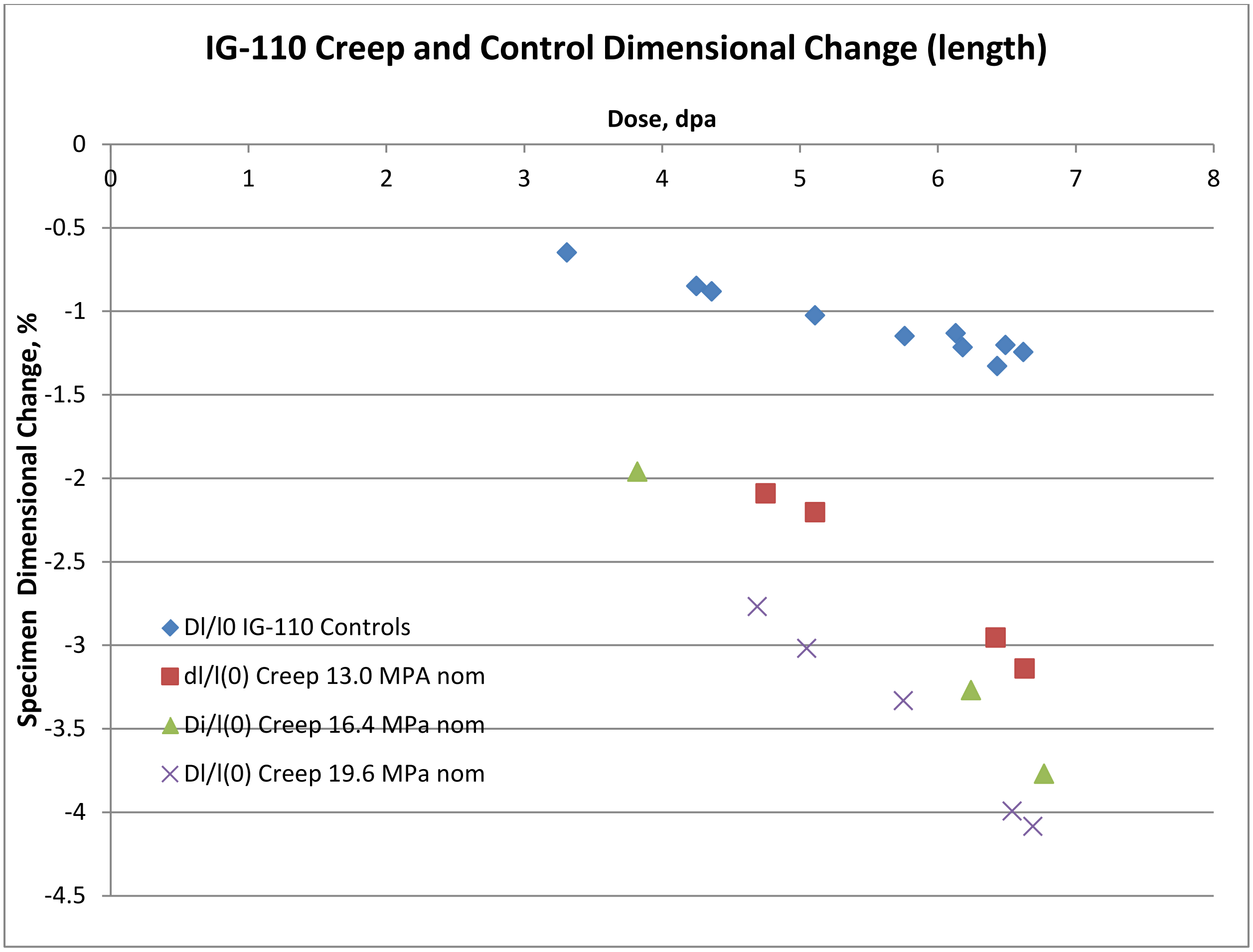

Figure 17 Dimensional changes (length) of IG-110 creep and control specimens from AGC-1

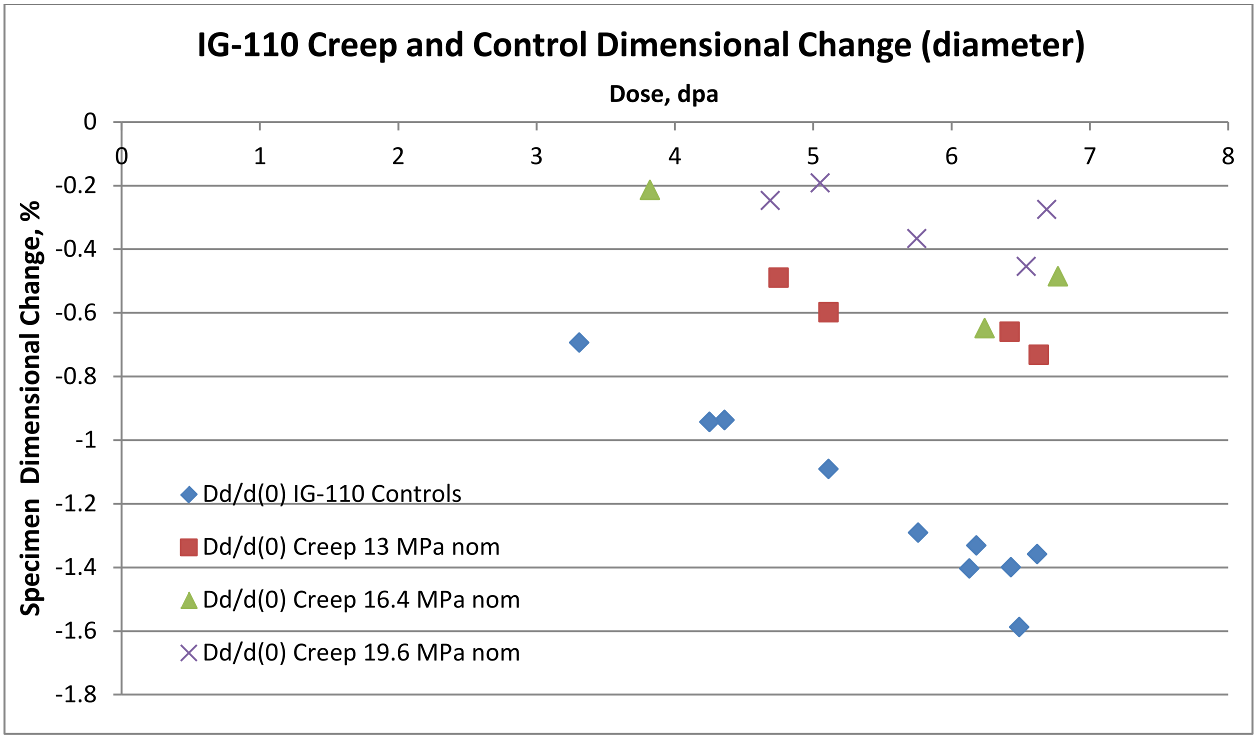

Figure 18 Dimensional changes (Diameter) of IG-110 creep and control specimens from AGC-1

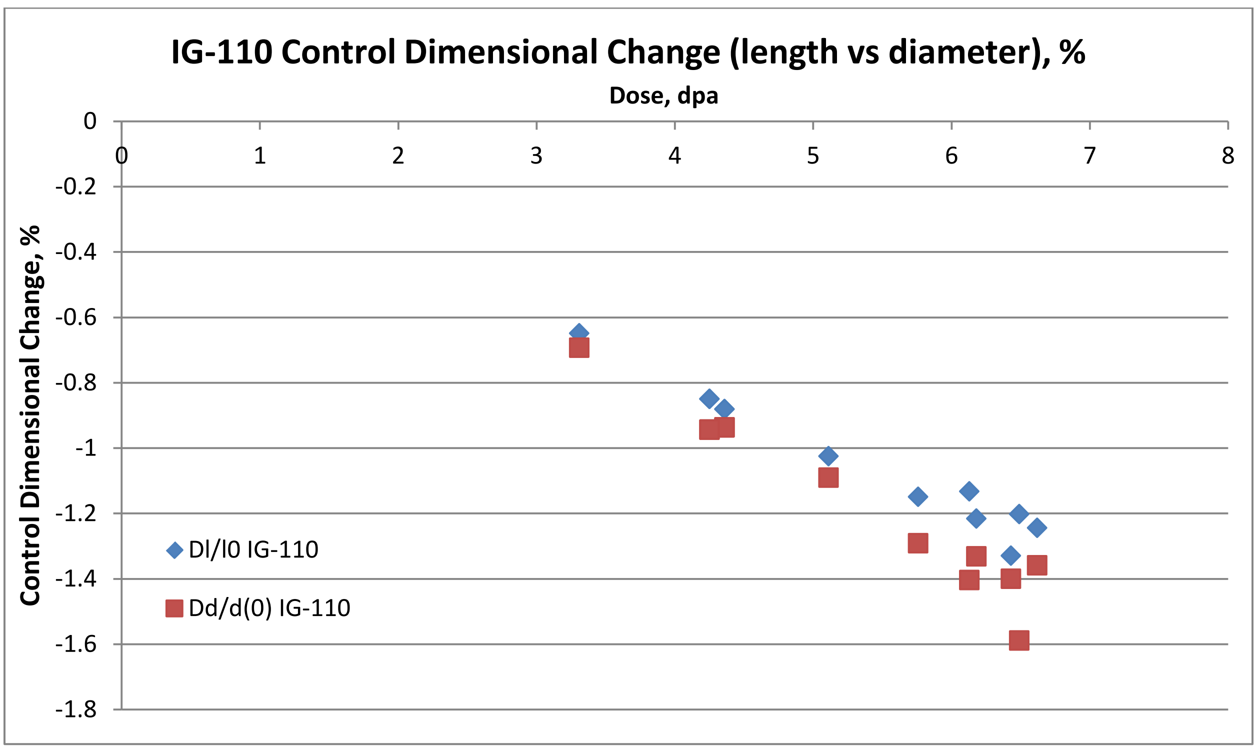

Figure 19 Dimensional changes of IG-110 control specimens in the length and diametral direction illustrating the very slight anisotropy of the iso-molded grade (data from AGC-1)

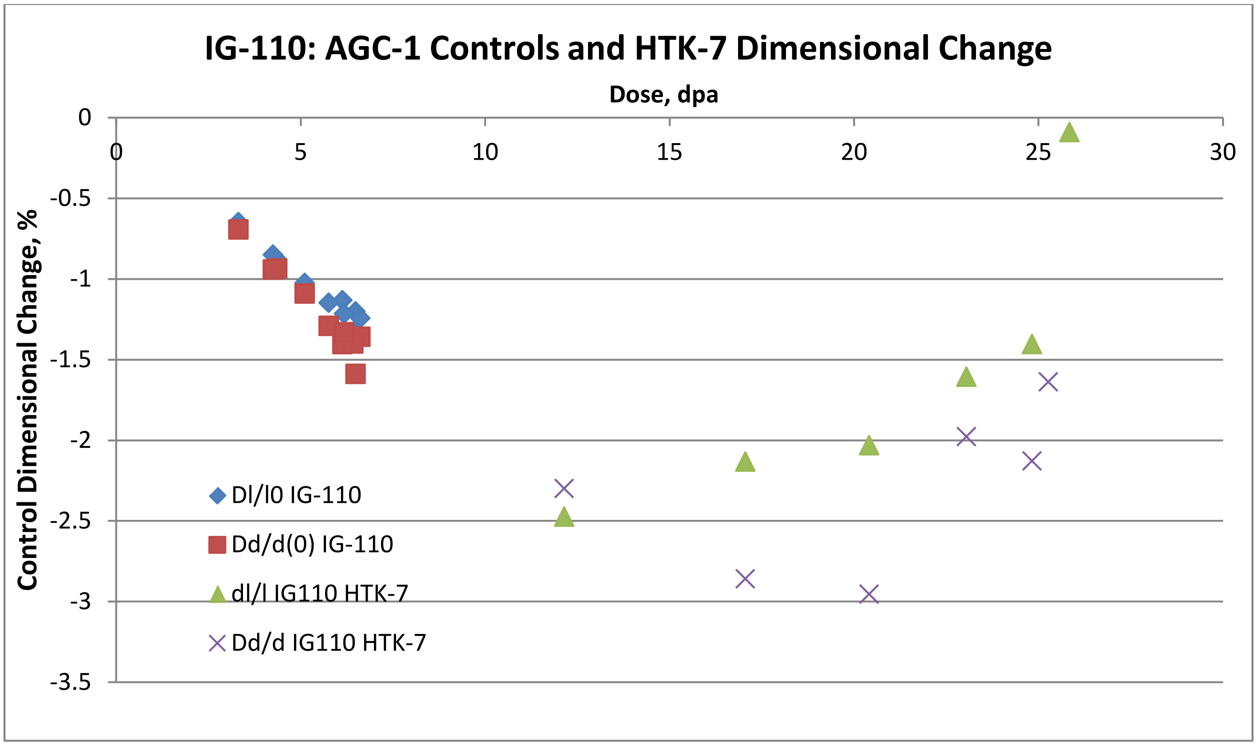

Figure 20 Comparison of Grade IG-110 Behavior from Experiments AGC-1 and HTK-7

The Volume change behavior of IG-110 is reported in Figure 21.

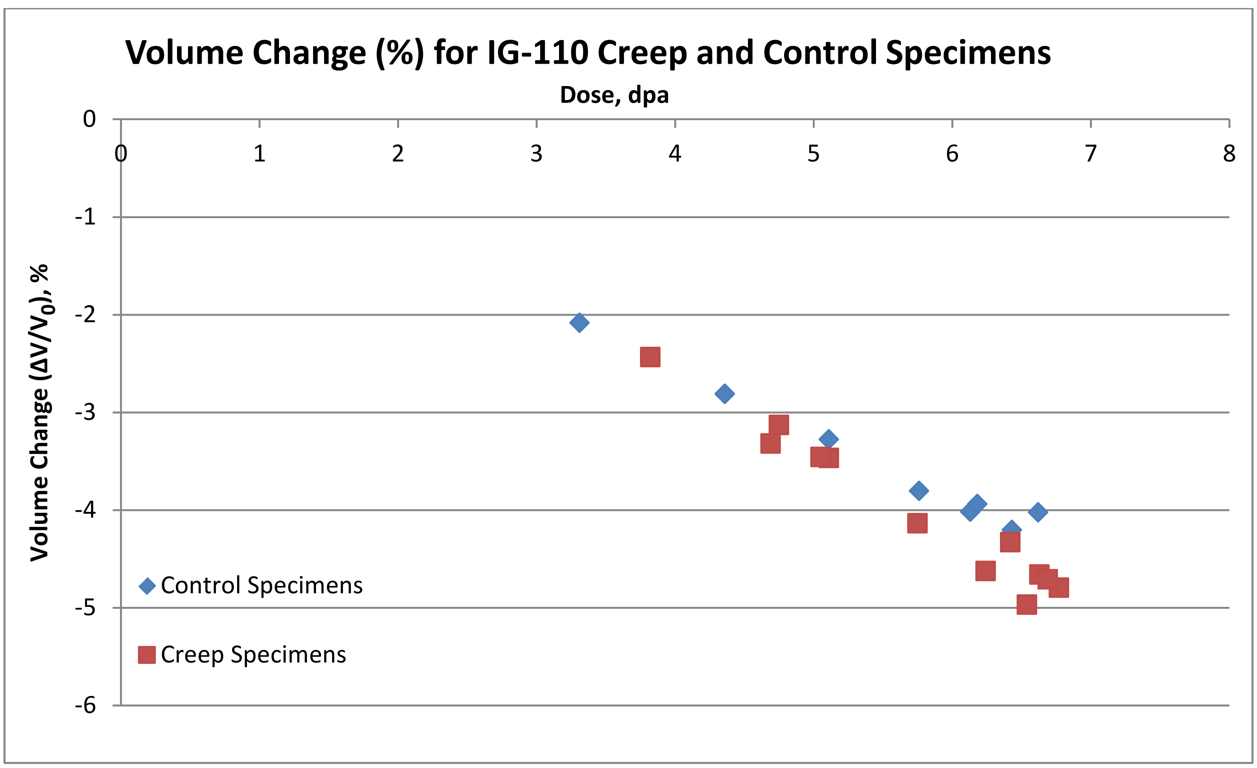

Figure 21 Volume change data for IG-110 from the AGC-1 capsule

Again the dimensional changes for the creep and control longitudinal and diametral directions were completely different, yet the volume behavior is remarkably similar, as it was for the case of H-451 (Figure 16). This suggests again that creep is volume conserving at the doses observed in AGC-1.

5.3. Dimensional and Volume Changes for Grade NBG-17 (Code A)

The dimensional changes observed from AGC-1 for grade NBG-17 are shown in Figure 22, Figure 23 and Figure 24. Similarly to IG-110 there is only minimal anisotropy shown in the irradiation induced dimensional changes of this vibrationally molded grade NBG-17 (Figure 24) compared to the extruded grade H-451 (Figure 8).

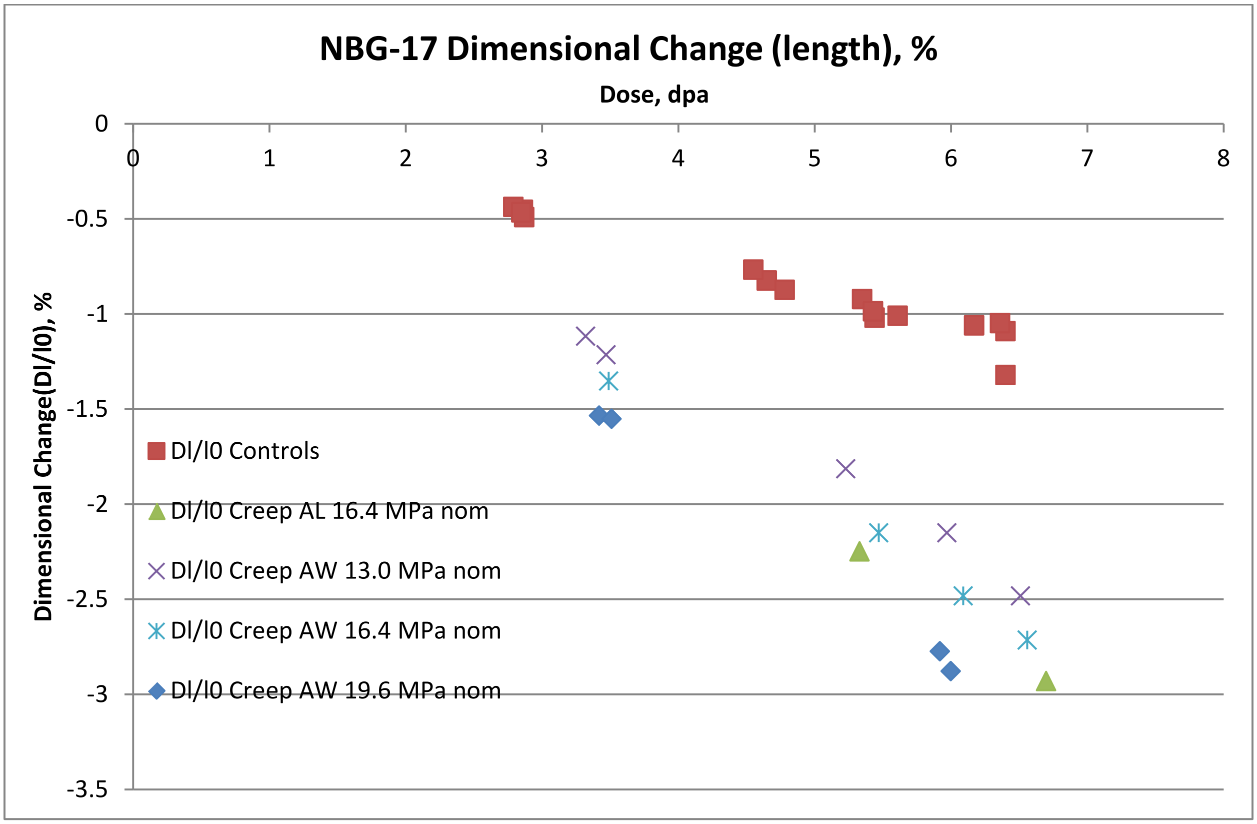

Figure 22 Dimensional changes (length) of NBG-17 creep and control specimens from AGC-1

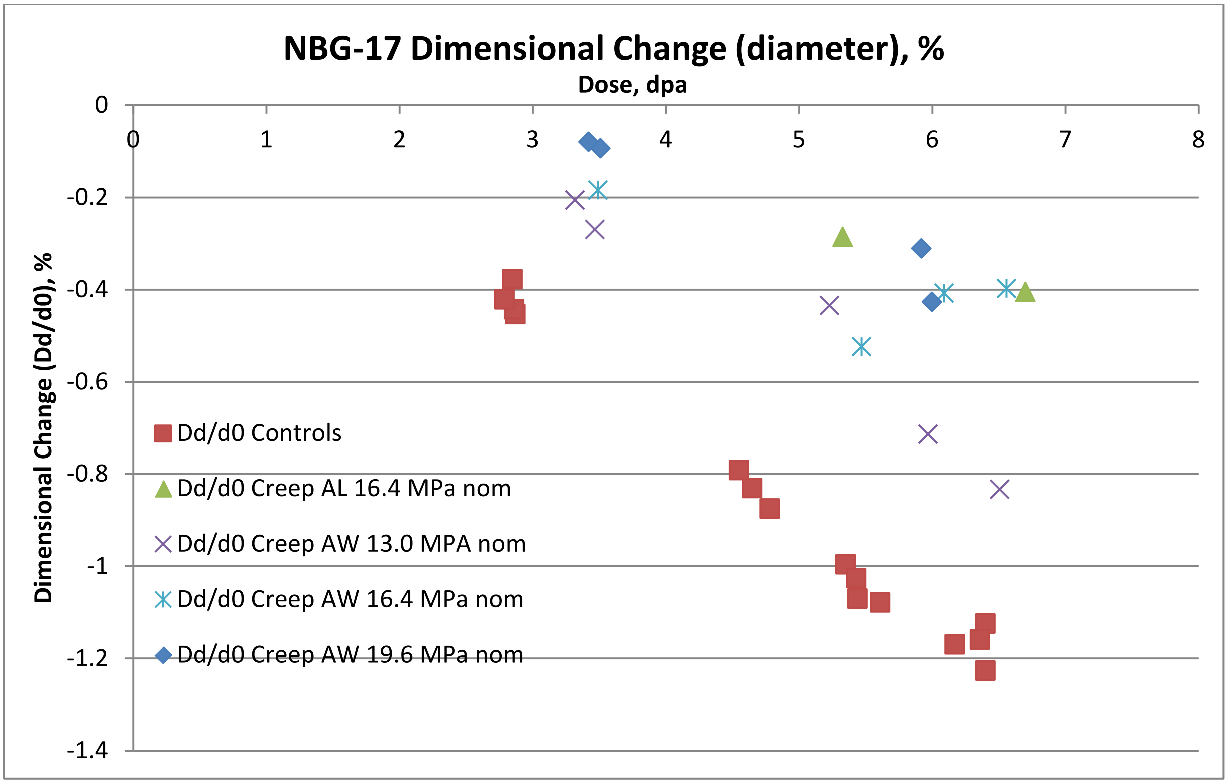

Figure 23 Dimensional changes (Diameter) of NBG-17 creep and control specimens from AGC-1

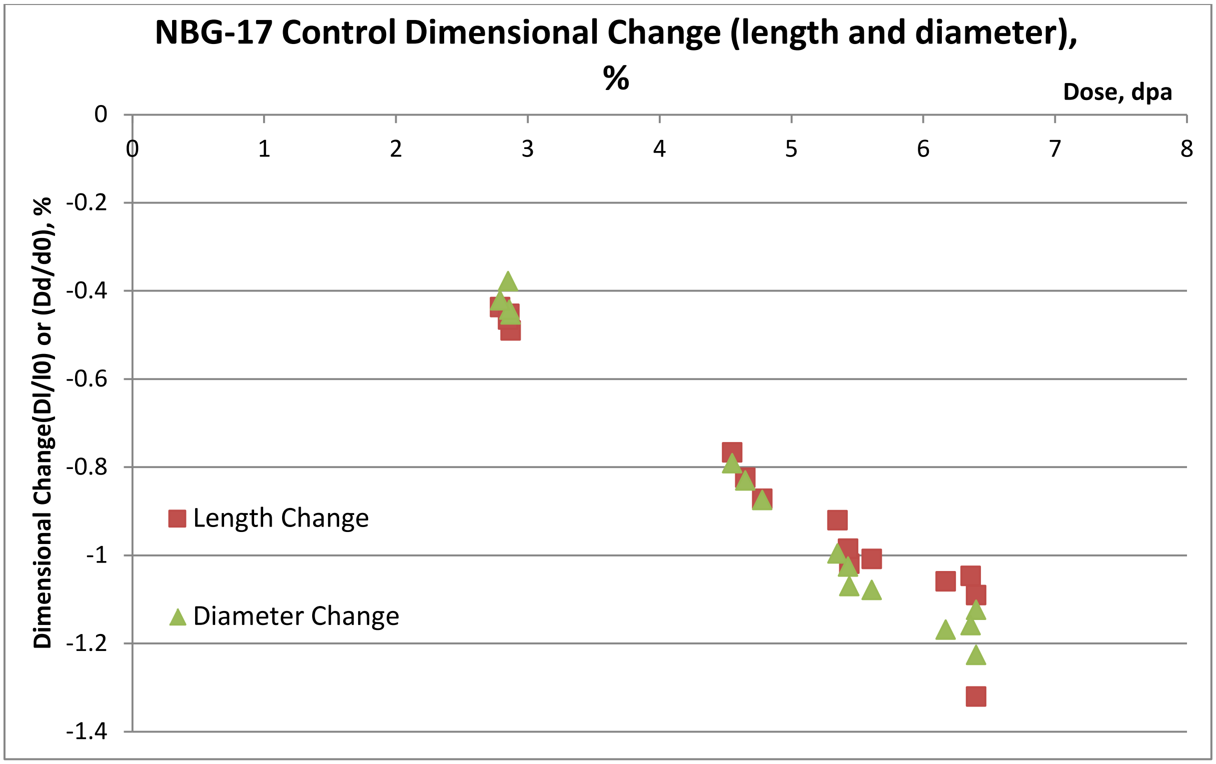

Figure 24 Dimensional changes of NBG-17 control specimens in the length and diametral direction illustrating the very slight anisotropy of the vibro-molded grade (data from AGC-1)

The Volume change behavior of NBG-17 is reported in Figure 25.

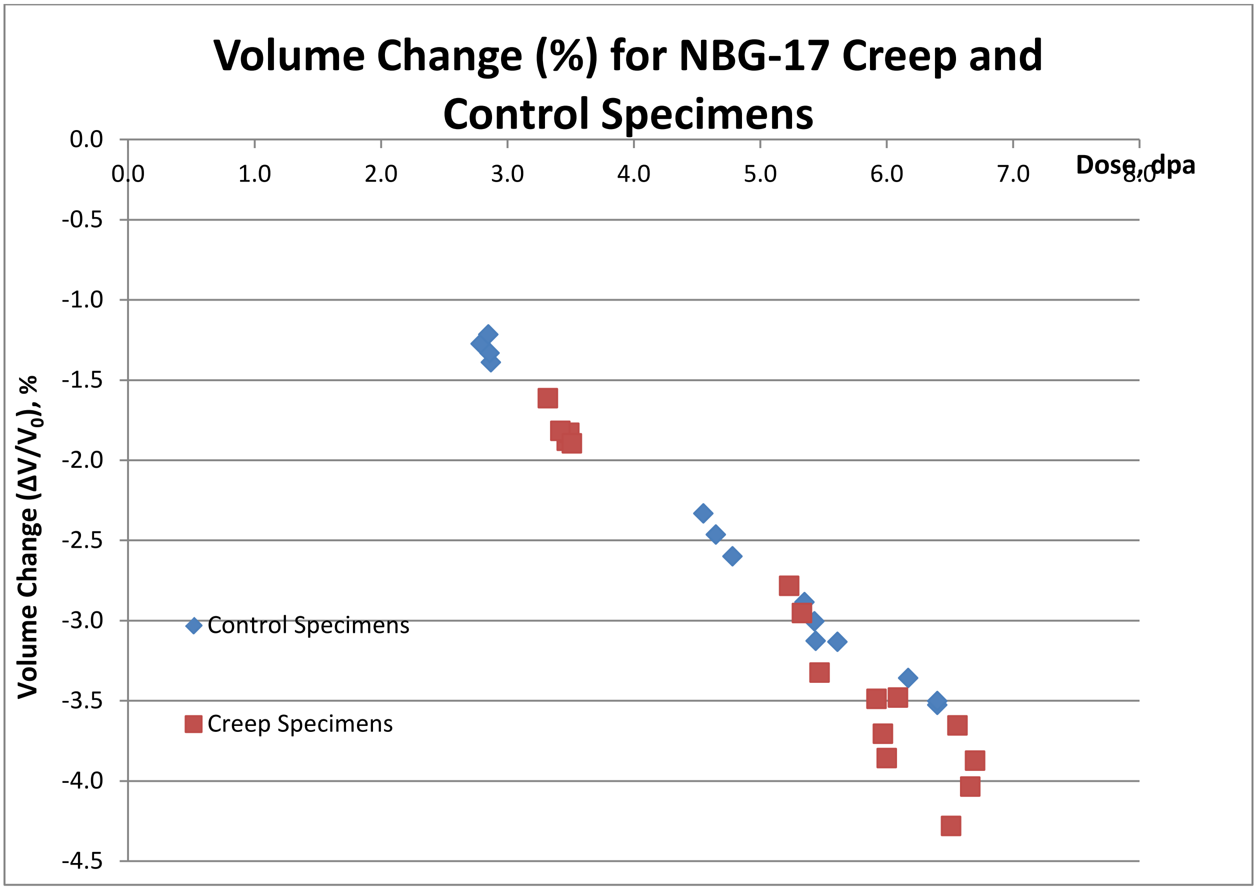

Figure 25 Volume change data for NBG-17 from the AGC-1 capsule

5.4 Dimensional and Volume Changes for Grade NBG-18 (Code B)

The dimensional changes observed from AGC-1 for grade NBG-18 are shown in Figure 26, Figure 27 and Figure 28 . Again there is only minimal anisotropy shown in the irradiation induced dimensional changes of this vibrationally molded grade NBG-18 (Figure 28) compared to the extruded grade H-451 (Figure 8).

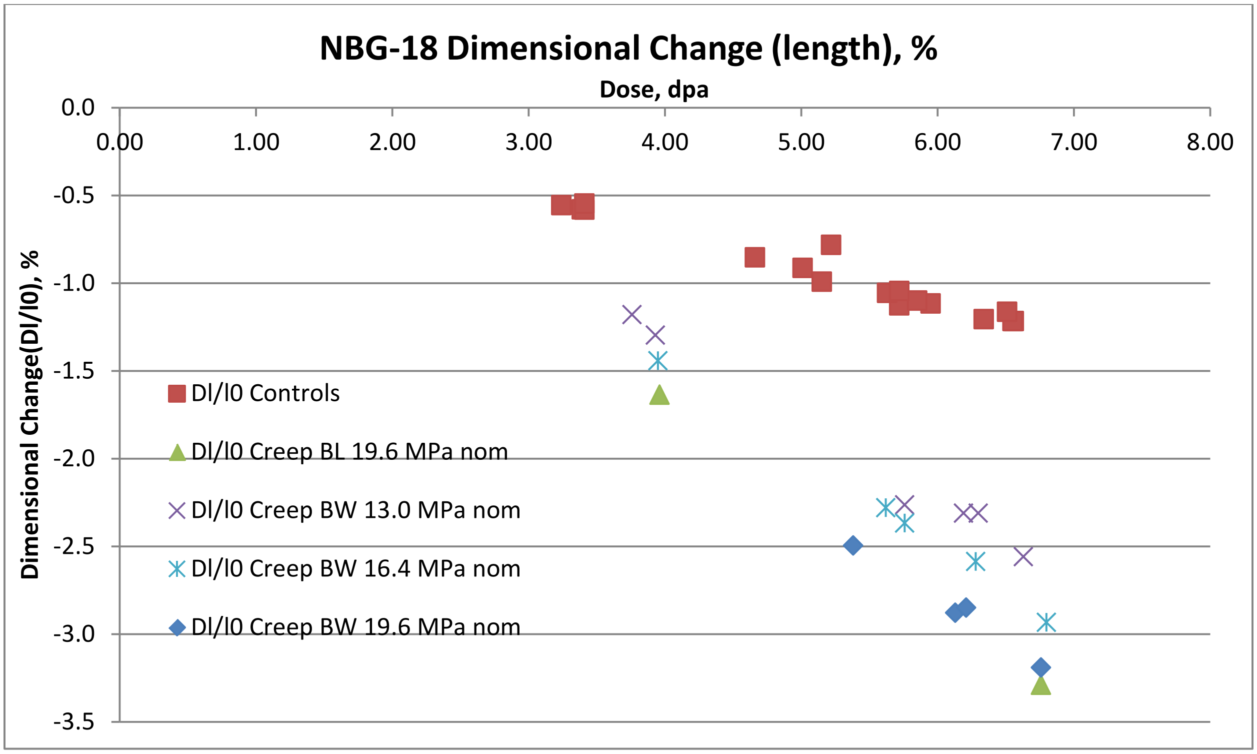

Figure 26 Dimensional changes (length) of NBG-18 creep and control specimens from AGC-1

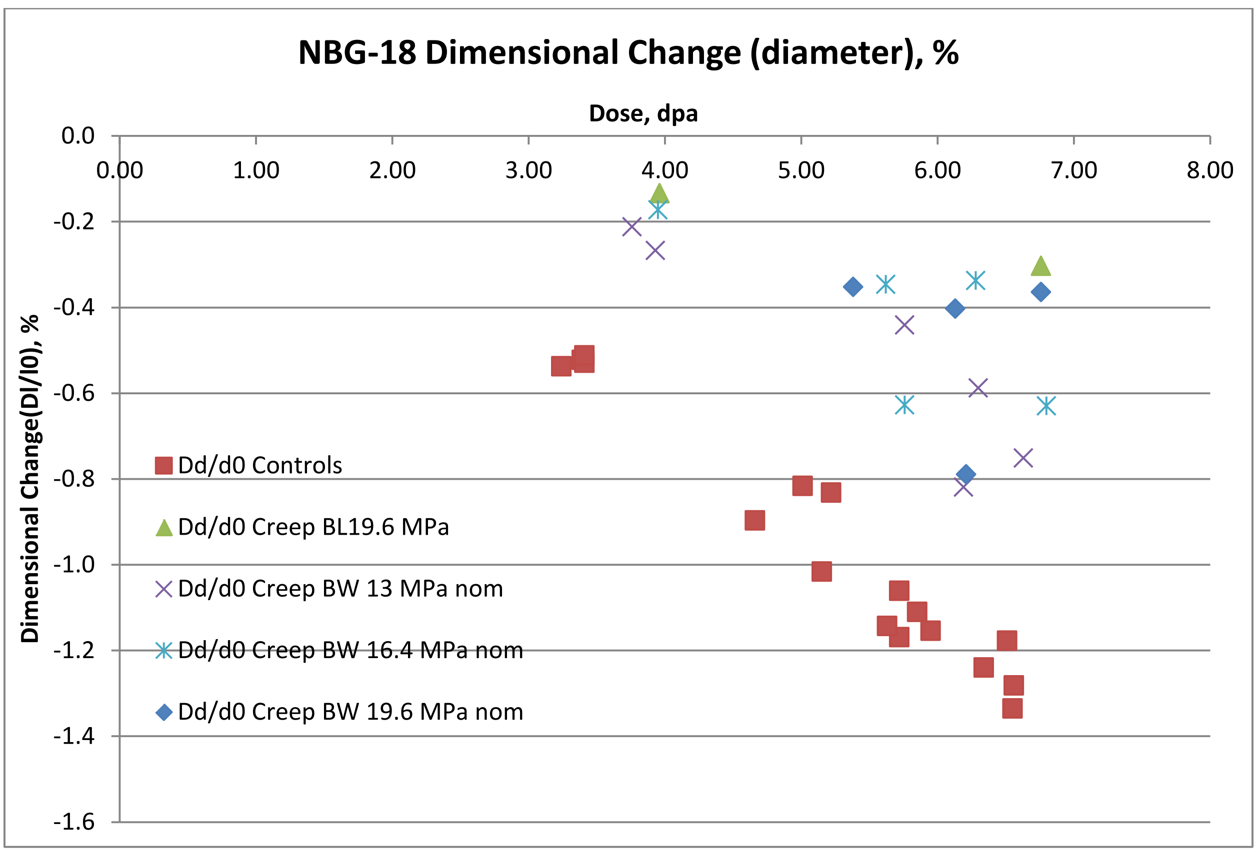

Figure 27 Dimensional changes (Diameter) of NBG-18 creep and control specimens from AGC-1

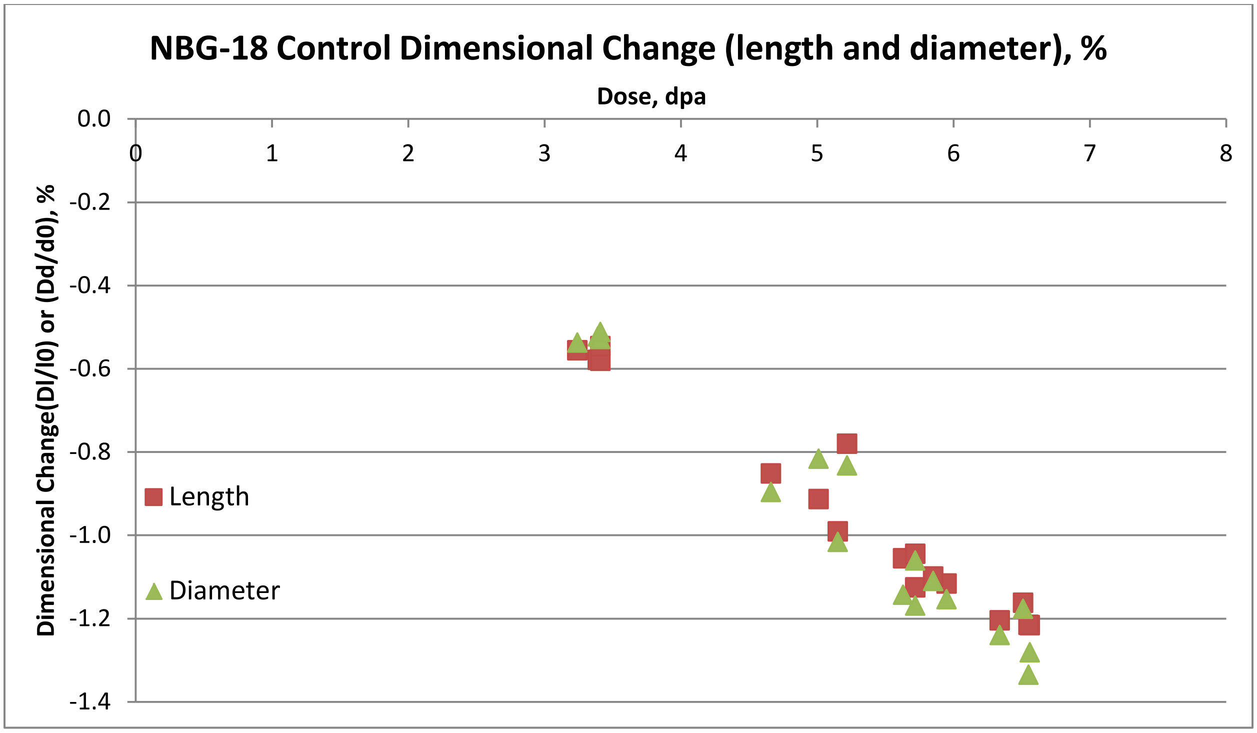

Figure 28 Dimensional changes of NBG-18 control specimens in the length and diametral direction illustrating the very slight anisotropy of the vibro-molded grade (data from AGC-1)

A comparison of the behaviors of Grades NGB-17 and -18 is shown in Figure 29 .

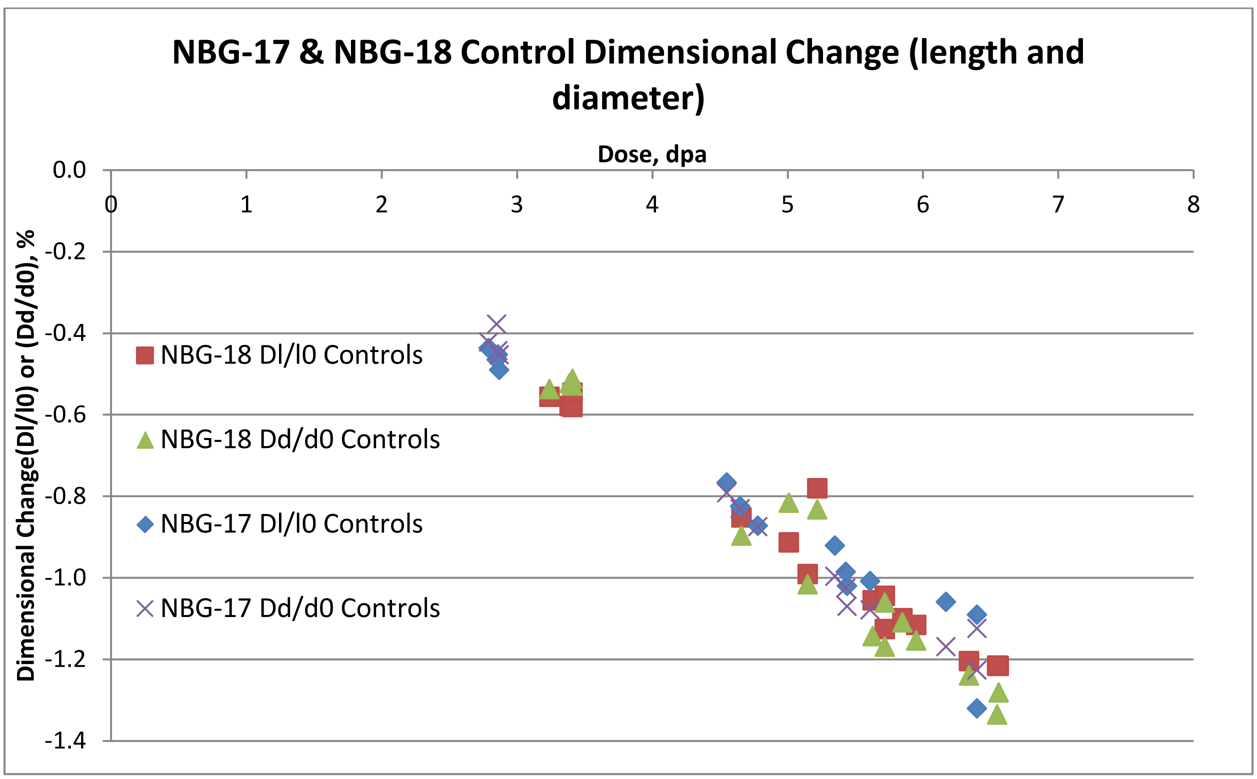

Figure 29 Comparison of the control specimen behavior (longitudinal and diametral) for NBG-17 and NBG-18

Despite the large difference in grain size between NBG-17 (0.8 mm) and NBG-18 (1.6 mm) both vibrationally molded grades behave dimensionally in a very similar fashion (Figure 29). Both are very isotropic at AGC-1 doses and temperatures.

The volume change behavior for NBG-18 is shown in Figure 30. Volume behavior is similar as seen for all other graphite grades (i.e., volume conserving on creep).

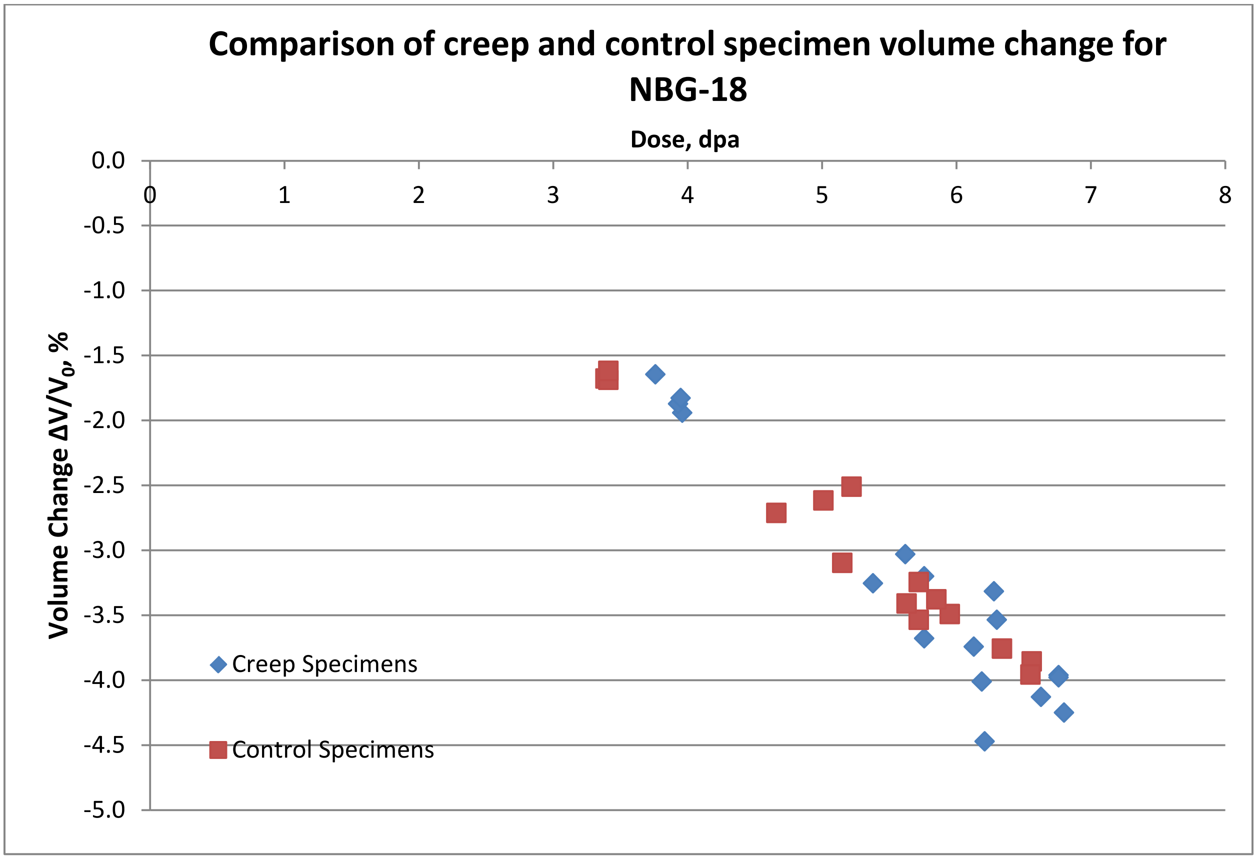

Figure 30 Volume change data for NBG-18 from the AGC-1 capsule

5.5. Dimensional and Volume Changes for Grade PCEA (Code D)

The dimensional changes observed from AGC-1 for grade PCEA are shown in Figure 31, Figure 32 and Figure 33. Unlike the H-451, there is only minimal anisotropy shown in the irradiation induced dimensional changes of this extruded grade PCEA (Figure 33) compared to the older extruded grade H-451 (Figure 8). Figure 33 shows the control dimensional changes of both AG and WG. For minimal anisotropy the AG length change should match that of the WG diametral change, which it does reasonably well.

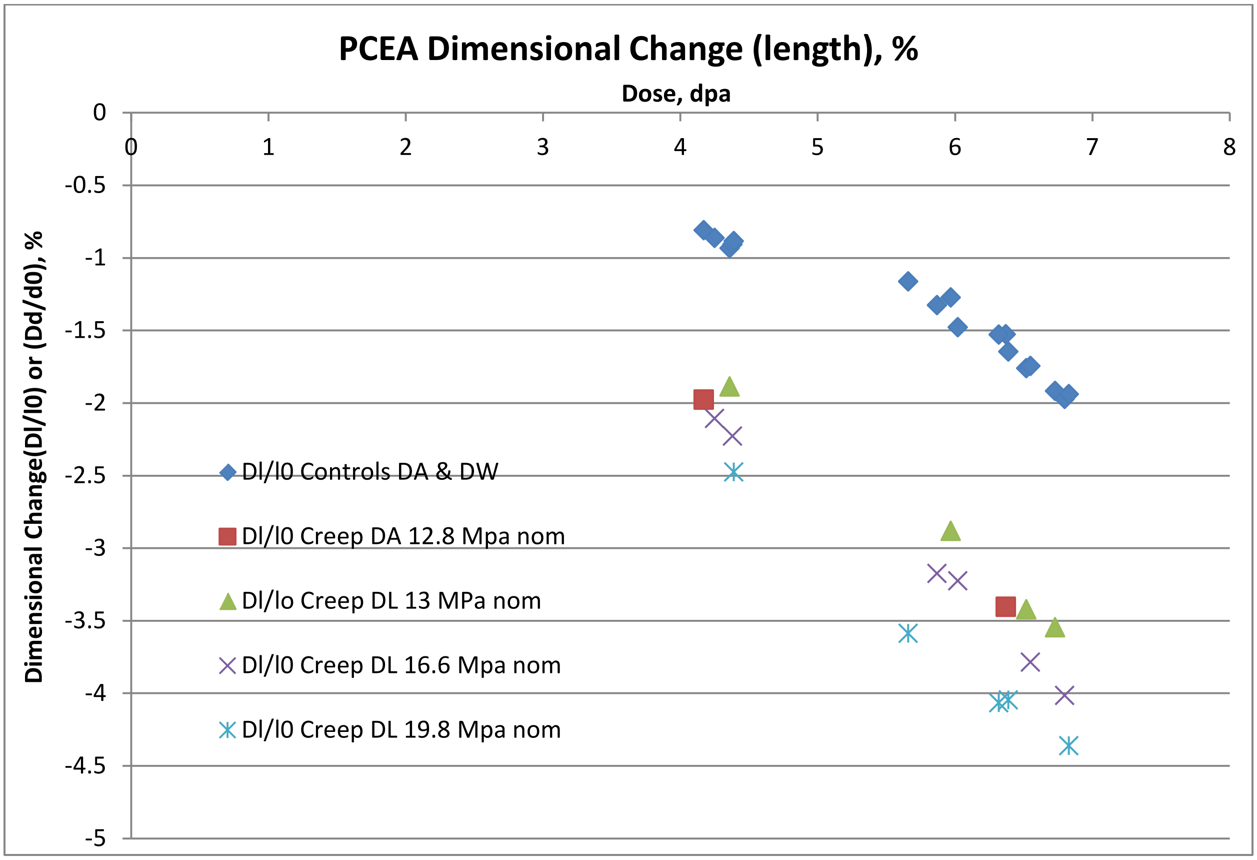

Figure 31 Dimensional changes (length) of PCEA creep and control specimens from AGC-1

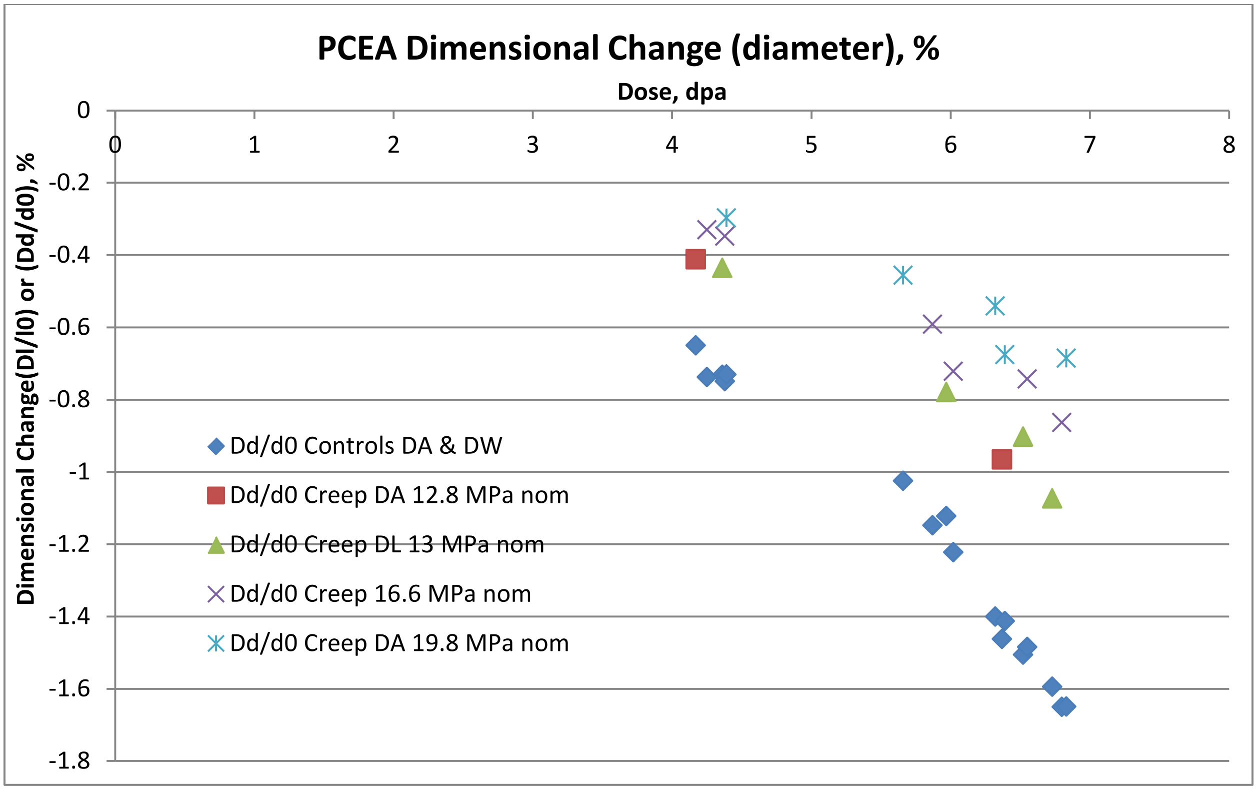

Figure 32 Dimensional changes (Diameter) of PCEA creep and control specimens from AGC-1

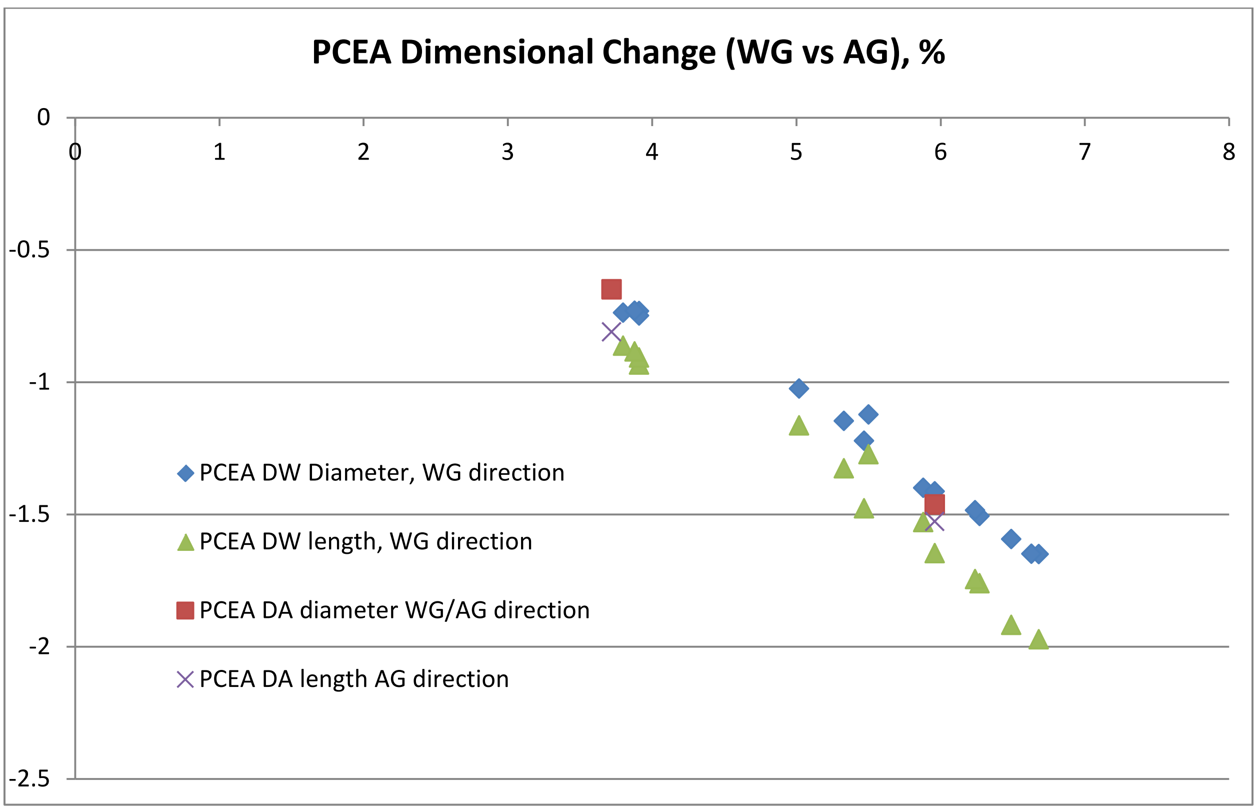

Figure 33 Dimensional changes of PCEA control specimens in the length and diametral direction illustrating the slight anisotropy of the near-isotopic extruded grade (data from AGC-1)

The volume change data for grade PCEA is shown in Figure 34. Volume behavior is similar as seen for all other graphite grades (i.e., volume conserving on creep).

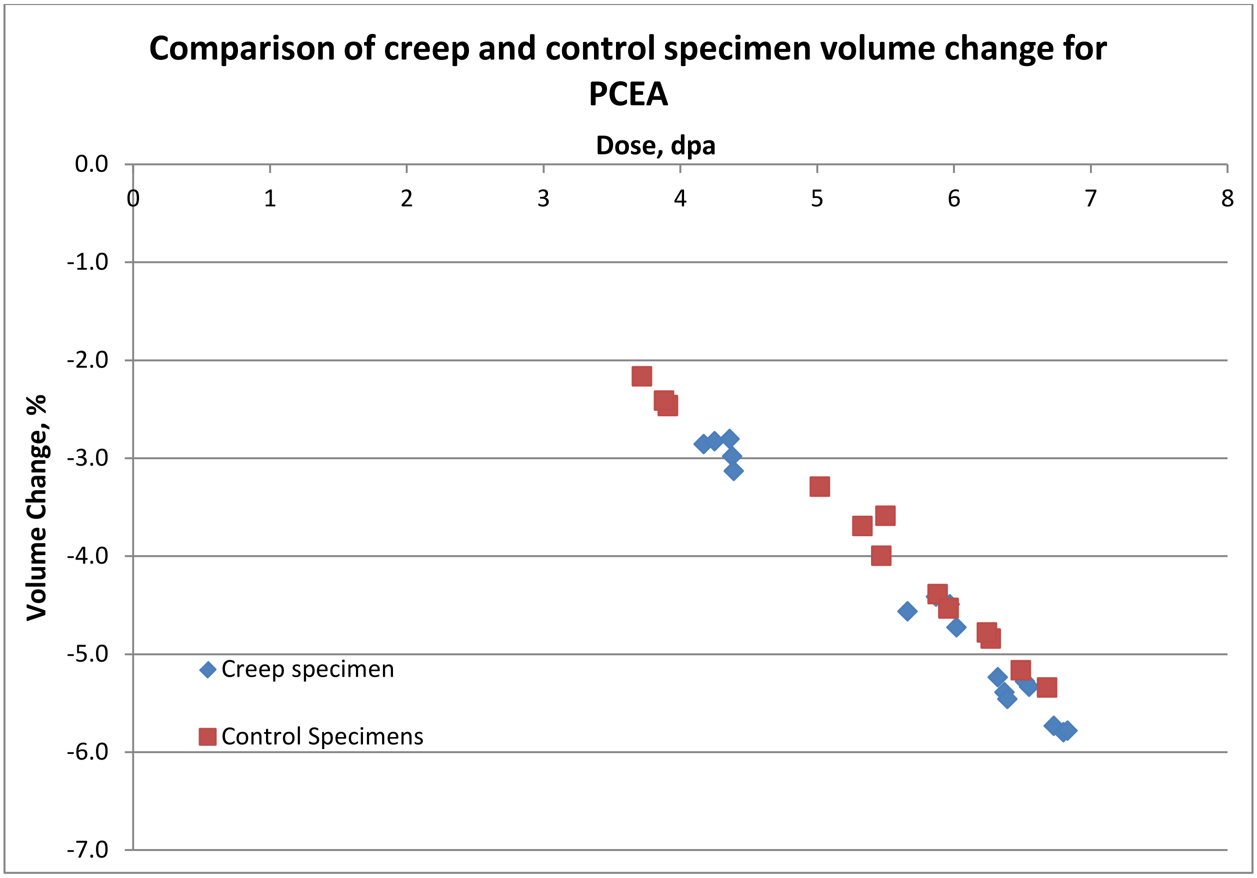

Figure 34 Volume change data for PCEA from the AGC-1 capsule

The volume change behavior of PCEA is somewhat similar to that of H-451 as shown in Figure 35. A comparison of the dimensional changes of these two extruded grades is in Figure 36. The H-451 dimensional changes appear to bracket those of PCEA indicating that the isotropy of PCEA is a little better than that of H-451.

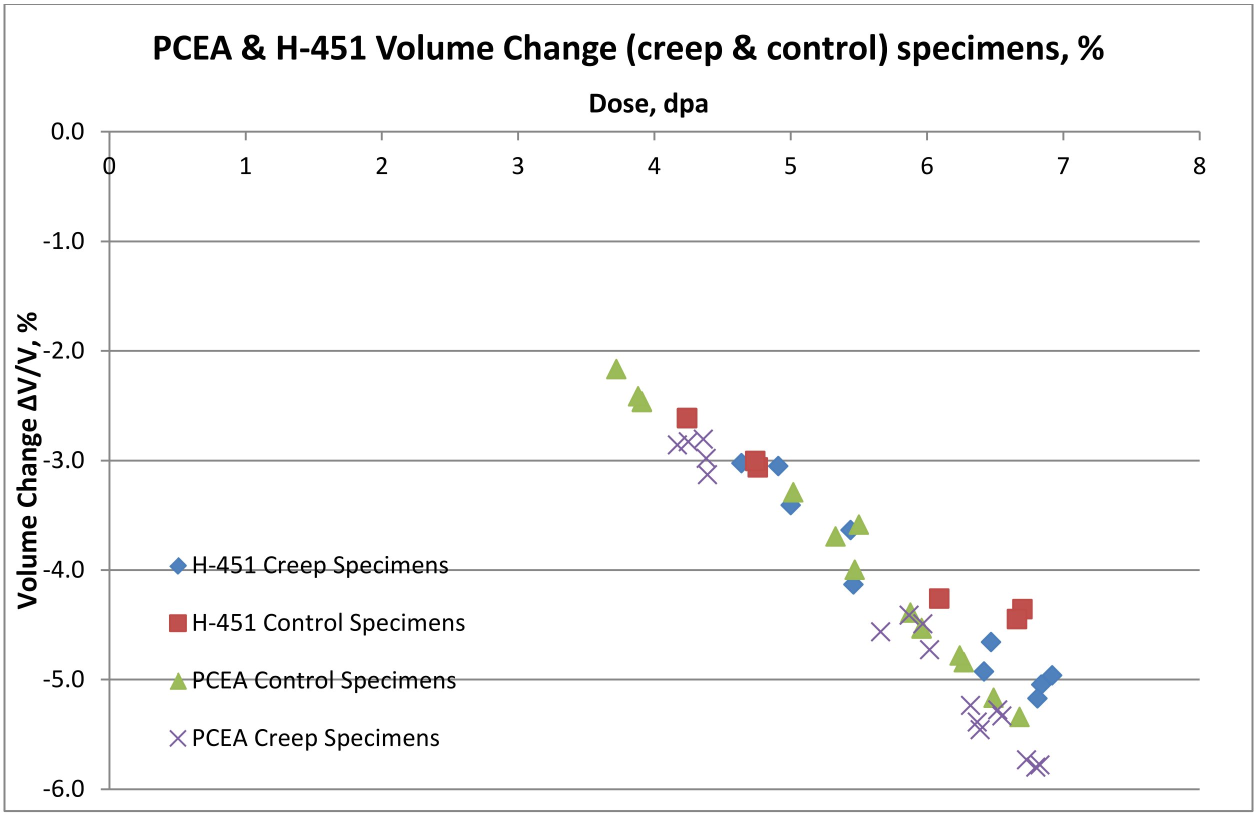

Figure 35 A comparison of the volume change behavior of creep and control specimens for grades PCEA and H-451

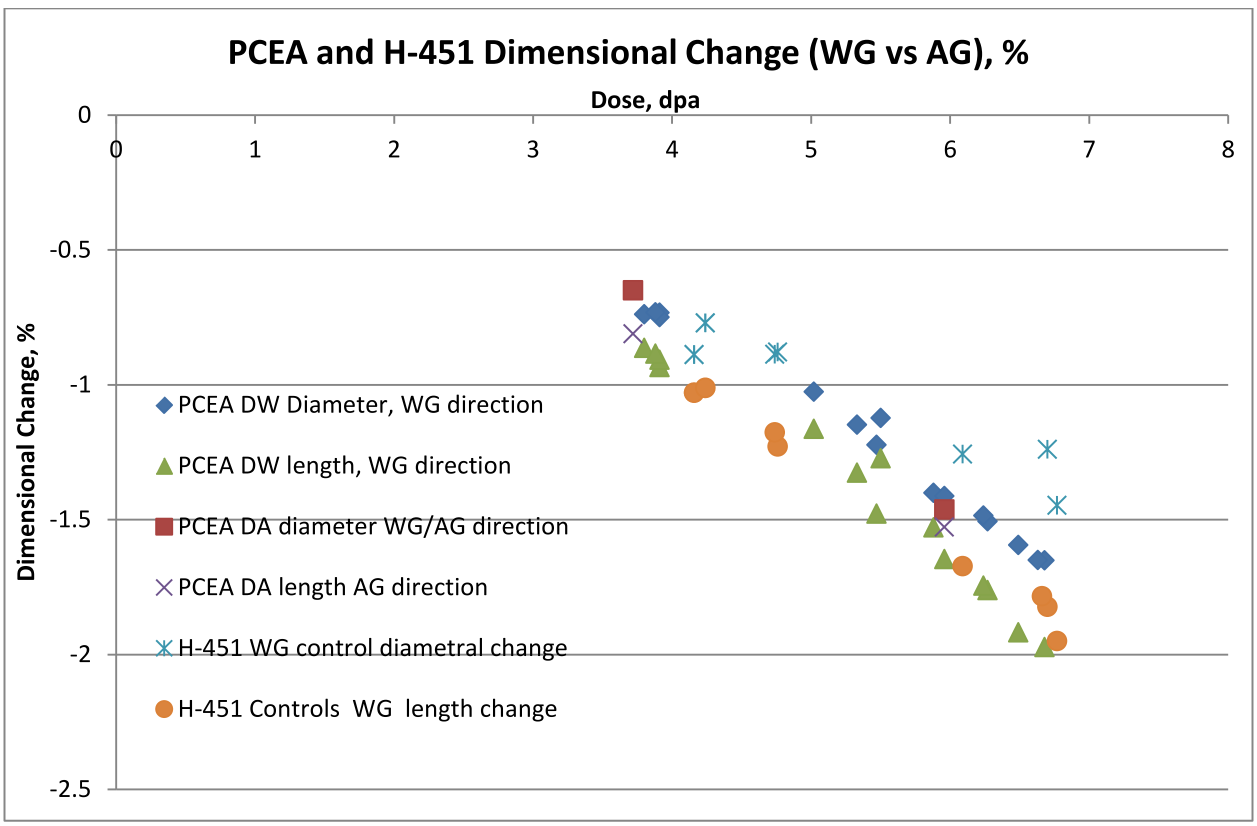

Figure 36 A comparison of the dimensional behaviors of grades PCEA and H-451

5.6. Dimensional and Volume Changes for Grade IG-430 (Code F)

The dimensional changes observed from AGC-1 for grade IG-430 are shown in Figure 37, Figure 38 and Figure 39 . Surprisingly there is extensive anisotropy shown in the irradiation induced dimensional changes of this iso-molded grade IG 430 (Figure 39) even when compared to the older extruded grade H-451 (Figure 8). The length change of the control specimen is particularly disturbing for IG-430, displaying definite early turnaround behavior (Figure 39).

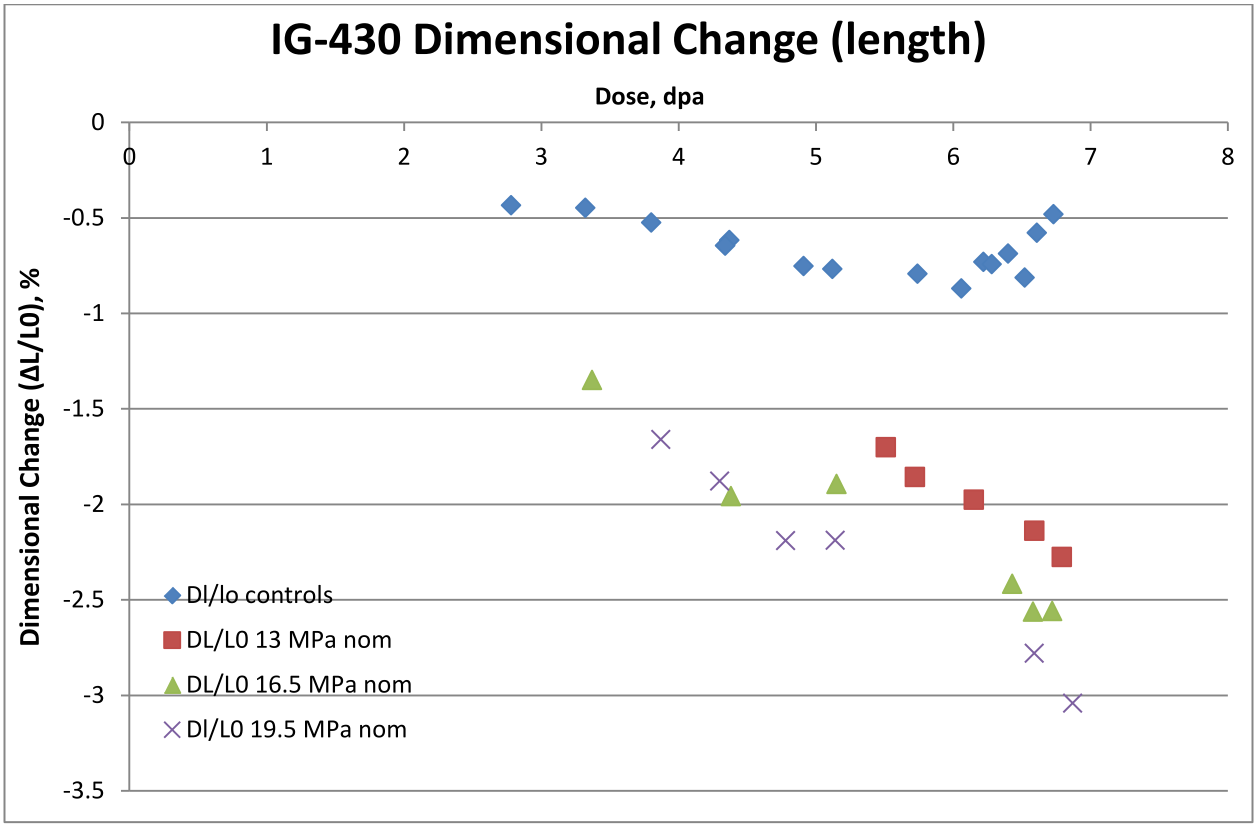

Figure 37 Dimensional changes (length) of IG-430 creep and control specimens from AGC-1

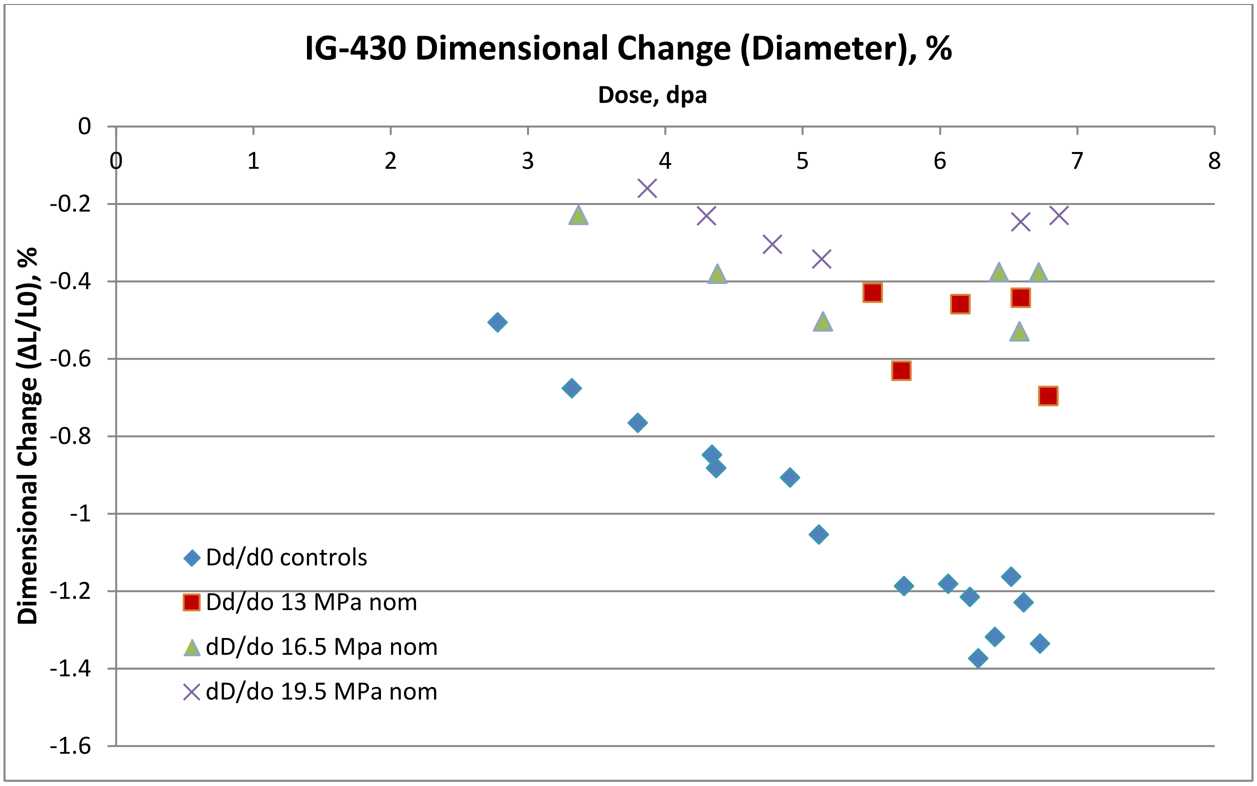

Figure 38 Dimensional changes (Diameter) of IG-430 creep and control specimens from AGC-1

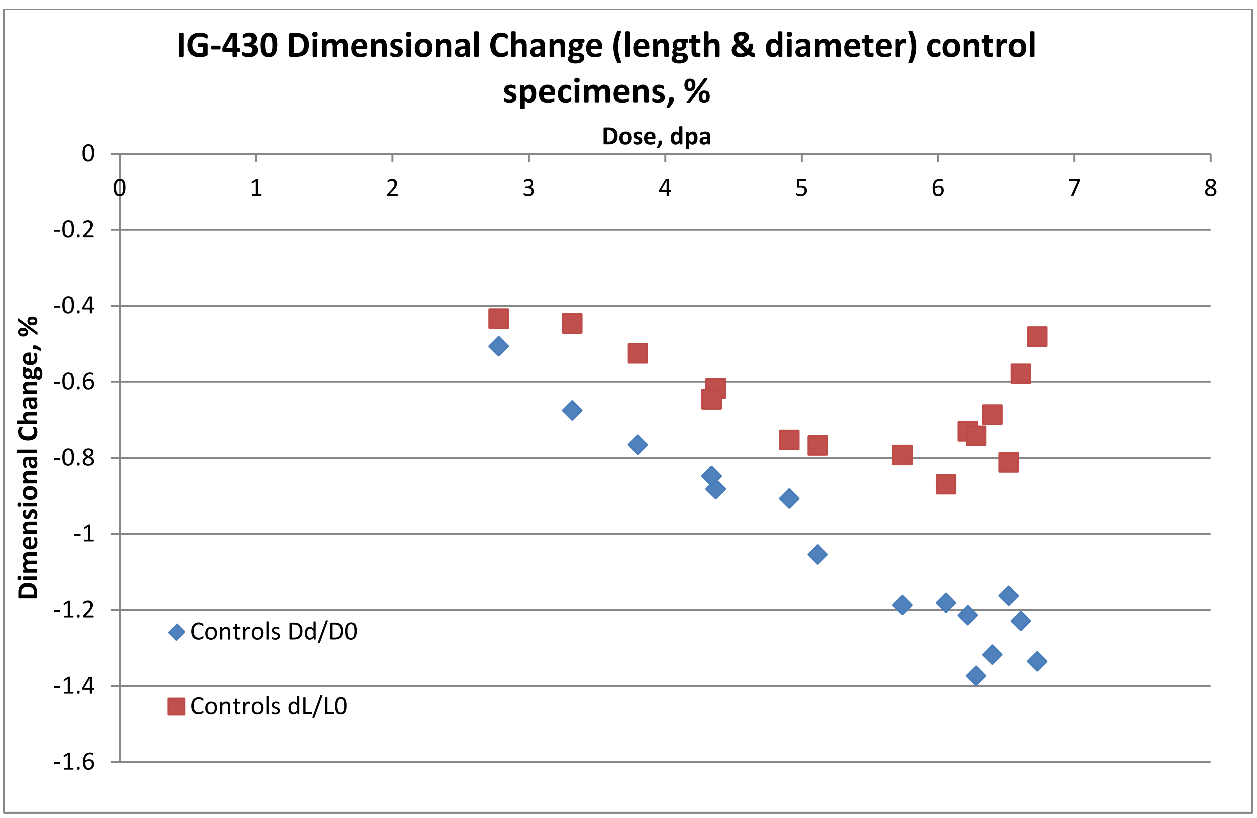

Figure 39 IG-430 dimensional change (control only) showing the anisotropic behavior this iso-molded graphite

A comparison of the dimensional change behavior for both iso-molded grades, IG-430 and IG-110 is shown in Figure 40. It is seen that the behavior of IG-110 appears superior compared to IG-430 over the dose and temperature range of AGC-1.

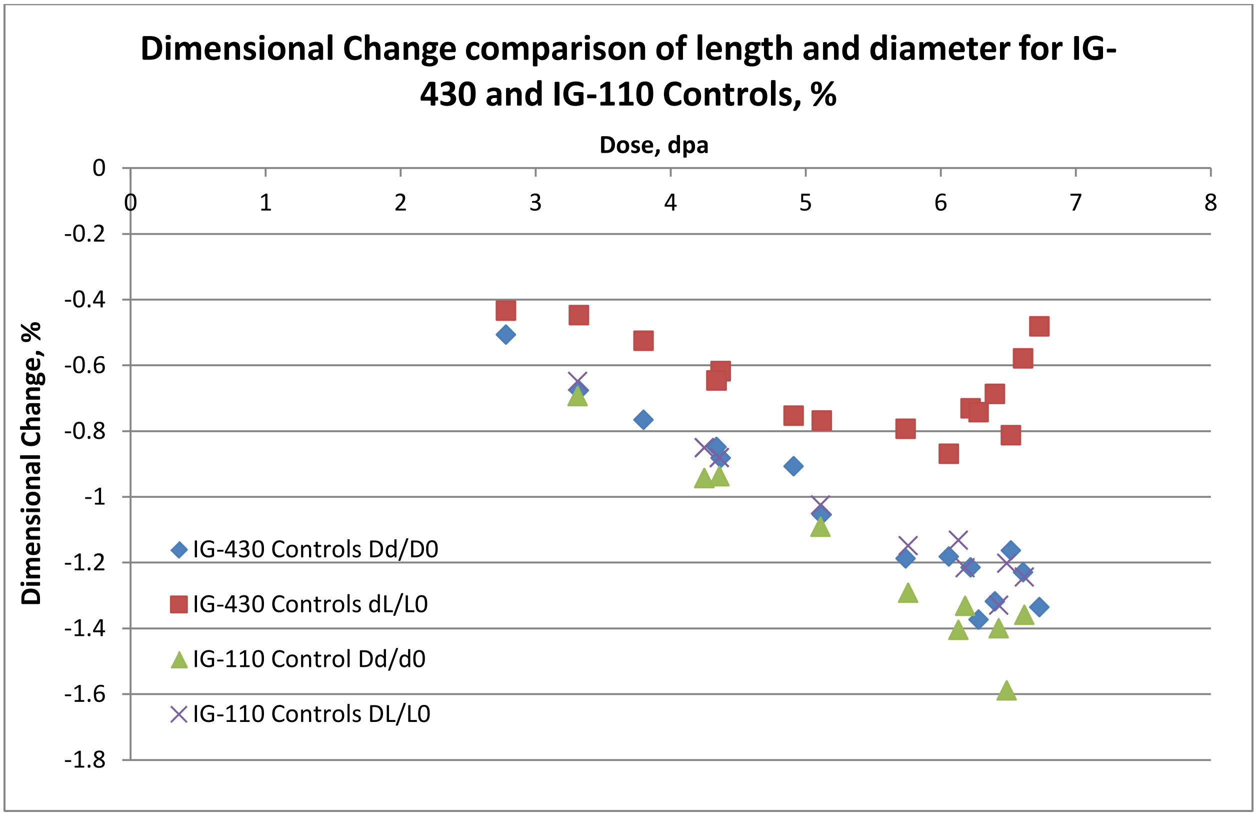

Figure 40 Comparison of the control specimen dimensional changes of iso-molded grades IG-110 and IG-430 showing the early dimensional turn-around behavior id IG-430

The volume change data for grade IG-430 is shown in Figure 41. The creep behavior is volume conserving, but only at doses >6 dpa. The volume change behavior of IG-430 is shown in comparison to IG-110 (both iso-molded grades) in Figure 42 and is very different to that of IG-110. The IG-430 volume change data shows a definite early turnaround trend. This is considered an undesirable feature of IG-430 and its continued investigation in the AGC series of experiments is not recommended.

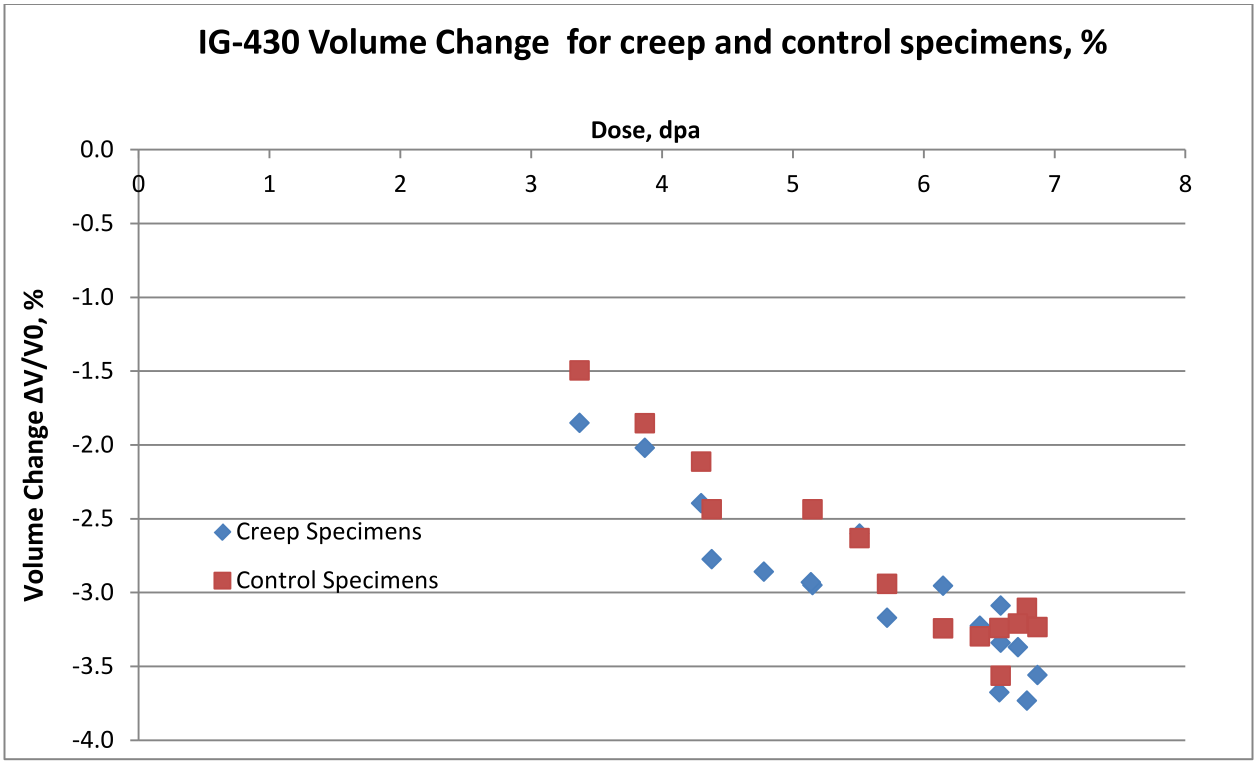

Figure 41 Volume change data for IG-430 from the AGC-1 capsule

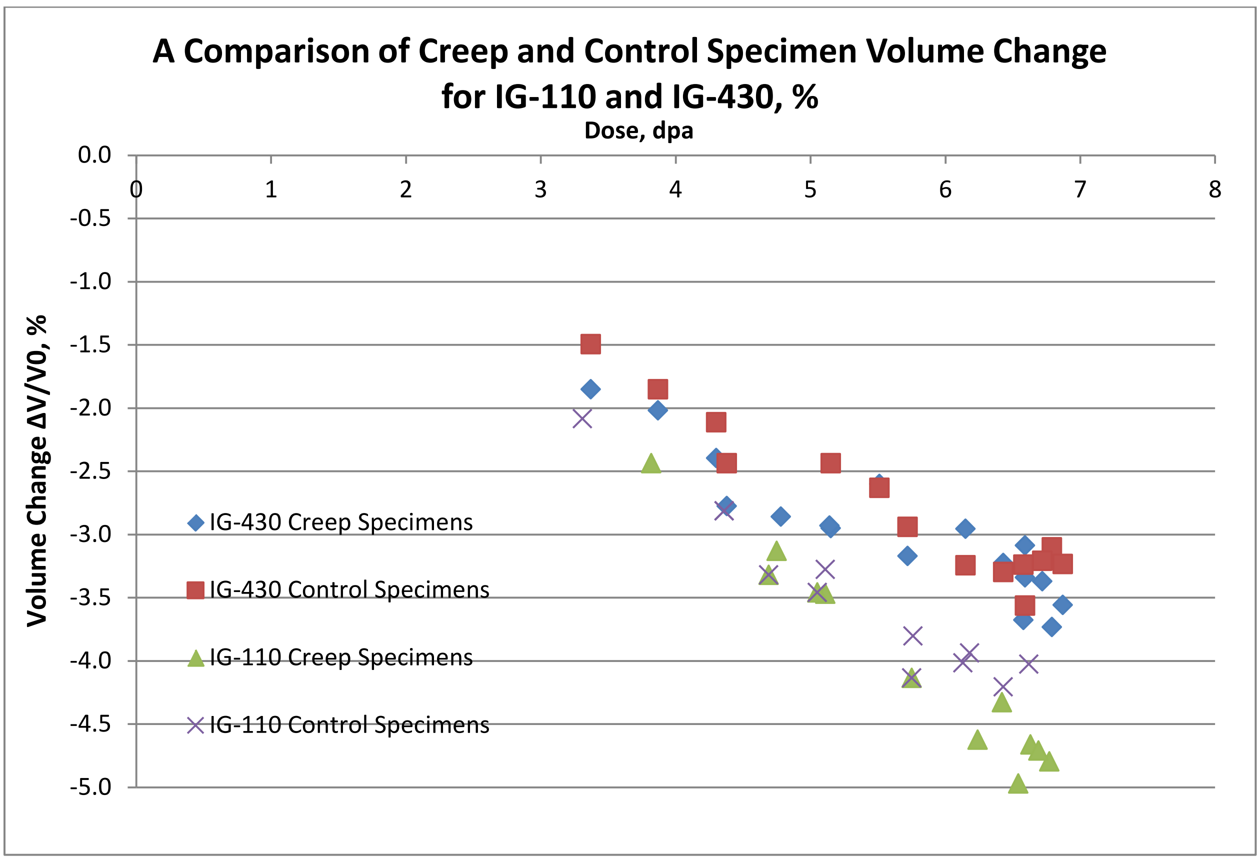

Figure 42 Comparison of the dimensional behaviors of grades IG-430 and IG-110

Finally, it should be noted that both iso-molded grades exhibited lower irradiated Poisson's ratio value after irradiation than either the extruded or vibrationally molded grades. A similar trend was noted in the Pre-irradiation Data Report[6] and the results are shown in Table 30.

Table 30 Comparisons of mean Poisson's ratio values from creep and piggy-back (PB) specimen geometries for the major graphite grades from the Pre-Irradiation report[6].

GRADE	Poisson's Ratio (μ)	
	Creep Specimens	PB Specimens
NBG-17 (AG)	0.33	0.31
NBG-18 (AG)	0.32	0.31
H-451	0.31	0.30
PCEA (WG)	0.31	0.26
IG-110	0.25	0.22
IG-430	0.17	0.21

5.7. Creep Data Discrimination

All of the creep and control specimen data have been used in this first round of analysis and are analyzed here. However the large difference in specimen temperatures and the overall range of temperature in the creep section of AGC-1 is considered to be problematic. To demonstrate the effect on the quantity of data two criteria were set. First, the difference between the creep and control matched pair should not exceed 100°C (ideally this would be only ± 20°C), and secondly, the specimen irradiation temperature should be between 500°C and 700°C (again, ideally axial capsule temperature difference should not exceed ±50°C). As seen in the following analysis, these temperature limits drastically reduce the amount of data that would be available for analysis (Table 31 to Table 36). The numbers of affected specimens are summarized in Table 37.

Table 31 Irradiation temperature differences for NBG-17

Spec. ID.	Specimen pair temperature difference (stressed - unstressed)	Channel Temperatute variation (specimen temp - channel minimum temp) [470]	Channel Temperature Limits	
			Is T_{irr}>700°C	Is T_{irr}<500°C
	°C	°C		
3S8	70	185	false	false
4S11		115	false	false
2S4	36	233	true	false
1S13		197	false	false
1S12	121	119	false	false
1U12		-2	false	true
4S8	69	186	false	false
4U8		117	false	false
1S11	76	198	false	false
1U11		122	false	false
1S3	40	220	false	false
1U3		180	false	false
4S12		124	false	false
4U11		3	false	true
2U4	122	122	false	false
2U10		0	false	true
2S6	71	183	false	false
2U6		112	false	false
5S14	60	207	false	false
5U13		147	false	false
5S6	34	242	true	false
5U6		208	false	false
3S13	34	124	false	false
3U12		2		
6S15	123	123	false	false
6U14		0	false	true
AW13-02	77	204	false	false
3U8		127	false	false
6S8	76	200	false	false
6U8		124	false	false
6S1	36	233	true	false

Table 32 Irradiation temperature differences for NBG-18

Spec. I.D.	Specimen pair temperature difference (stressed - unstressed)	Channel Temperatute variation (specimen temp - channel minimum temp) [504]	Channel Temperature Limits	
			Is T_{irr}>700°C	Is T_{irr}<500°C
	°C	°C		
4S7	94	95	false	false
5S2		1	false	false
3S12	36	210	true	false
2S12		174	false	false
4S14	94	99	false	false
4U13		5	false	false
BW12-02	93	93	false	false
1U1		0	false	false
BW12-03	76	171	false	false
4U7		95	false	false
4S5	40	194	false	false
4U5		154	false	false
3S2	60	167	false	false
3U2		107	false	false
1S4	36	196	false	false
1U4		160	false	false
5U5	94	95	false	false
6U3		1	false	false
5S15	83	164	false	false
5U14		81	false	false
2S11	83	161	false	false
2U11		78	false	false
5S8	48	182	false	false
5U8		134	false	false
2S2	34	205	true	false
2U2		171	false	false
3S14	71	152	false	false
3U13		81	false	false
3S11	61	174	false	false
3U11		113	false	false
6S13		170	false	false
6U12		109	false	false
6S6		205	true	false

Table 33 Irradiation temperature differences for H-451

Spec. ID.	Specimen pair temperature difference (stressed - unstressed)	Channel Temperatute variation (specimen temp - channel minimum temp) [567]	Channel Temperature Limits	
			Is T_{irr}>700°C	Is T_{irr}<500°C
	°C	°C		
4S2		75	false	false
4U12	74	1	false	false
4S13		61	false	false
4U12	60	1	false	false
1S15		82	false	false
1U14	69	13	false	false
1S8		139	true	false
1U8	32	107	false	false
6U5		60	false	false
	60			
5U7		0	false	false
5S7		74	false	false
	74			
5U7		0	false	false
2S13		116	false	false
2U12		68	false	false
6S5		141	true	false
4U2	31	110	false	false
6S9		86	false	false
6U9	71	15	false	false
3S10		130	false	false
3U10	40	90	false	false
3S1		145	true	false
3U1	31	114	false	false

Table 34 Irradiation temperature differences for PCEA

Spec. ID.	Specimen pair temperature difference (stressed - unstressed) °C	Channel Temperatute variation (specimen temp - channel minimum temp) [533] °C	Channel Temperature Limits	
			Is T_{irr}>700°C	Is T_{irr}<500°C
4S6	74	79	false	false
5S11		5	false	false
4S1	48	147	false	false
3S6		99	false	false
1S14	73	73	false	false
1U13		0	false	false
4S15	61	146	false	false
4U14		85	false	false
4U1	35	181	true	false
4U6		146	false	false
1S2	34	173	true	false
1U2		139	false	false
5S12	74	78	false	false
5UII		4	false	false
4S14	75	76	false	false
2U13		1	false	false
5S9	77	141	false	false
5U9		64	false	false
2S8	76	137	false	false
2U8		61	false	false
5S4	36	173	true	false
5U4		137	false	false
2S1	37	178	true	false
2U1		141	false	false
6S11	76	77	false	false
6U11		1	false	false
3S15	84	136	false	false
3U14		52	false	false
DW1101	49	154	false	false
3U6		105	false	false
1S6	49	150	false	false
1U6		101	false	false
6S4	36	177	true	false

Table 35 Irradiation temperature differences for IG-110

Spec. ID.	Specimen pair temperature difference (stressed - unstressed) °C	Channel Temperatute variation (specimen temp - channel minimum temp) [507] °C	Channel Temperature Limits Is T_{irr}>700°C	Is T_{irr}<500°C
1S9	59	114	false	false
1U7		55	false	false
1S7	73	128	false	false
1U7		55	false	false
4S9	37	201	true	false
4U9		164	false	false
4S4	31	206	true	false
4U4		175	false	false
2S7	61	167	false	false
2U7		106	false	false
5S13	94	94	false	false
5U12		0	false	false
5S1	31	205	true	false
5U1		174	false	false
1U9	61	121	false	false
3U9		60	false	false
3S9	75	135	false	false
3U9		60	false	false
6S14	84	159	false	false
6U13		75	false	false
SPARE1	35	206	true	false
SPARE 2		171	false	false
2S5	40	186	false	false
2U5		146	false	false

Table 36 Irradiation temperature differences for IG-430

Spec. ID.	pair temperature difference (stressed - unstressed) °C	Channel Temperatute variation (specimen temp - channel minimum temp) [518] °C	Channel Temperature Limits Is T_{irr}>700°C	Is T_{irr}<500°C
4S10	82	161	false	false
4U10		79	false	false
3S3	49	180	false	false
3U3		131	false	false
FW 13-01	82	154	false	false
1U10		72	false	false
4S3	37	208	true	false
4U3		171	false	false
1S5	36	200	true	false
1U5		164	false	false
6U7	121	85	false	false
2U14		-36	false	true
2S14	45	101	false	false
2U9		56	false	false
2S9	75	131	false	false
2U9		56	false	false
5S10	41	189	false	false
5U10		148	false	false
5S2	36	206	true	false
5U2		170	false	false
2S3	40	185	false	false
2U3		145	false	false
3S7	94	94	false	false
3U7		0	false	false
3S5	75	104	false	false
3U5		29	false	false
6S10	62	118	false	false
6U10		56	false	false
6S7	75	131	false	false
6U10		56	false	false
3S4	37	199	true	false
3U4		162	false	false
6S2	31	200	true	false
6U2		169	false	false

Table 37 Summary table of the numbers of effected specimens

Specimen rejected, 500<T_{irr}<700C, creep and control within 100C	
GRADE	Specimens/data point rejected
NBG-17	10 of 15
NGB-18	3 of 17
H-451	3 of 11
PCEA	5 of 17
IG-110	4 of 12
IG-430	7 of 17

Ideally the control (unstressed) and creep (stressed) specimen should be within ± 20°C of one another, imposition of this requirement would completely disqualify the AGC-1 experiment. Moreover, ideally the temperature variation along the axial creep/control sections of the capsule would be less than ±50°C. Yet we see that for AGC-1 this variation frequently exceeded 100°C. Although all data is analyzed here it would be beneficial to re-run the analysis rejecting data that does not meet the agreed temperature limits.

6. Creep Strain Analysis

Using the approved methodology we have analyzed the AGC-1 dimensional data and determined the creep strain behavior for all major graphite grades. The creep strain data is determined as the difference between the stressed and unstressed specimen dimensional changes. From this data the basic creep strain data is derived as from the verified methodology and demonstrated for H-451 historical grade graphite. Once the strain data has been established the normalized secondary and total creep strain is plotted to determine the creep strain constant.

6.1. Creep Strain Analysis for NBG-17 (Code A)

The NBG-17 creep strain data are reported in Table 38 and Table 39 and plotted in Figure 43 and Figure 44. The normalized total creep strain is plotted in Figure 45 and Figure 46. Longitudinal and lateral normalized secondary creep strains are plotted in Figure 47 and Figure 48, respectively.

Table 38 Derived creep strain (mm and %) for NBG-17 in the longitudinal direction normalized to the peak applied stress

Specimen Number	I.D. Number		Companion Specimen Number	Companion Specimen I.D. Number	Creep Stress MPa	Total Creep Strain (creep-control) Longitudanal (mm)	Longitudanal %	Lateral (mm)	Lateral %	Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress Normalised secondary creep strain %	Stress Normlised total creep strain, microns	Primary Creep Strain microns	Normalized Primary Creep Strain mirons
AL8-01	3S8		4S11	AL8-02	-16.58	-0.361	-1.423	0.069	0.545	4.99	-0.1481	-1.2750	-1.5177	-429.9579	-37.6238	-44.83
AL6-02	2S4		1S13	AL6-01	-16.32	-0.408	-1.610	0.092	0.719	6.55	-0.1458	-1.4637	-1.7700	-494.2502	-37.0358	-44.83
AW1-03	1S12		1U12	AW2-03	-13.15	-0.184	-0.724	0.023	0.183	3.17	-0.1136	-0.6106	-0.9159	-275.8483	-29.8573	-44.83
AW6-02	4S8		4U8	AW7-01	-12.54	-0.266	-1.047	0.045	0.357	4.89	-0.1083	-0.9388	-1.4774	-418.6045	-28.4566	-44.83
AW1-02	1S11		1U11	AW2-02	-13.16	-0.287	-1.131	0.045	0.356	5.71	-0.1136	-1.0175	-1.5260	-430.8611	-29.8625	-44.83
AW1-01	1S3		1U3	AW2-01	-13.17	-0.361	-1.422	0.043	0.336	6.34	-0.1138	-1.3084	-1.9596	-541.1120	-29.9020	-44.83
AW4-02	2U4		2U10	AW5-01	-16.30	-0.228	-0.900	0.033	0.258	3.18	-0.1408	-0.7595	-0.9191	-276.6970	-37.0072	-44.83
AW4-01	2S6		2U6	AW4-03	-16.30	-0.324	-1.278	0.045	0.351	5.13	-0.1408	-1.1375	-1.3768	-392.9713	-37.0007	-44.83
AW9-01	5S14		5U13	AW10-01	-16.56	-0.374	-1.474	0.085	0.671	5.85	-0.1430	-1.3311	-1.5855	-446.0491	-37.5985	-44.83
AW7-03	5S6		5U6	AW9-03	-16.55	-0.412	-1.625	0.106	0.829	6.48	-0.1429	-1.4817	-1.7666	-492.0334	-37.5610	-44.83
AW5-02	3S13		3U12	AW6-01	-19.75	-0.278	-1.097	0.044	0.342	3.11	-0.1705	-0.9261	-0.9252	-278.2849	-44.8290	-44.83
AW12-01	6S15		6U14	AW13-01	-19.47	-0.275	-1.086	0.036	0.284	3.18	-0.1682	-0.9178	-0.9299	-279.2619	-44.2030	-44.83
AW13-02	SPARE		3U8	AW5-03	-19.73	-0.470	-1.852	0.087	0.686	5.64	-0.1704	-1.6814	-1.6814	-470.2179	-44.7832	-44.83
AW10-03	6S8		6U8	AW12-03	-19.49	-0.480	-1.893	0.076	0.599	5.72	-0.1683	-1.7243	-1.7459	-486.7232	-44.2317	-44.83
AW10-02	6S1		5U3	AW9-02	-19.47	-0.509	-2.007	0.093	0.727	6.51	-0.1681	-1.8390	-1.8633	-516.5981	-44.1986	-44.83

Table 39 Derived creep strain (mm and %) for NBG-17 in the lateral direction normalized to the peak applied lateral stress

Creep Stress MPa	Specimen Number	I.D. Number	Companion Specimen No	Companion Specimen I.D. Number	Piosson's Ratio from PIE data	Lateral Creep Stress MPa	Total Creep Strain (creep-control) Longitudanal (mm)	Longitudanal %	Lateral (mm)	Lateral %	Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress Normalised secondary creep strain %/MPa	Stress Nomlised total creep strain, microns/MPa	Primary Creep Strain microns	Normalized Primary Creep Strain mirons
-16.58	AL8-01	3S8	4S11	AL8-02	-0.229	3.796	-0.361	-1.423	0.069	0.545	4.99	0.000328	0.54499	0.84612	107.746	4.1628	6.46
-16.32	AL6-02	2S4	1S13	AL6-01	-0.223	3.639	-0.408	-1.610	0.092	0.719	6.55	0.000314	0.71911	1.16468	148.353	3.9904	6.46
-13.15	AW1-03	1S12	1U12	AW2-03	-0.244	3.212	-0.184	-0.724	0.023	0.183	3.17	0.000287	0.18241	0.33466	42.705	3.5228	6.46
-12.54	AW6-02	4S8	4U8	AW7-01	-0.264	3.308	-0.266	-1.047	0.045	0.357	4.89	0.000296	0.35692	0.63576	81.032	3.6284	6.46
-13.16	AW1-02	1S11	1U11	AW2-02	-0.235	3.094	-0.287	-1.131	0.045	0.356	5.71	0.000277	0.35561	0.67725	86.347	3.3936	6.46
-13.17	AW1-01	1S3	1U3	AW2-01	-0.206	2.719	-0.361	-1.422	0.043	0.336	6.34	0.000243	0.33604	0.72831	92.790	2.9820	6.46
-16.30	AW4-02	2U4	2U10	AW5-01	-0.238	3.872	-0.228	-0.900	0.033	0.258	3.18	0.000346	0.25805	0.39272	50.088	4.2466	6.46
-16.30	AW4-01	2S6	2U6	AW4-03	-0.211	3.438	-0.324	-1.278	0.045	0.351	5.13	0.000307	0.35118	0.60198	76.748	3.7703	6.46
-16.56	AW9-01	5S14	5U13	AW10-01	-0.209	3.469	-0.374	-1.474	0.085	0.671	5.85	0.000310	0.67034	1.13890	145.059	3.8040	6.46
-16.55	AW7-03	5S6	5U6	AW9-03	-0.215	3.563	-0.412	-1.625	0.106	0.829	6.48	0.000318	0.82868	1.37072	174.657	3.9073	6.46
-19.75	AW5-02	3S13	3U12	AW6-01	-0.298	5.893	-0.278	-1.097	0.044	0.342	3.11	0.000527	0.34138	0.34136	43.519	6.4632	6.46
-19.47	AW12-01	6S15	6U14	AW13-01	-0.237	4.615	-0.275	-1.086	0.036	0.284	3.18	0.000412	0.28339	0.36184	46.163	5.0616	6.46
-19.73	AW13-02	SPARE	3U8	AW5-03	-0.216	4.252	-0.470	-1.852	0.087	0.686	5.64	0.000380	0.68516	0.94966	121.012	4.6629	6.46
-19.49	AW10-03	6S8	6U8	AW12-03	-0.250	4.864	-0.480	-1.893	0.076	0.599	5.72	0.000435	0.59808	0.72464	92.350	5.3342	6.46
-19.47	AW10-02	6S1	5U3	AW9-02	-0.291	5.660	-0.509	-2.007	0.093	0.727	6.51	0.000506	0.72657	0.75642	96.434	6.2079	6.46

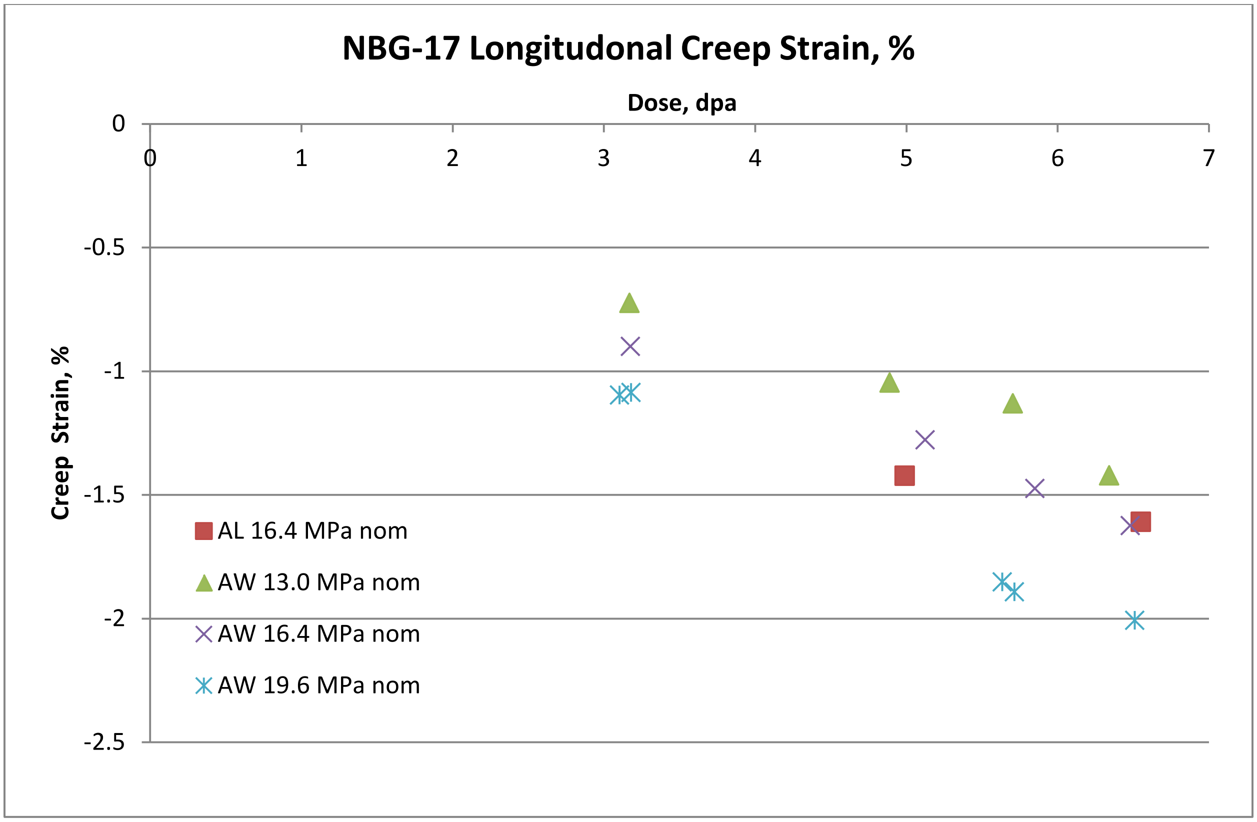

Figure 43 longitudinal creep strain (%) for NBG-17

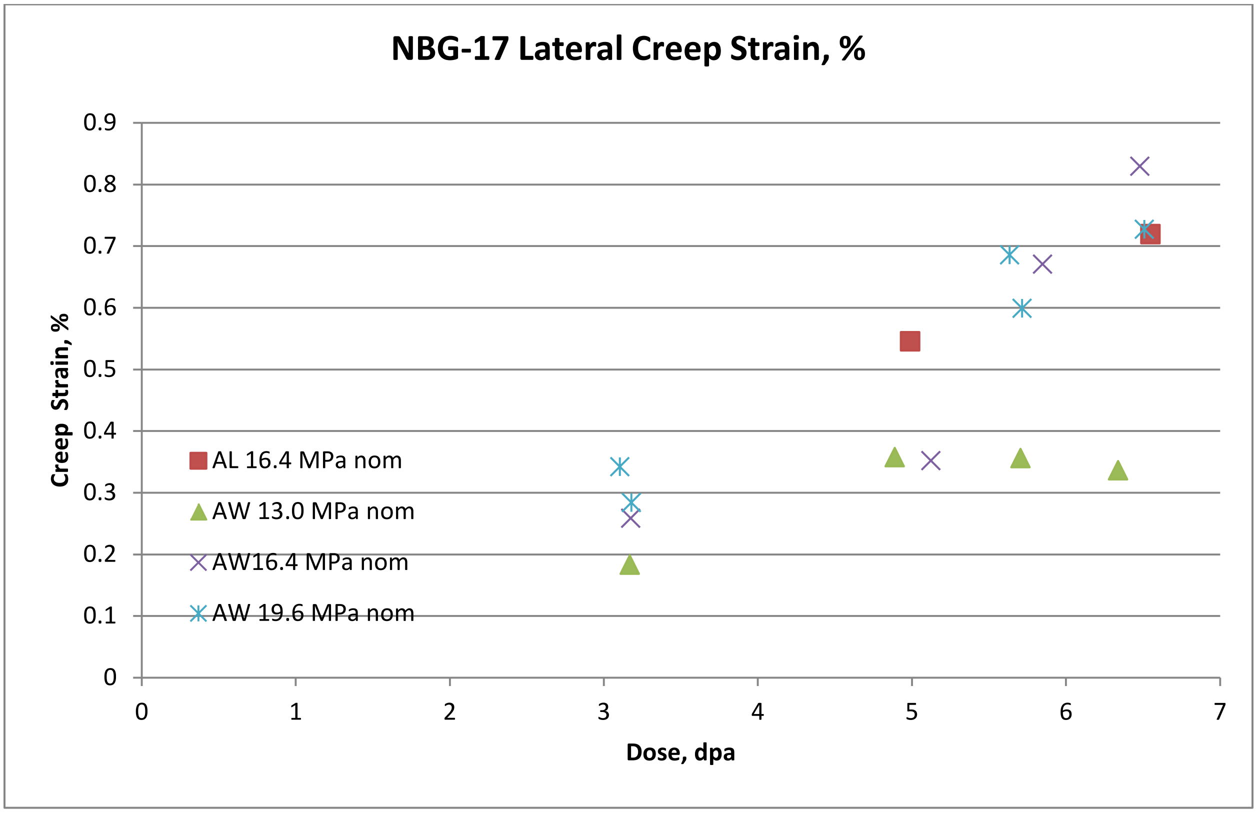

Figure 44 lateral creep strain (%) for NBG-17

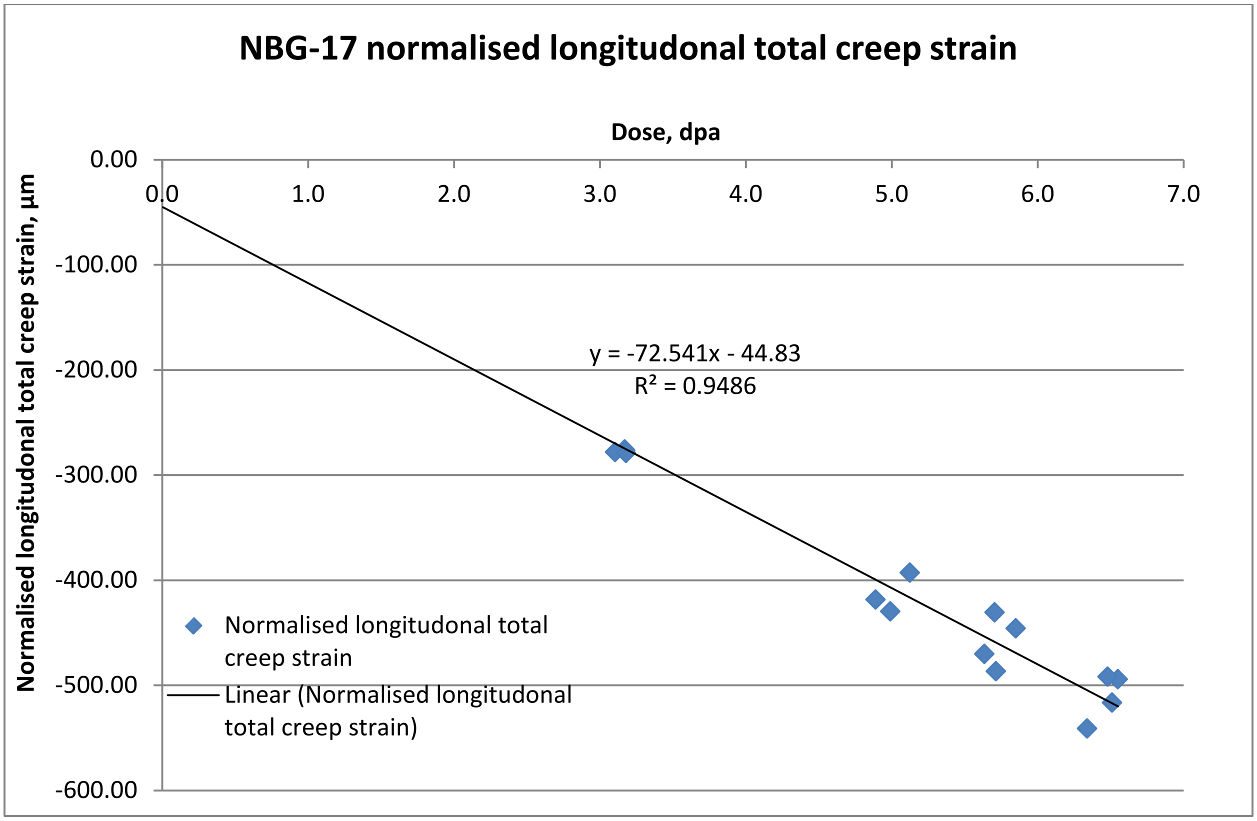

Figure 45 Normalized total longitudinal creep strain (microns) for NBG-17

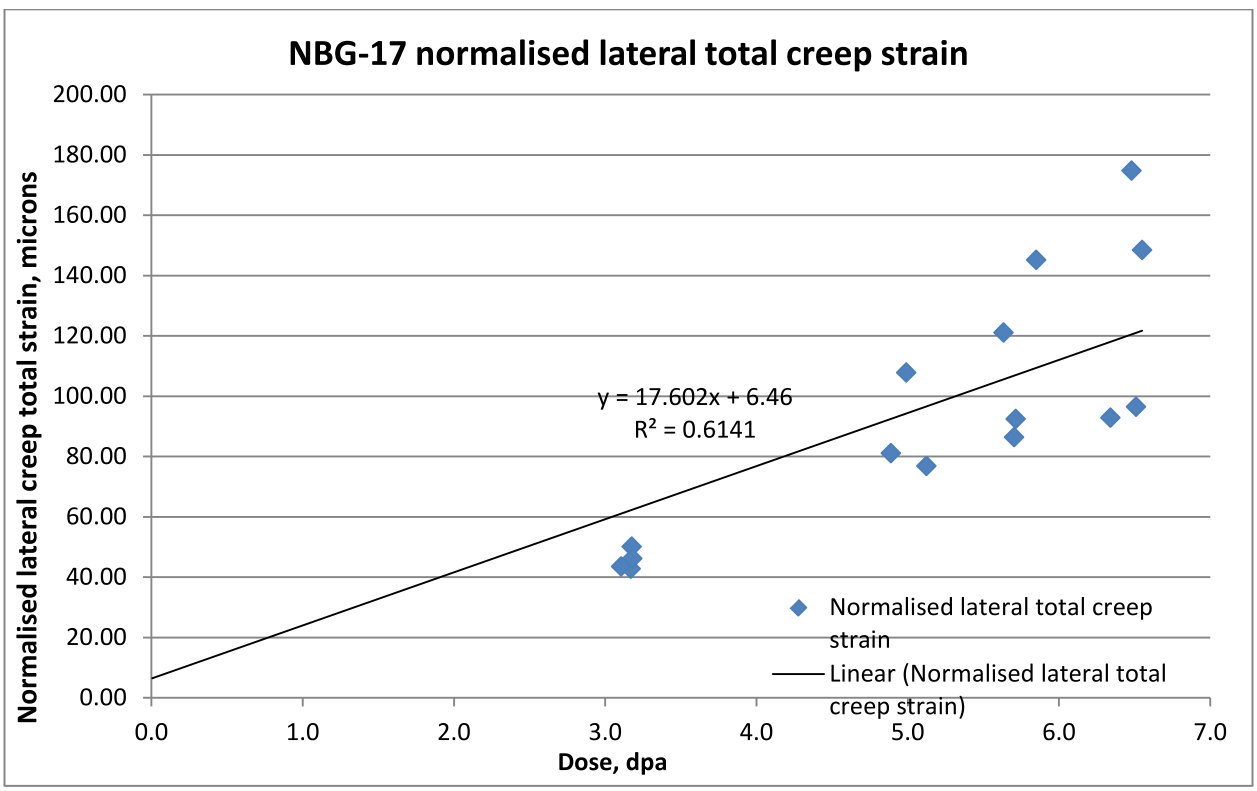

Figure 46 Normalized total lateral creep strain (microns) for NBG-17

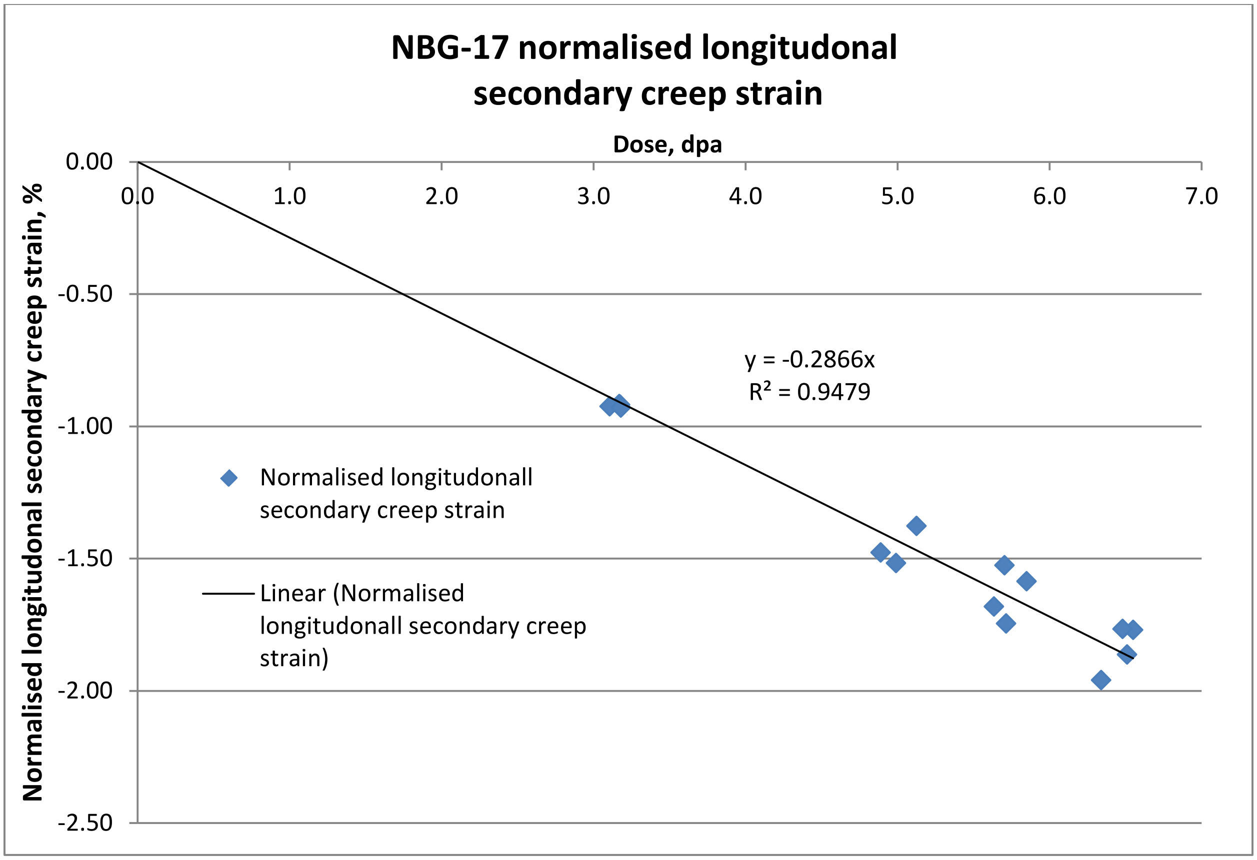

Figure 47 Normalized secondary longitudinal creep strain (%) for NBG-17

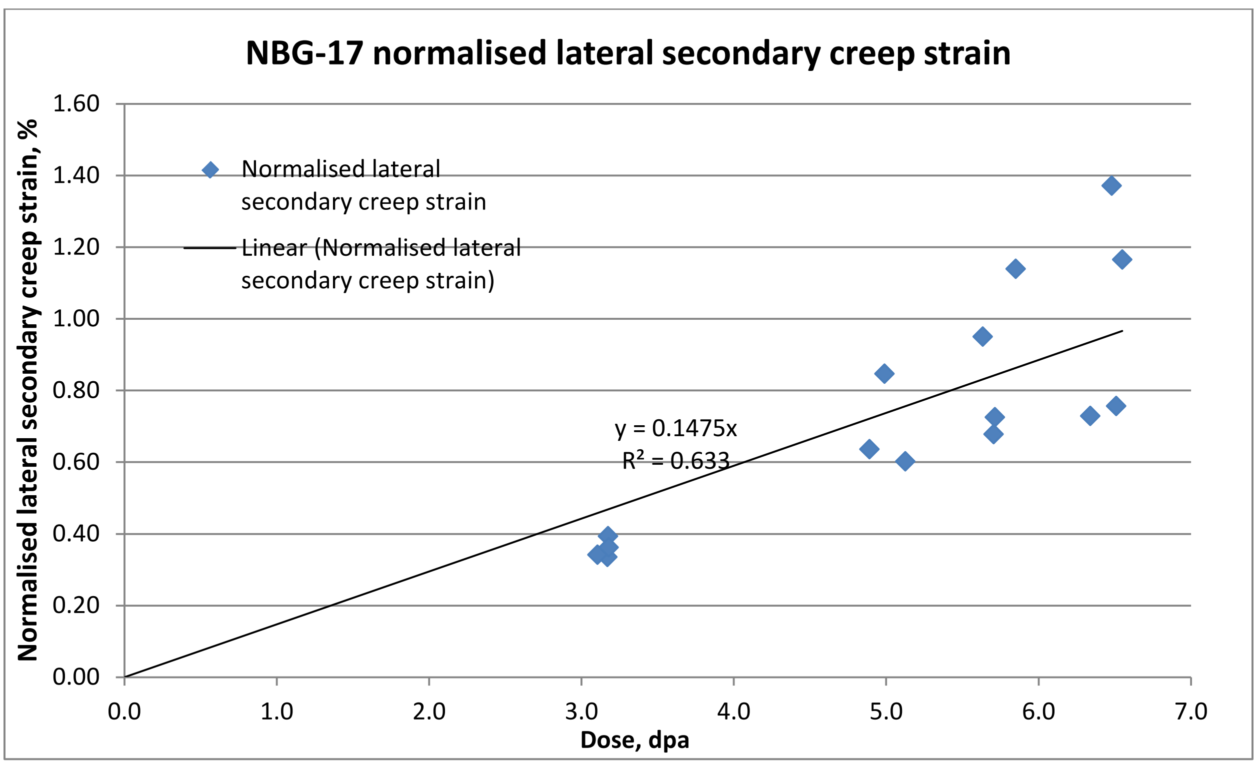

Figure 48 Normalized secondary lateral creep strain (%) for NBG-17

The creep strain ratio for NBG-17 was calculated from the ratio of the gradients of the normalized total creep strain (Figure 45 and Figure 46). Thus, the ratio = 17.602/-72.541=- 0.243. This value of the creep strain ratio compares very favorably with both the irradiated Poisson's Ratio (PR) values of 0.262 (S.D. 0.027) for all control samples, and, 0.241 (SD=0.026) for all creep samples. As noted previously, the PR values appear to be reduced by irradiation (Table 30)[6]. The PR and creep strain ratios are discussed in section 7.

The creep coefficient, K is calculated from the gradients of the normalized secondary creep plots (Figure 47 and Figure 48) divided by the normalizing stress. Thus the creep coefficient for NBG-17 (longitudinal) was K = 0.2886/-19.73 = 0.0145 %/dpa·MPa or 0.099 $10^{-30}cm^2/n{\cdot}Pa$. The lateral value of K was 0.148/5.893 = 0.0250 %/dpa·MPa or 0.170 $10^{-30}cm^2/n{\cdot}Pa$. These K values compare well with literature values for K as discussed later in section 7.

6.2. Creep Strain Analysis for NBG-18 (Code B)

The NBG-18 creep strain data are reported in Table 40 and Table 41 and plotted in Figure 49 and Figure 50. The normalized total creep strain is plotted in Figure 51 and Figure 52. Longitudinal and lateral normalized secondary creep strains are plotted in Figure 53 and Figure 54.

Table 40 Derived creep strain (mm and %) for NBG-18 in the longitudinal direction normalized to the peak applied stress

Longitudonal																
			Companion Specimen		Creep Stress	Total Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress Normalised secondary creep strain	Stress Normlised total creep strain, microns	Primary Creep Strain	Normalized Primary Creep Strain
Specimen Number	I.D. Number		Number	I.D. Number	MPa	Longitudanal		Lateral							microns	mirons
						(mm)	%	(mm)	%				%			
BL7-01	4S7		BL7-02	5S5	-19.4688	-0.268	-1.06	0.050	0.39	3.68	-0.160	-0.90	-0.909	-271.654	-40.6334	-41.16
BL6-03	3S12		BL6-02	2S12	-19.7155	-0.526	-2.07	0.125	0.98	6.66	-0.162	-1.91	-1.911	-526.054	-41.1483	-41.16
BW7-03	4S14		BW8-03	4U13	-12.5413	-0.158	-0.62	0.041	0.33	3.50	-0.103	-0.52	-0.819	-248.776	-26.1749	-41.16
BW12-02	SPARE 1W		BW1-02	1U1	-13.155	-0.182	-0.72	0.033	0.26	3.67	-0.108	-0.61	-0.910	-272.125	-27.4558	-41.16
BW12-03	SPARE 2W		BW8-02	4U7	-12.5157	-0.308	-1.22	0.050	0.39	5.49	-0.103	-1.11	-1.753	-485.730	-26.1214	-41.16
BW7-02	4S5		BW8-01	4U5	-12.5285	-0.303	-1.20	0.072	0.57	6.13	-0.103	-1.09	-1.720	-477.489	-26.1481	-41.16
BW3-02	3S2		BW5-02	3U3	-13.177	-0.301	-1.19	0.045	0.35	5.96	-0.108	-1.08	-1.612	-450.393	-27.5017	-41.16
BW1-01	1S4		BW1-03	1U4	-13.1593	-0.344	-1.35	0.062	0.49	6.49	-0.108	-1.25	-1.868	-515.226	-27.4647	-41.16
BW9-03	5U5		BW11-02	6U3	-16.3325	-0.227	-0.90	0.043	0.34	3.68	-0.134	-0.76	-0.920	-274.603	-34.0875	-41.16
BW9-02	5S15		BW10-02	5U14	-16.5748	-0.347	-1.37	0.060	0.47	5.32	-0.136	-1.23	-1.464	-412.523	-34.5932	-41.16
BW2-02	2S11		BW3-01	2U11	-16.2906	-0.349	-1.38	0.050	0.39	5.46	-0.134	-1.24	-1.504	-422.614	-34.0000	-41.16
BW9-01	5S8		BW10-01	5U8	-16.5529	-0.377	-1.49	0.098	0.77	6.07	-0.136	-1.35	-1.609	-449.472	-34.5475	-41.16
BW2-01	2S2		BW2-03	2U2	-16.2934	-0.436	-1.72	0.090	0.70	6.68	-0.134	-1.58	-1.917	-527.271	-34.0060	-41.16
BW5-01	3S14		BW7-01	3U13	-19.7229	-0.417	-1.64	0.069	0.54	5.02	-0.162	-1.48	-1.482	-416.920	-41.1637	-41.16
BW3-03	3S11		BW5-03	3U11	-19.7121	-0.463	-1.82	0.094	0.74	5.88	-0.162	-1.66	-1.662	-462.794	-41.1411	-41.16
BW11-01	6S13		BW12-01	6U12	-19.4722	-0.458	-1.80	0.035	0.27	5.97	-0.160	-1.64	-1.666	-463.868	-40.6405	-41.16
BW10-03	6S6		BW11-03	6U6	-19.4892	-0.514	-2.03	0.104	0.81	6.64	-0.160	-1.87	-1.889	-520.605	-40.6760	-41.16

Table 41 Derived creep strain (mm and %) for NBG-18 in the lateral direction normalized to the peak applied lateral stress

Lateral																	
Creep Stress	Specimen	I.D.	Companion Specimen		Piosson's Ratio	Lateral Creep Stress	Total Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress Normalised	Stress Normlised total	Primary Creep Strain	Normalized Primary Creep
MPa	Number	Number	Number	I.D. Number	from PIE data	MPa	Longitudanal		Lateral					secondary creep strain	creep strain, microns/MPa	microns	mirons
							(mm)	%	(mm)	%				%			
-19.4688	BL7-01	4S7	BL7-02	5S5	-0.246	4.7835	-0.268	-1.06	0.050	0.39	3.68	0.03839	0.350	0.4110	58.104	4.8756	-5.72
-19.7155	BL6-03	3S12	BL6-02	2S12	-0.285	5.6130	-0.526	-2.07	0.125	0.98	6.66	0.04505	0.933	0.9329	124.588	5.7211	-5.72
-12.5413	BW7-03	4S14	BW8-03	4U13	-0.253	3.1780	-0.158	-0.62	0.041	0.33	3.50	0.02611	0.299	0.5283	73.146	3.2392	-5.72
-13.155	BW12-02	SPARE 1W	BW1-02	1U1	-0.246	3.2414	-0.182	-0.72	0.033	0.26	3.67	0.02663	0.235	0.4071	57.747	3.3038	-5.72
-12.5157	BW12-03	SPARE 2W	BW8-02	4U7	-0.298	3.7334	-0.308	-1.22	0.050	0.39	5.49	0.03068	0.359	0.5404	74.759	3.8053	-5.72
-12.5285	BW7-02	4S5	BW8-01	4U5	-0.224	2.8026	-0.303	-1.20	0.072	0.57	6.13	0.02303	0.543	1.0878	144.457	2.8566	-5.72
-13.177	BW3-02	3S2	BW5-02	3U3	-0.299	3.9412	-0.301	-1.19	0.045	0.35	5.96	0.03238	0.318	0.4535	63.604	4.0172	-5.72
-13.1593	BW1-01	1S4	BW1-03	1U4	-0.295	3.8807	-0.344	-1.35	0.062	0.49	6.49	0.03189	0.456	0.6598	89.923	3.9554	-5.72
-16.3325	BW9-03	5U5	BW11-02	6U3	-0.243	3.9753	-0.227	-0.90	0.043	0.34	3.68	0.03266	0.307	0.4335	61.030	4.0519	-5.72
-16.5748	BW9-02	5S15	BW10-02	5U14	-0.230	3.8122	-0.347	-1.37	0.060	0.47	5.32	0.03132	0.439	0.6463	88.118	3.8856	-5.72
-16.2906	BW2-02	2S11	BW3-01	2U11	-0.272	4.4359	-0.349	-1.38	0.050	0.39	5.46	0.03645	0.352	0.4460	62.708	4.5214	-5.72
-16.5529	BW9-01	5S8	BW10-01	5U8	-0.264	4.3617	-0.377	-1.49	0.098	0.77	6.07	0.03584	0.737	0.9485	126.670	4.4457	-5.72
-16.2934	BW2-01	2S2	BW2-03	2U2	-0.289	4.7153	-0.436	-1.72	0.090	0.70	6.68	0.03875	0.666	0.7929	106.899	4.8061	-5.72
-19.7229	BW5-01	3S14	BW7-01	3U13	-0.269	5.3134	-0.417	-1.64	0.069	0.54	5.02	0.04366	0.501	0.5289	73.240	5.4157	-5.72
-19.7121	BW3-03	3S11	BW5-03	3U11	-0.250	4.9182	-0.463	-1.82	0.094	0.74	5.88	0.04041	0.699	0.7979	107.534	5.0129	-5.72
-19.4722	BW11-01	6S13	BW12-01	6U12	-0.226	4.3929	-0.458	-1.80	0.035	0.27	5.97	0.03610	0.235	0.3005	44.155	4.4776	-5.72
-19.4892	BW10-03	6S6	BW11-03	6U6	-0.210	4.0966	-0.514	-2.03	0.104	0.81	6.64	0.03366	0.779	1.0677	141.836	4.1755	-5.72

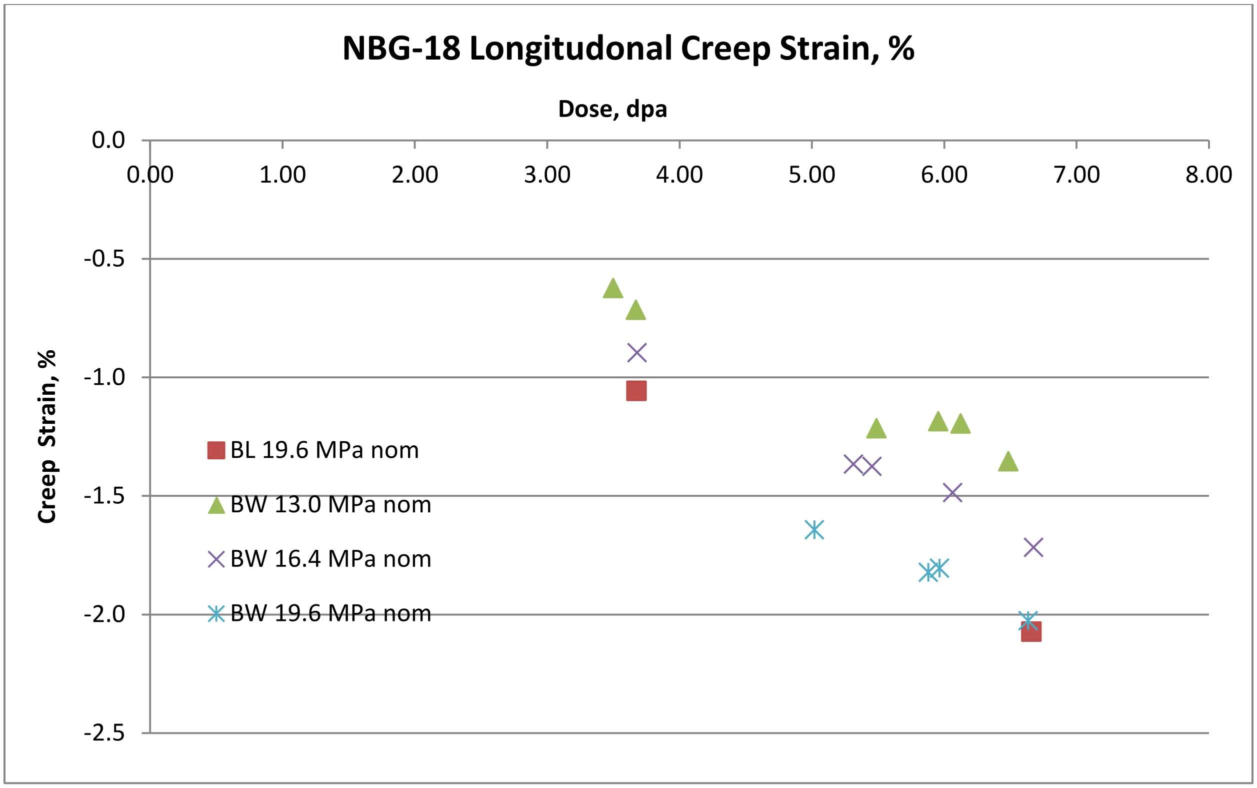

Figure 49 longitudinal creep strain (%) for NBG-18

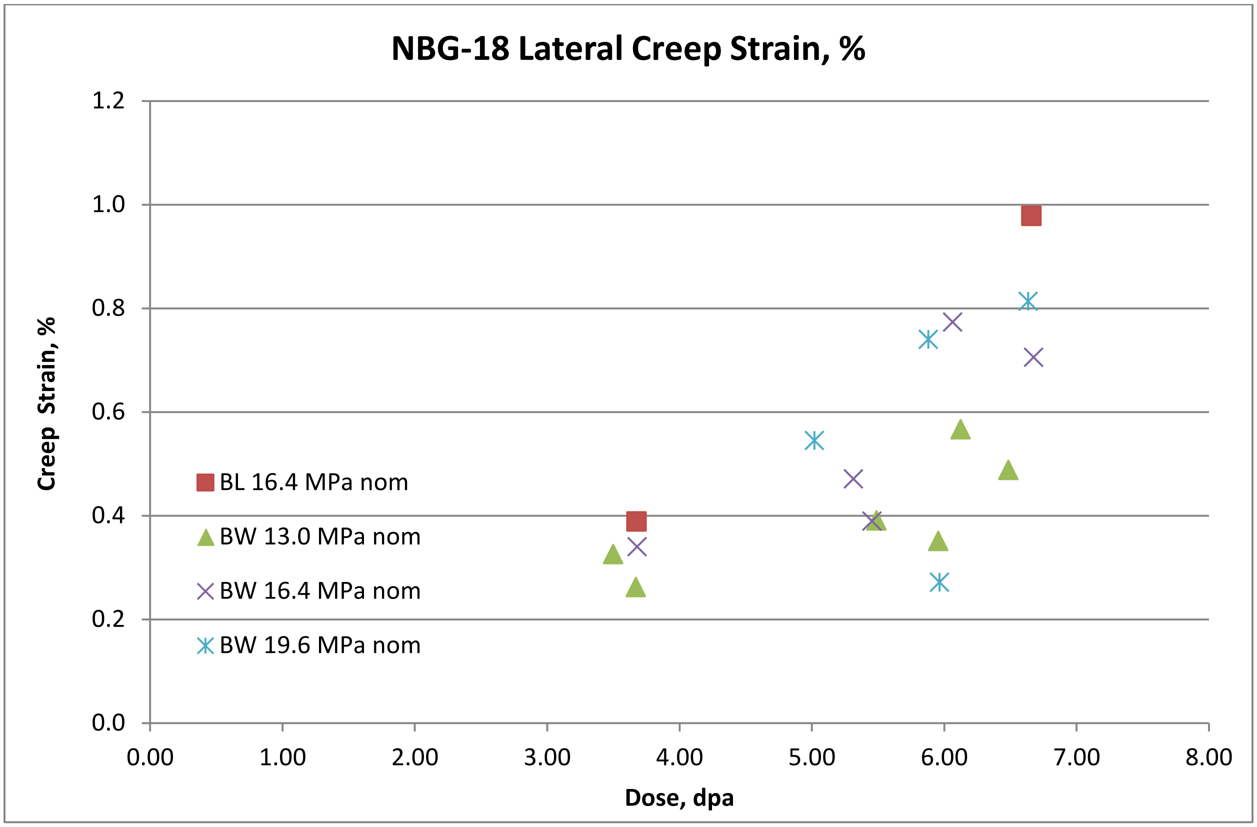

Figure 50 lateral creep strain (%) for NBG-18

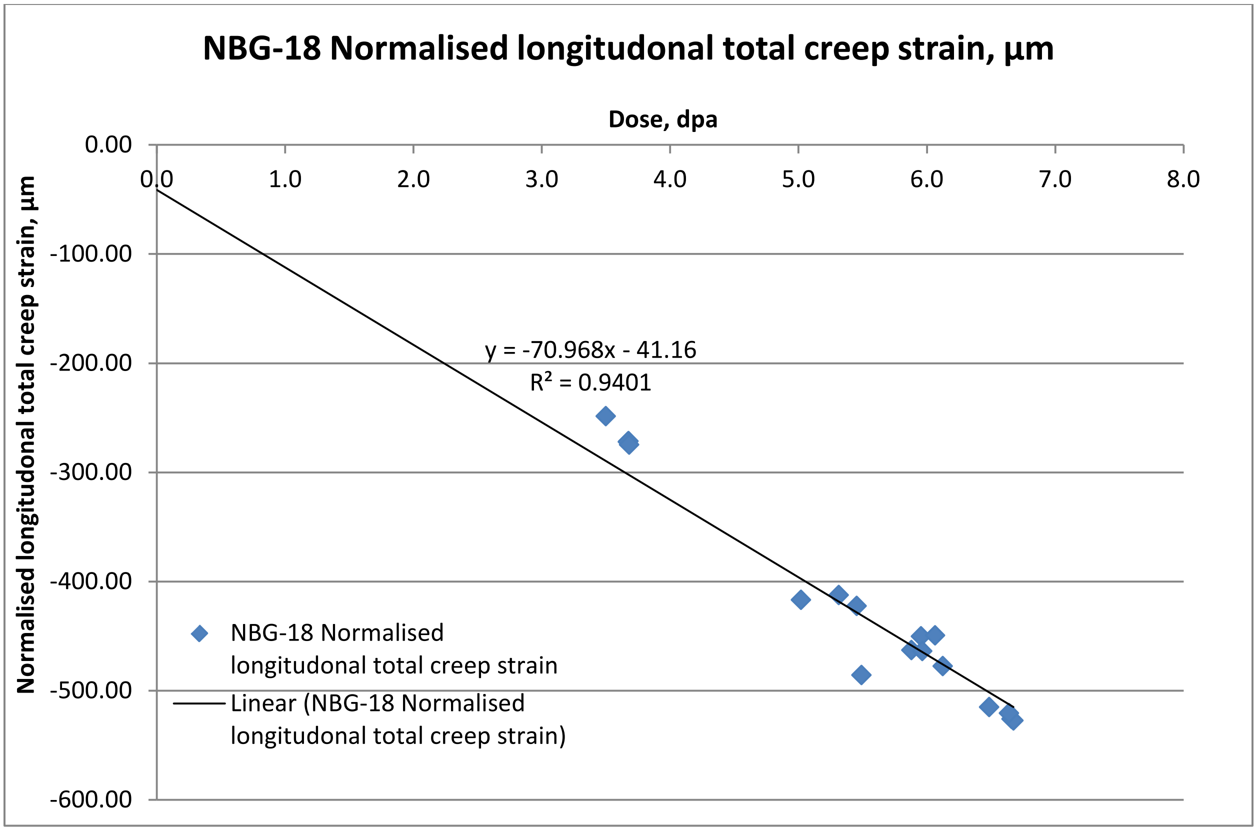

Figure 51 Normalized total longitudinal creep strain (microns) for NBG-18

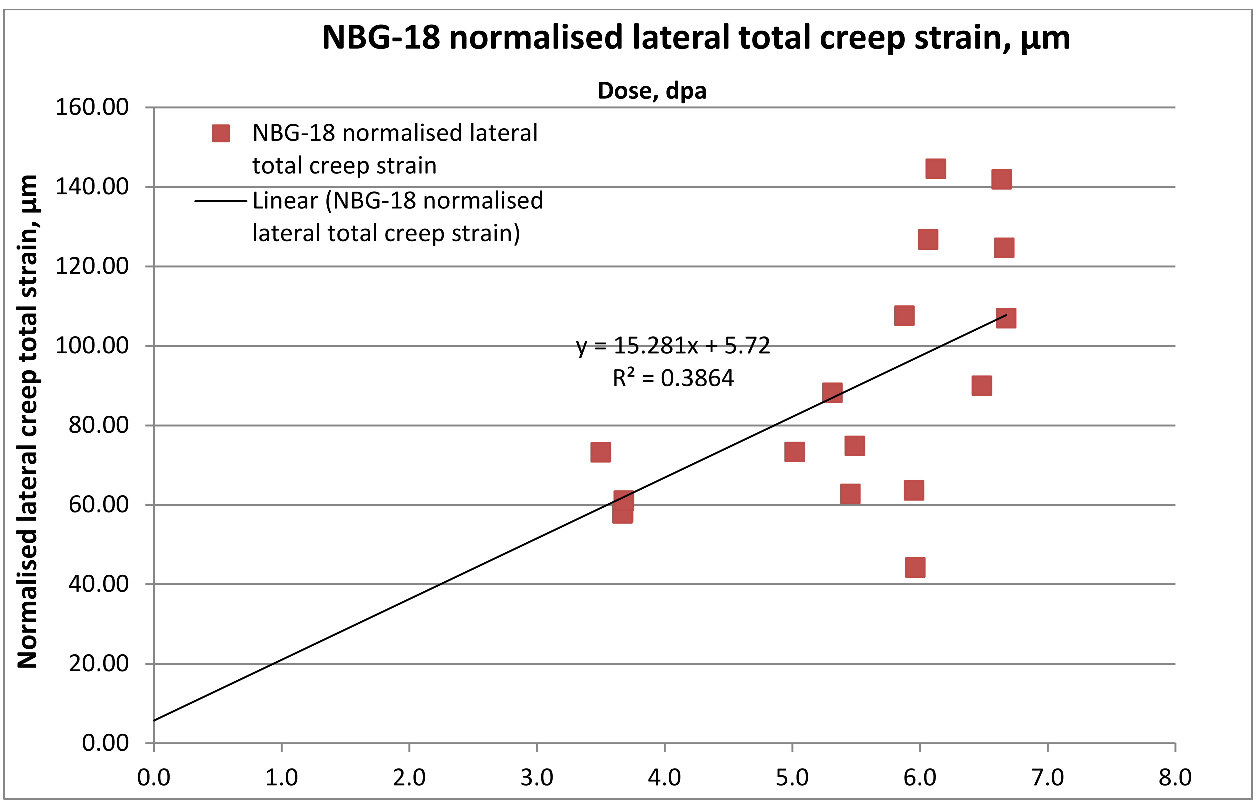

Figure 52 Normalized total lateral creep strain (microns) for NBG-18

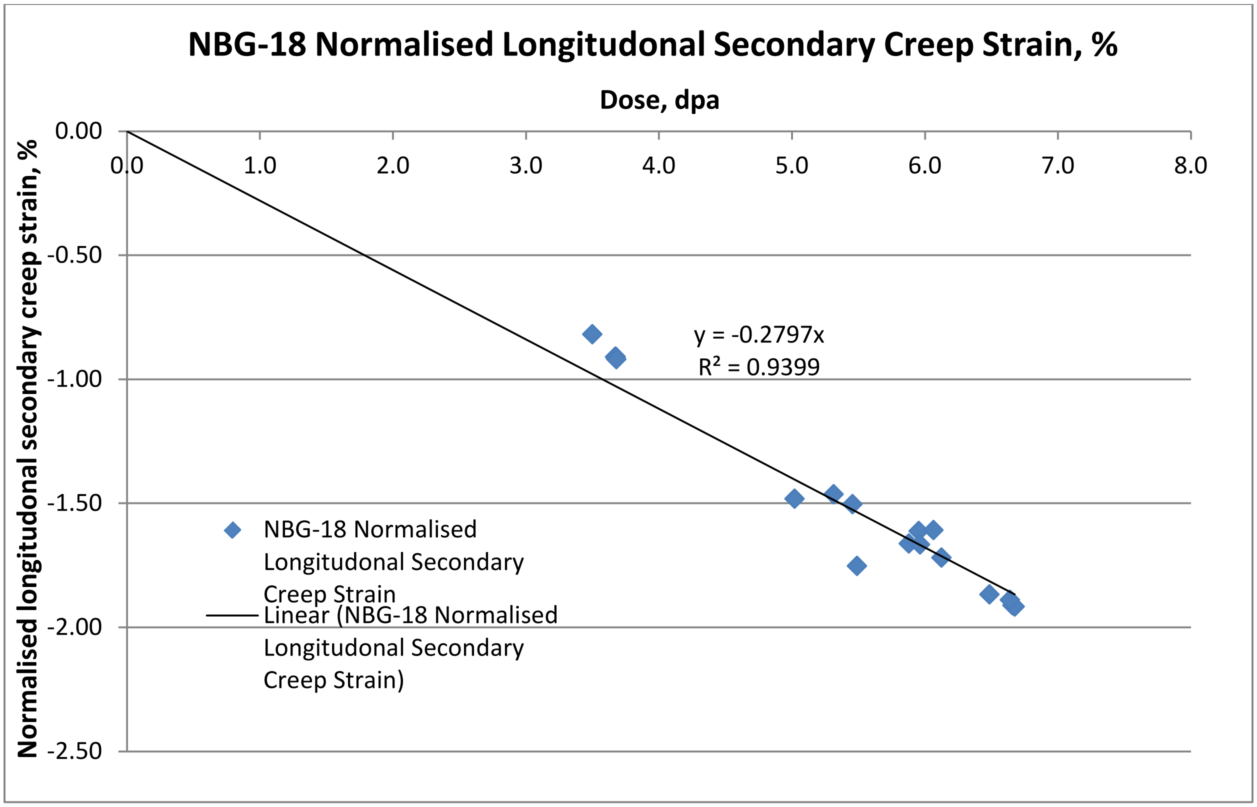

Figure 53 Normalized secondary longitudinal creep strain (%) for NBG-18

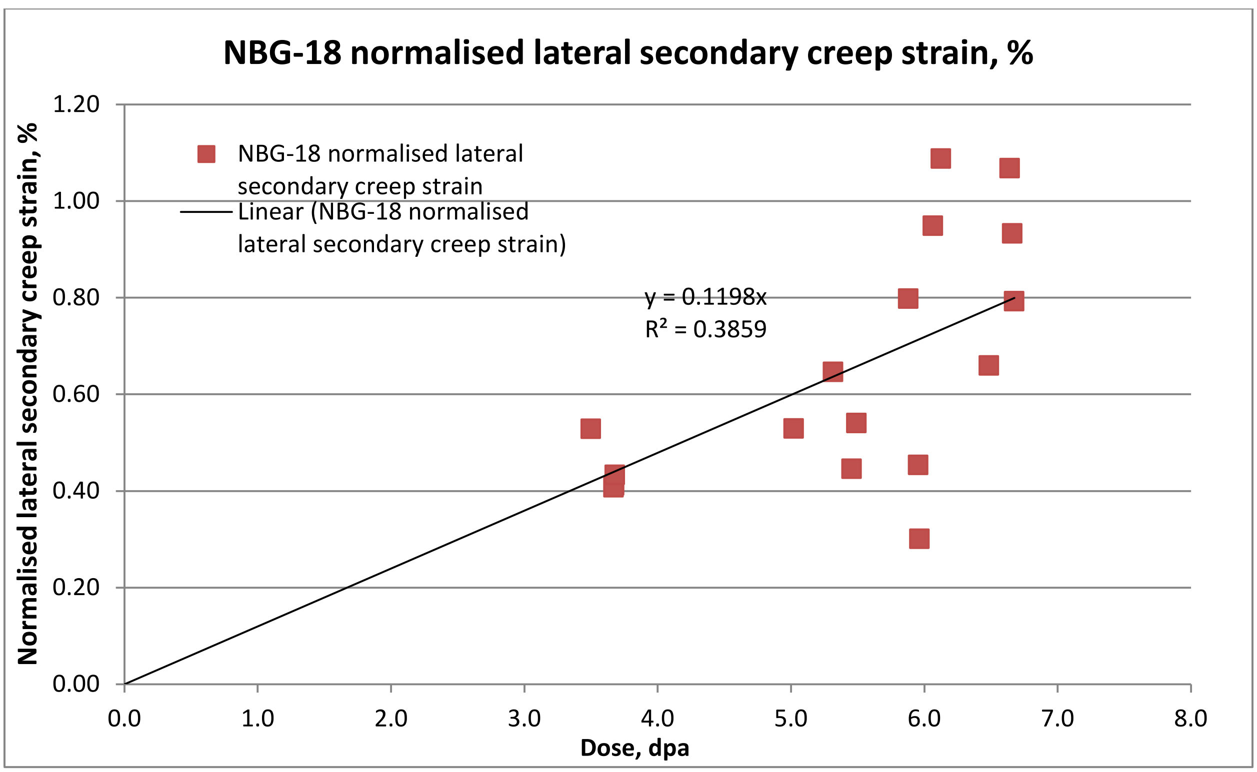

Figure 54 Normalized secondary lateral creep strain (%) for NBG-18

The creep strain ratio for NBG-18 was calculated from the ratio of the gradients of the normalized total creep strain (Figure 51 and Figure 52). Thus, the ratio = 15.281/-70.968 = 0.215. This value of the creep strain ratio is less than both the irradiated Poisson's Ratio values of 0.159 (S.D. 0.027) all control samples, and, 0.273 (SD=0.024) for all creep samples. The PR values appear to be reduced by irradiation (Table 30)[6]. The PR and creep strain ratios are discussed in section 7.

The creep coefficient, K is calculated from the gradients of the normalized secondary creep plots (Figure 53 and Figure 54) divided by the normalizing stress. Thus the creep coefficient for NBG-18 (longitudinal) was K = 0.-2797/-19.723 = 0.0142 %/dpa·MPa or 0.096 $10^{-30}cm^2$/n·Pa. The lateral value of K was 0.1198/5.613 = 0.0213 %/dpa·MPa or $0.145^{-30}cm^2$/n·Pa. These K values compare well with literature values for K as discussed later in section 7.

6.3. Creep Strain Analysis for H-451 (Code C)

The H-451 data has been determined previously (Section 4) but is reproduced here for convenience. As for previous grades the H-451 creep strain data are reported in Table 42 and Table 43 and plotted in Figure 55 and Figure 56. The normalized total creep strain is plotted in Figure 57 and Figure 58. Longitudinal and lateral normalized secondary creep strains are plotted in Figure 59 and Figure 60.

Table 42 Derived creep strain (mm and %) for H-451 in the longitudinal direction normalized to the peak applied stress

Specimen Number	I.D. Number		Companion Specimen Number	I.D. N	Compressive Creep Stress MPa	Creep Strain (creep-control) Longitudanal (mm)	%	Lateral (mm)	%	Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress Normalised secondary creep strain %	Stress Normlised total creep strain, microns µm	Primary Creep Strain microns	Normalized Primary Creep Strain mirons
CW11-01	4S2		CW12-01	4U12	-12.5720	-0.30798	-1.21444	0.065046	0.511478	4.535	-0.14222	-1.0722	-1.689438214	-485.262989	-36.1232	-56.92
CW11-02	4S13		CW12-01	4U12	-12.5470	-0.30145	-1.18859	0.064971	0.510379	4.36	-0.14193	-1.0467	-1.652449074	-475.9243684	-36.0513	-56.92
CW7-03	1S15		CW8-03	1U14	-13.1928	-0.3430	-1.3523	0.0478	0.3758	5.1000	-0.14924	-1.2031	-1.806420794	-514.974522	-37.9068	-56.92
CW7-01	1S8		CW8-02	1U8	-13.2109	-0.4804	-1.8948	0.0774	0.6084	6.7700	-0.14944	-1.7454	-2.617115425	-720.3926465	-37.9589	-56.92
CW14-01	6U5		CW13-01	5U7	-16.5715	-0.3611	-1.4245	0.0637	0.5006	4.4400	-0.18746	-1.2370	-1.478726229	-431.6649164	-47.6149	-56.92
CW12-02	5S7		CW 13-01	5U7	-16.6245	-0.4551	-1.7945	0.0633	0.4981	4.6200	-0.18806	-1.6064	-1.914152734	-542.2430776	-47.7673	-56.92
CW9-01	2S13		CW9-02	2U12		Lost in Hot Cell At INL										
CW13-02	6S5		CW11-03	4U2	-16.3337	-0.74954	-2.95562	0.126684	0.995531	6.8450	-0.18477	-2.7708	-3.36040368	-909.025823	-46.9316	-56.92
CW13-03	6S9		CW14-02	6U9	-19.5447	-0.5706	-2.2496	0.0720	0.5662	5.1000	-0.22109	-2.0285	-2.055940735	-578.2792371	-56.1580	-56.92
CW10-01	3S10		CW10-03	3U10	-19.8092	-0.6611	-2.6063	0.1410	1.1097	6.2800	-0.22409	-2.3822	-2.382137812	-661.0452197	-56.9179	-56.92
CW9-03	3S1		CW10-02	3U1	-19.7653	-0.7831	-3.0888	0.1511	1.1872	6.7350	-0.22359	-2.8652	-2.871545186	-784.7957892	-56.7916	-56.92

Table 43 Derived creep strain (mm and %) for H-451 in the lateral direction normalized to the peak applied lateral stress

LATERAL STRESS																	
Longitudonal Creep Stress MPa	Creep Specimen No	I.D. No	Companion (Control) Spec No	Control I.D. No	Irr Poissons Ratio	Lateral Creep Stress MPa	Creep Strain (creep-control) Longitudanal (mm)	%	Lateral (mm)	%	Mean Dose, DPA	Primary Creep (σ/E) %	Secondary Creep, %	Stress Normalised secondary creep strain %	Stress normalised total secondary creep strain, microns/MPa	Primary Creep Strain microns	Normalized Primary Creep Strain mirons
-12.5720	CW11-01	4S2	CW12-01	4U12	-0.2241	2.8173852	-0.30798	-1.21444	0.065046	0.511478	4.535	0.036652	0.4748	0.925423324	126.75	4.6547	9.07
-12.5470	CW11-02	4S13	CW12-01	4U12	-0.3143	3.9435221	-0.30145	-1.18859	0.064971	0.510379	4.36	0.051301	0.4591	0.639224009	90.45	6.5153	9.07
-13.1928	CW7-03	1S15	CW8-03	1U14	-0.2838	3.74411664	-0.3430	-1.3523	0.0478	0.3758	5.1000	0.048707	0.3271	0.479758979	70.11	6.1858	9.07
-13.2109	CW7-01	1S8	CW8-02	1U8	-0.3052	4.03196668	-0.4804	-1.8948	0.0774	0.6084	6.7700	0.052452	0.5560	0.757159352	105.32	6.6614	9.07
-16.5715	CW14-01	6U5	CW13-01	5U7	-0.3027	5.01619305	-0.3611	-1.4245	0.0637	0.5006	4.4400	0.065256	0.4354	0.476596091	69.74	8.2875	9.07
-16.6245	CW12-02	5S7	CW 13-01	5U7	-0.2912	4.8410544	-0.4551	-1.7945	0.0633	0.4981	4.6200	0.062978	0.4351	0.49349249	71.78	7.9981	9.07
	CW9-01	2S13	CW9-02	2U12			Companion Lost inHot Cell At INL										
-16.3337	CW13-02	6S5	CW11-03	4U2	-0.2993	4.88867641	-0.74954	-2.95562	0.126684	0.995531	6.8450	0.063597	0.9319	1.046755851	142.27	8.0768	9.07
-19.5447	CW13-03	6S9	CW14-02	6U9	-0.1956	3.82294332	-0.5706	-2.2496	0.0720	0.5662	5.1000	0.049733	0.5164	0.741780188	103.39	6.3161	9.07
-19.8092	CW10-01	3S10	CW10-03	3U10	-0.2772	5.49111024	-0.6611	-2.6063	0.1410	1.1097	6.2800	0.071434	1.0382	1.038196861	141.01	9.0721	9.07
-19.7653	CW9-03	3S1	CW10-02	3U1	-0.2702	5.34058406	-0.7831	-3.0888	0.1511	1.1872	6.7350	0.069476	1.1177	1.149172223	155.28	8.8234	9.07

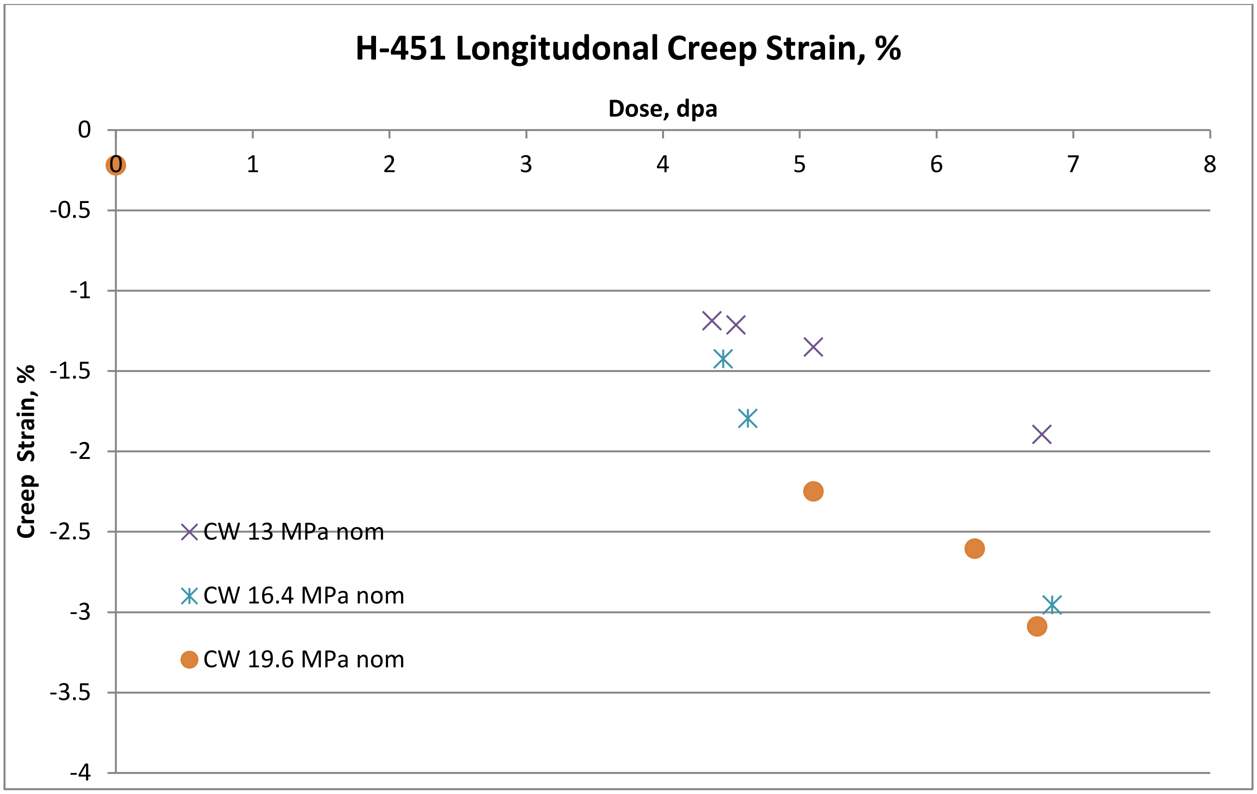

Figure 55 longitudinal creep strain (%) for H-451

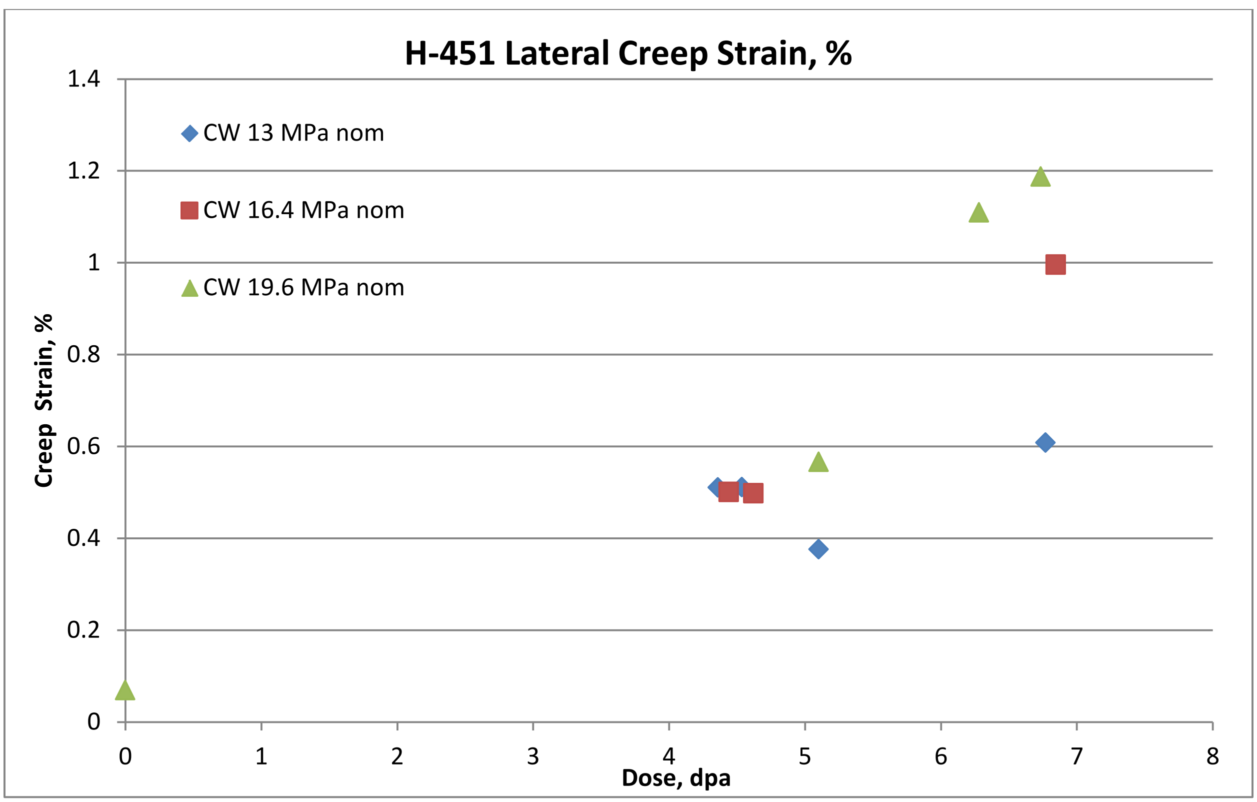

Figure 56 lateral creep strain (%) for H-451

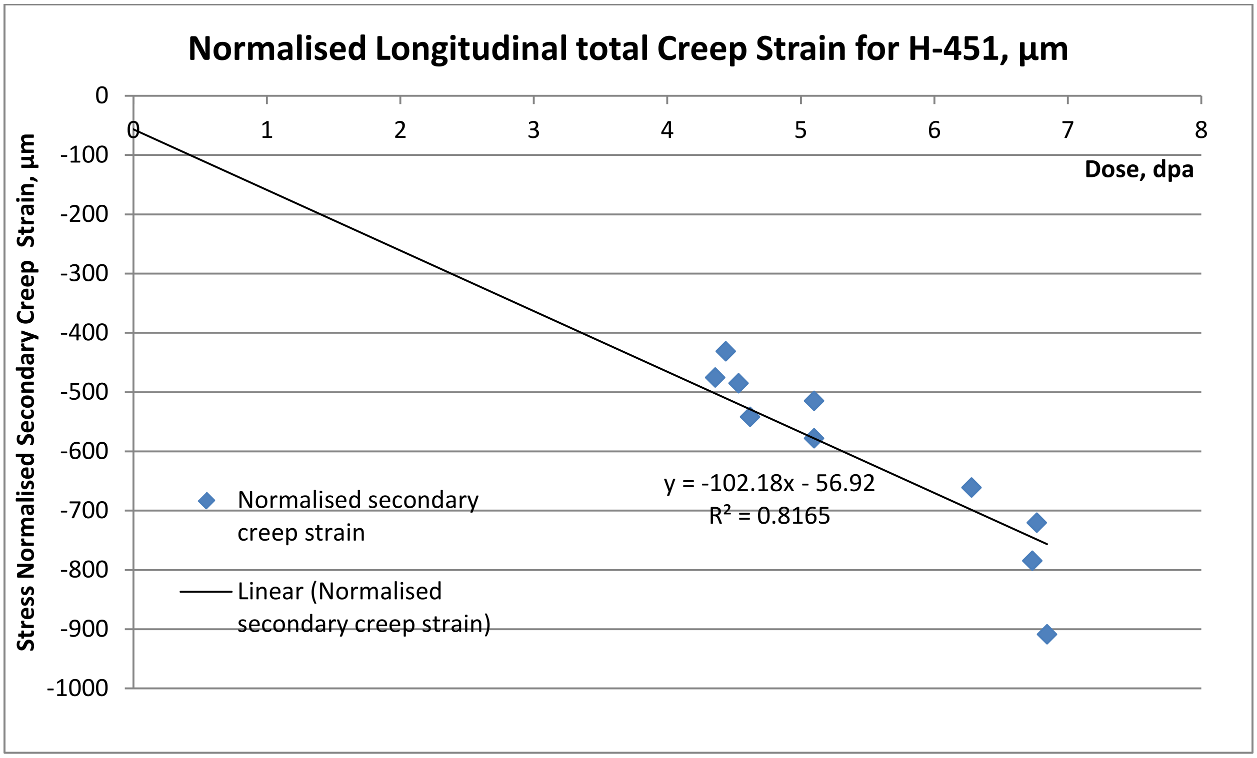

Figure 57 Normalized total longitudinal creep strain (microns) for H-451

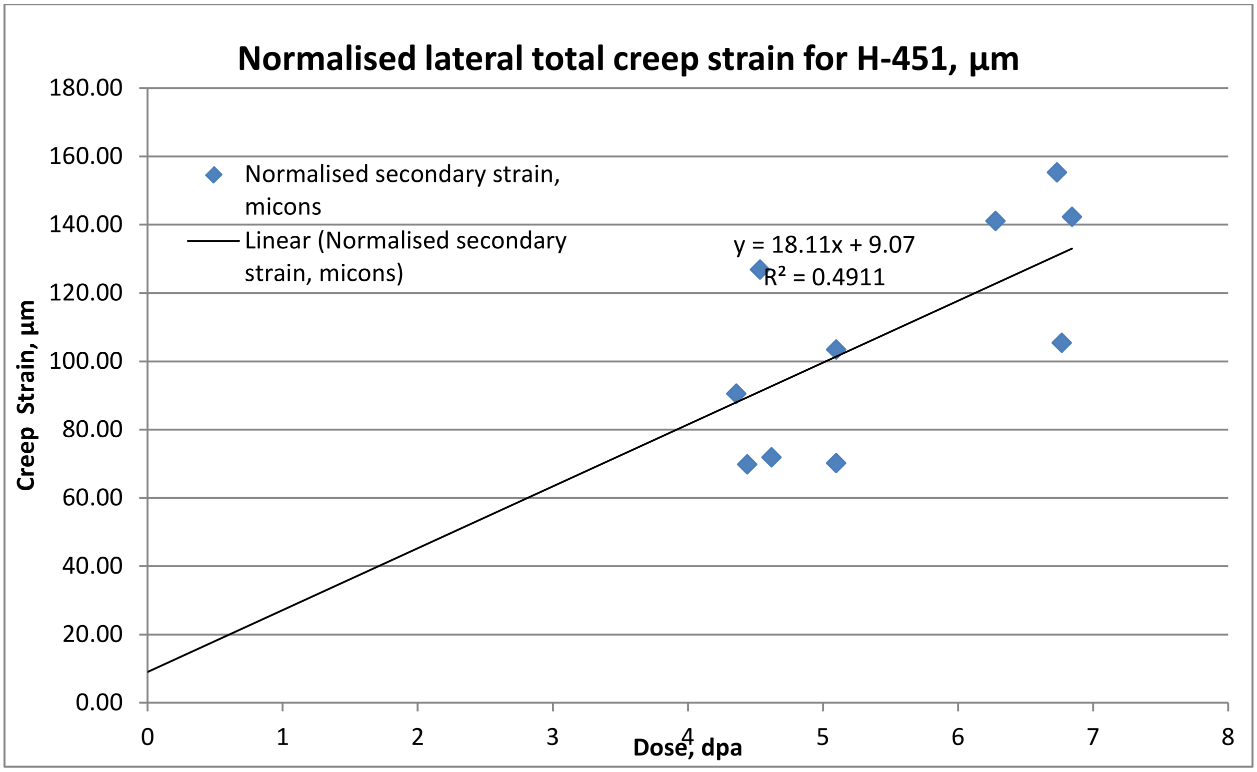

Figure 58 Normalized total lateral creep strain (microns) for H-451

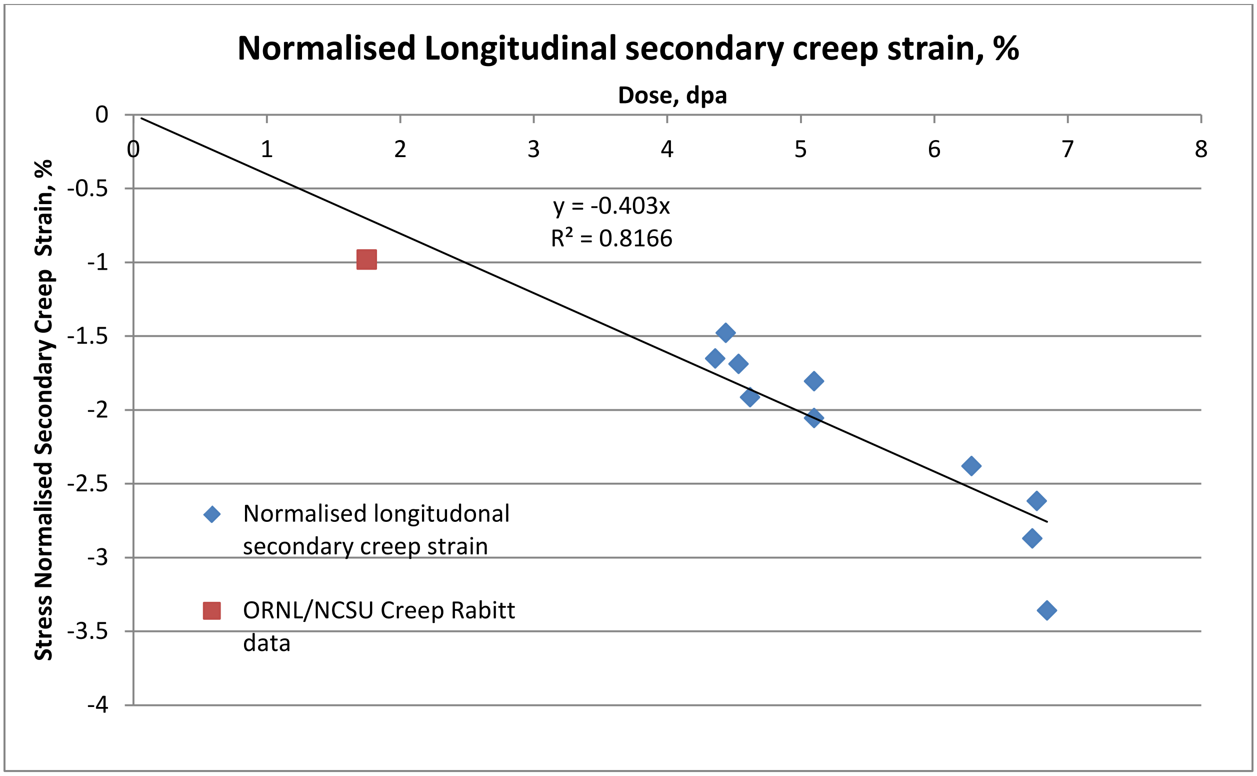

Figure 59 Normalized secondary longitudinal creep strain (%) for H-451

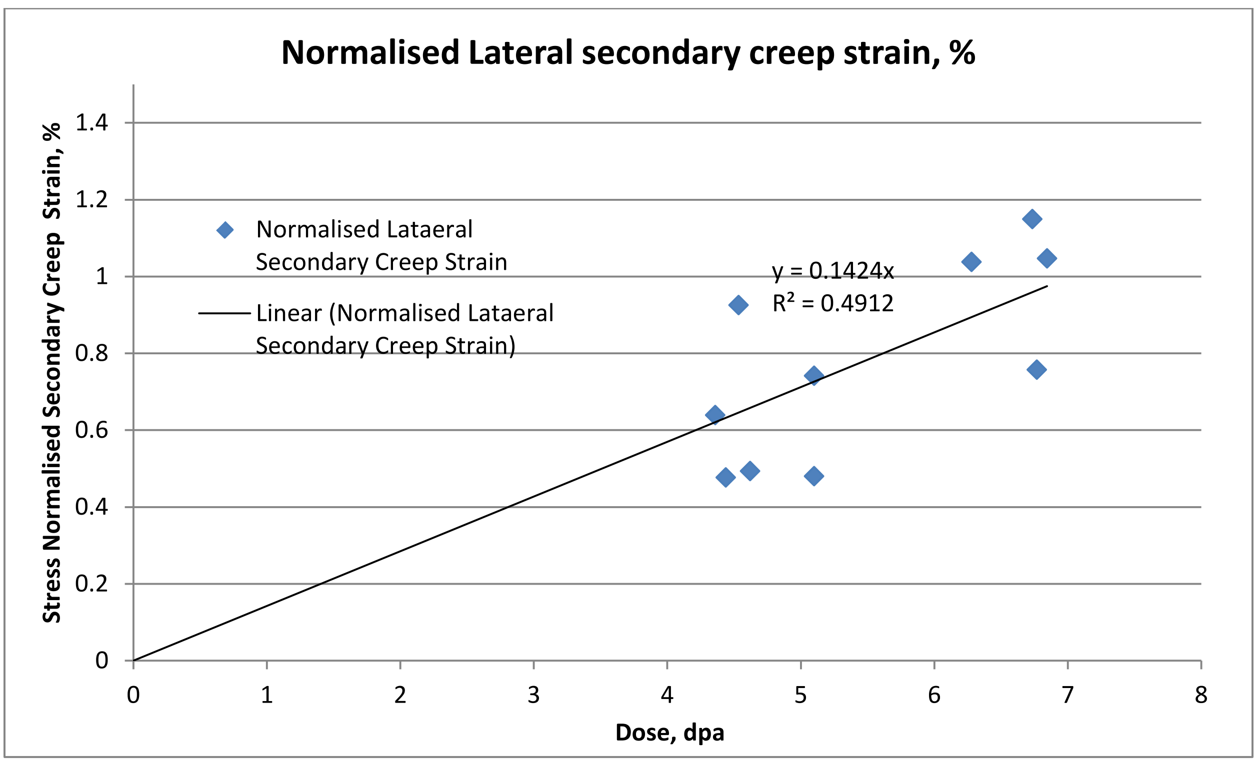

Figure 60 Normalized secondary lateral creep strain (%) for H-451

The creep strain ratio for H-451 was calculated from the ratio of the gradients of the normalized total creep strain (Figure 57 and Figure 58). Thus, the ratio = 18.11/-102.18=-0.177. This value of the creep strain ratio is less than both the irradiated Poisson's Ratio values of 0.283 (S.D. 0.028) all control samples, and, 0.278 (SD=0.036) for all creep samples. The PR and creep strain ratios are discussed in section 7.

The creep coefficient, K is calculated from the gradients of the normalized secondary creep plots (Figure 59 and Figure 60) divided by the normalizing stress. Thus the creep coefficient for H-451 (longitudinal) was K = 0.-405/-19.723 = 0.203 %/dpa·MPa or 0.138 ($10^{-30}cm^2$/n·Pa. The lateral value of K was 0.1424/5.491 = 0.0259 %/dpa·MPa or 0.176 ($10^{-30}m^2$/n·Pa. These K values compare well with literature values for K as discussed later in section 7.

6.4. Creep Strain Analysis for PCEA (Code D)

The PCEA creep strain data are reported in Table 44 and Table 45 and plotted in Figure 61 and Figure 62. The normalized total creep strain is plotted in Figure 63 and Figure 64. Longitudinal and lateral normalized secondary creep strains are plotted in Figure 65 and Figure 66.

Table 44 Derived creep strain (mm and %) for PCEA in the longitudinal direction normalized to the peak applied stress

LONGITUDINAL STRAIN																
Specimen	I.D. Number	Companion Specimen			Compressive Creep Stress	Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E0),%	Secondary Creep, %	Stress Normalised secondary creep strain	Stress Normlised total creep strain, microns	Primary Creep Strain	Normalized Primary Creep Strain
Number			Number	I.D. Number	MPa	Longitudanal		Lateral					%		microns	mirons
						(mm)	%	(mm)	%							
DA701	4S6		DA702	5S11	-12.55	-0.297	-1.168	0.030	0.239	3.945	-0.13974	-1.028	-1.638844	-472.636	-35.4952	-56.57
DA602	4S1		DA601	3S6	-13.18	-0.477	-1.878	0.063	0.497	6.165	-0.14675	-1.731	-2.627127	-723.526	-37.2740	-56.57
DW1-03	1S14		DW2-03	1U13	-13.18	-0.242	-0.953	0.038	0.296	4.135	-0.120048	-0.833	-1.264058	-367.093	-37.2833	-56.57
DW6-02	4S15		DW7-02	4U14	-12.74	-0.408	-1.608	0.044	0.343	5.735	-0.116039	-1.492	-2.342512	-640.703	-36.0383	-56.57
DW6-03	4U1		DW7-01	4U6	-12.76	-0.422	-1.661	0.077	0.603	6.395	-0.116248	-1.545	-2.420969	-660.597	-36.1033	-56.57
DW1-01	1S2		DW2-01	1U2	-13.47	-0.413	-1.629	0.066	0.521	6.61	-0.122689	-1.506	-2.235904	-613.809	-38.1034	-56.57
DW8-02	5S12		**DW902**	5U11	-16.67	-0.316	-1.245	0.052	0.408	4.025	-0.151813	-1.094	-1.312033	-379.247	-47.1486	-56.57
DW3-03	2S14		**DW5-01**	2U13	-16.44	-0.335	-1.321	0.051	0.401	4.145	-0.149766	-1.171	-1.424778	-407.807	-46.5128	-56.57
DW8-01	5S9		**DW9-01**	5U9	-16.76	-0.469	-1.849	0.071	0.556	5.6	-0.152636	-1.696	-2.023895	-559.936	-47.4041	-56.57
DW3-02	2S8		**DW4-01**	2U8	-16.56	-0.443	-1.747	0.064	0.501	5.745	-0.150846	-1.596	-1.927483	-535.398	-46.8483	-56.57
DW7-03	5S4		**DW8-03**	5U4	-16.81	-0.518	-2.040	0.094	0.742	6.395	-0.153119	-1.887	-2.244899	-616.023	-47.5543	-56.57
DW3-01	2S1		**DW4-03**	2U1	-16.62	-0.519	-2.043	0.100	0.787	6.74	-0.151361	-1.892	-2.276741	-624.035	-47.0081	-56.57
DW10-01	6S11		**DW10-02**	6U11	-19.66	-0.404	-1.592	0.055	0.434	4.135	-0.179013	-1.413	-1.437283	-411.079	-55.5960	-56.57
DW5-02	3S15		**DW6-01**	3U14	-19.94	-0.615	-2.423	0.072	0.569	5.34	-0.181581	-2.242	-2.248549	-616.927	-56.3935	-56.57
DW11-01	Spare 1W		**DW5-03**	3U6	-20.00	-0.644	-2.538	0.109	0.860	6.1	-0.182144	-2.356	-2.355894	-644.260	-56.5686	-56.57
DW1-02	1S6		**DW2-02**	1U6	-19.78	-0.609	-2.400	0.094	0.737	6.175	-0.180123	-2.220	-2.244564	-615.954	-55.9407	-56.57
DW9-03	6S4		**DW10-03**	6U4	-19.79	-0.615	-2.423	0.122	0.963	6.73	-0.180201	-2.243	-2.266998	-621.710	-55.9651	-56.57

Table 45 Derived creep strain (mm and %) for PCEA in the lateral direction normalized to the peak applied lateral stress

LATERAL STRESS																	
Longitudonal Creep Stress	Creep Specimen No	I.D.	Companion (Control) Spec No	Control I.D. No	Irr Poissons Ratio (from PIE report)	Lateral Creep Stress	Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E0) %	Secondary Creep, %	Stress Normalised lateral secondary creep strain	Stress Normalised total secondary lateral creep strain,	Primary Creep Strain	Normalized Primary Creep Strain
MPa		No				MPa	Longitudanal		Lateral							microns	mirons
							(mm)	%	(mm)	%				%	microns		
-12.55	**DA701**	4S6	DA702	5S11	-0.2111	2.649	-0.297	-1.168	0.030	0.239	3.945	0.024127	0.215	0.4486	63.511	3.0641	6.40
-13.18	**DA602**	4S1	DA601	3S6	-0.2632	3.468	-0.477	-1.878	0.063	0.497	6.165	0.031589	0.465	0.7420	100.864	4.0118	6.40
-13.18	**DW1-03**	1S14	DW2-03	1U13	-0.2132	2.810	-0.242	-0.953	0.038	0.296	4.135	0.0312945	0.265	0.5215	74.205	3.2505	6.40
-12.74	**DW6-02**	4S15	DW7-02	4U14	-0.2905	3.701	-0.408	-1.608	0.044	0.343	5.735	0.041217	0.301	0.4503	65.173	4.2811	6.40
-12.76	**DW6-03**	4U1	DW7-01	4U6	-0.3079	3.930	-0.422	-1.661	0.077	0.603	6.395	0.0437645	0.559	0.7871	108.087	4.5457	6.40
-13.47	**DW1-01**	1S2	DW2-01	1U2	-0.2186	2.945	-0.413	-1.629	0.066	0.521	6.61	0.0327929	0.488	0.9167	124.495	3.4061	6.40
-16.67	**DW8-02**	5S12	**DW902**	5U11	-0.2834	4.724	-0.316	-1.245	0.052	0.408	4.025	0.052606	0.355	0.4157	60.770	5.4640	6.40
-16.44	**DW3-03**	2S14	**DW5-01**	2U13	-0.2452	4.032	-0.335	-1.321	0.051	0.401	4.145	0.0449013	0.356	0.4882	69.971	4.6638	6.40
-16.76	**DW8-01**	5S9	**DW9-01**	5U9	-0.2749	4.607	-0.469	-1.849	0.071	0.556	5.6	0.0513047	0.505	0.6057	84.954	5.3289	6.40
-16.56	**DW3-02**	2S8	**DW4-01**	2U8	-0.2833	4.692	-0.443	-1.747	0.064	0.501	5.745	0.0522525	0.448	0.5282	75.071	5.4273	6.40
-16.81	**DW7-03**	5S4	**DW8-03**	5U4	-0.2842	4.778	-0.518	-2.040	0.094	0.742	6.395	0.0532084	0.689	0.7968	109.280	5.5266	6.40
-16.62	**DW3-01**	2S1	**DW4-03**	2U1	-0.2833	4.708	-0.519	-2.043	0.100	0.787	6.74	0.0524307	0.735	0.8626	117.599	5.4458	6.40
-19.66	**DW10-01**	6S11	**DW10-02**	6U11	-0.1895	3.725	-0.404	-1.592	0.055	0.434	4.135	0.0414781	0.392	0.5821	81.863	4.3082	6.40
-19.94	**DW5-02**	3S15	**DW6-01**	3U14	-0.2773	5.529	-0.615	-2.423	0.072	0.569	5.34	0.0615666	0.507	0.5075	72.419	6.3947	6.40
-20.00	**DW11-01**	Spare 1W	**DW5-03**	3U6	-0.1949	3.898	-0.644	-2.538	0.109	0.860	6.1	0.0434064	0.817	1.1586	155.188	4.5085	6.40
-19.78	**DW1-02**	1S6	**DW2-02**	1U6	-0.2644	5.229	-0.609	-2.400	0.094	0.737	6.175	0.0582312	0.679	0.7181	99.233	6.0483	6.40
-19.79	**DW9-03**	6S4	**DW10-03**	6U4	-0.275	5.441	-0.615	-2.423	0.122	0.963	6.73	0.0605921	0.902	0.9165	124.468	6.2935	6.40

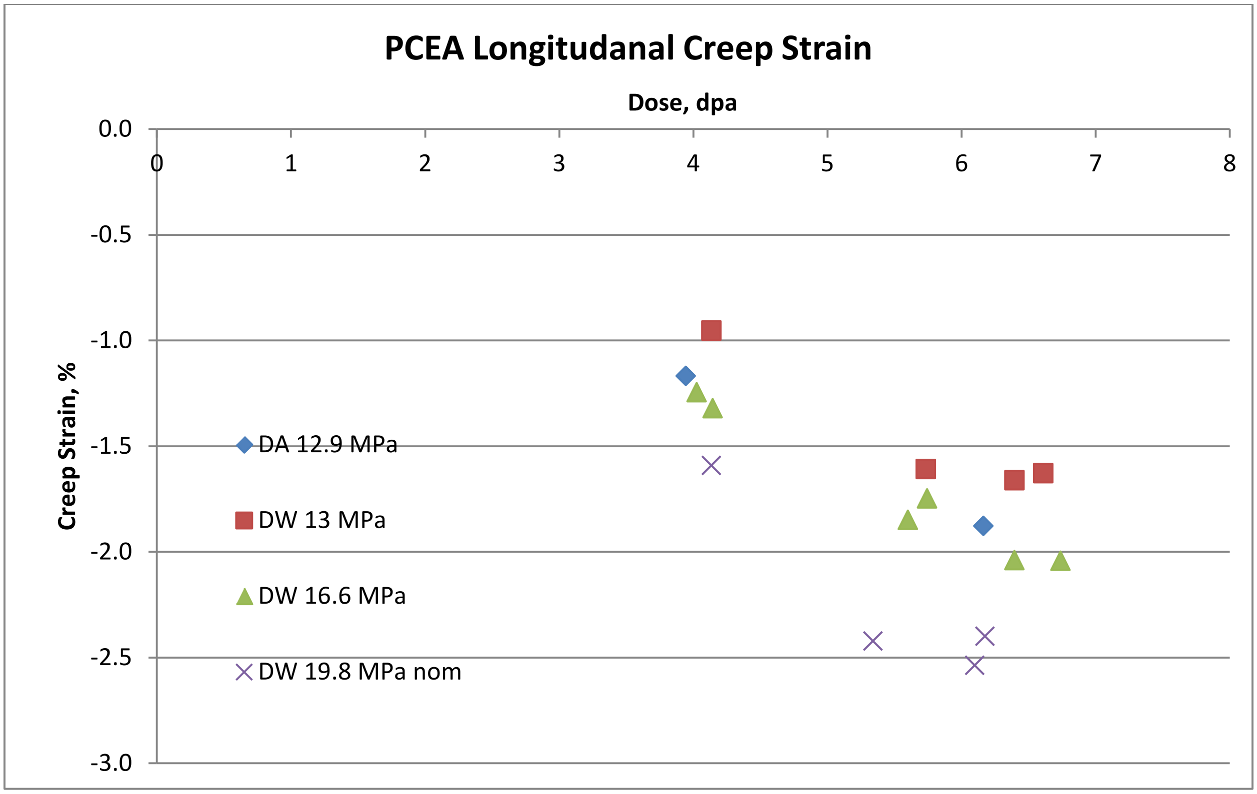

Figure 61 longitudinal creep strain (%) PCEA

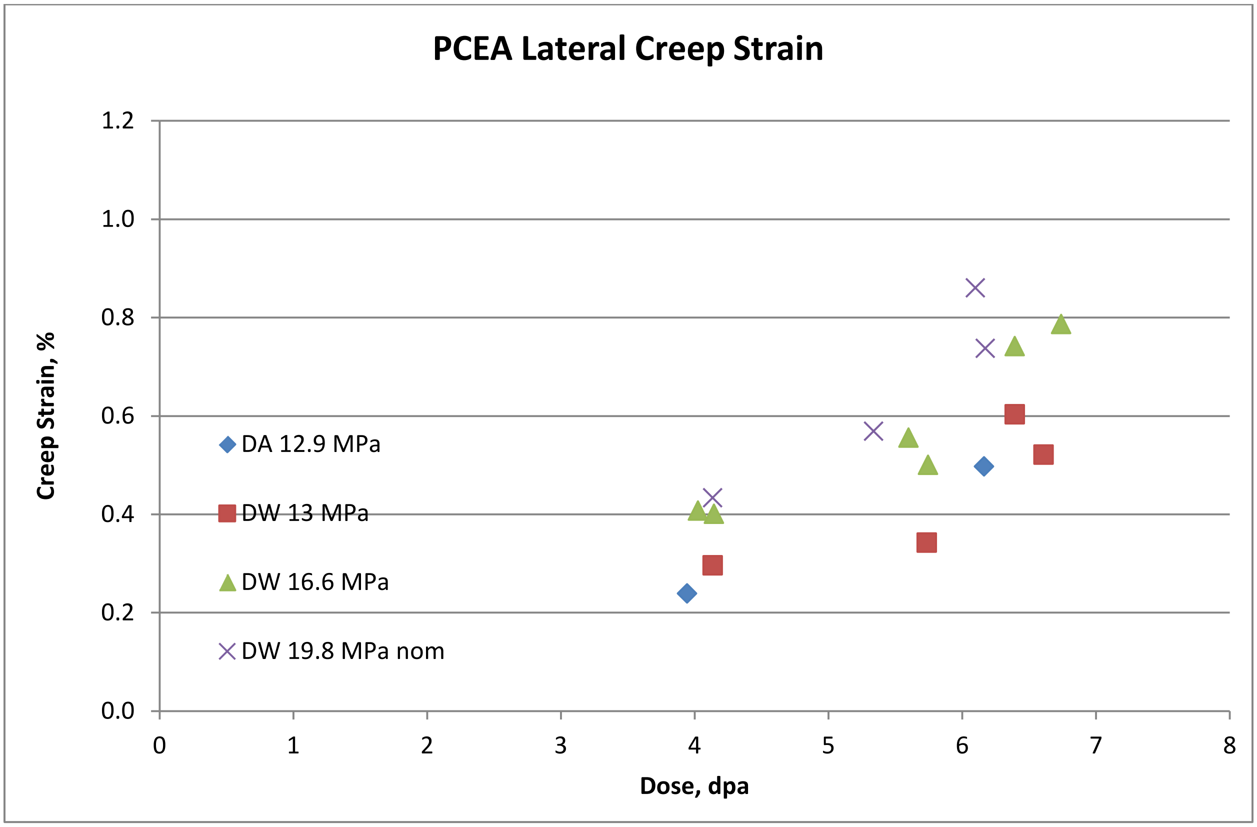

Figure 62 lateral creep strain (%) for PCEA

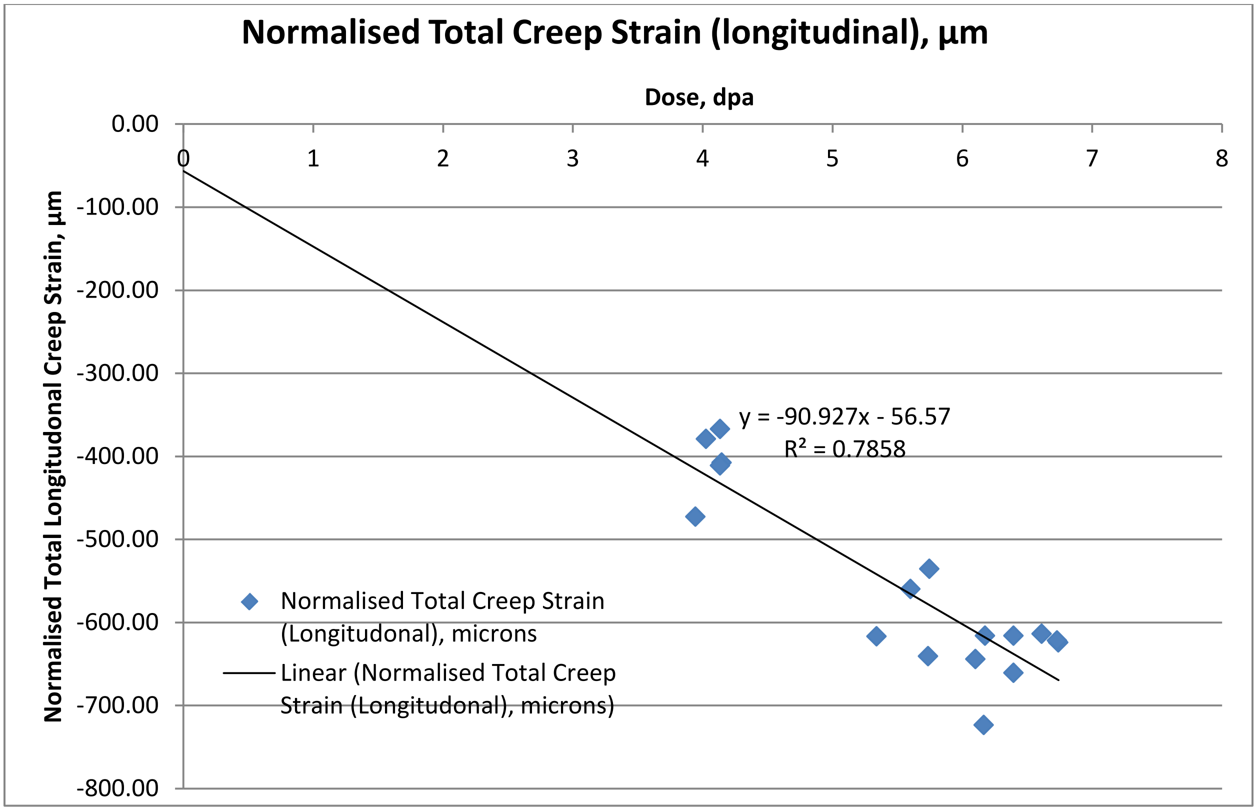

Figure 63 Normalized total longitudinal creep strain (microns) for PCEA

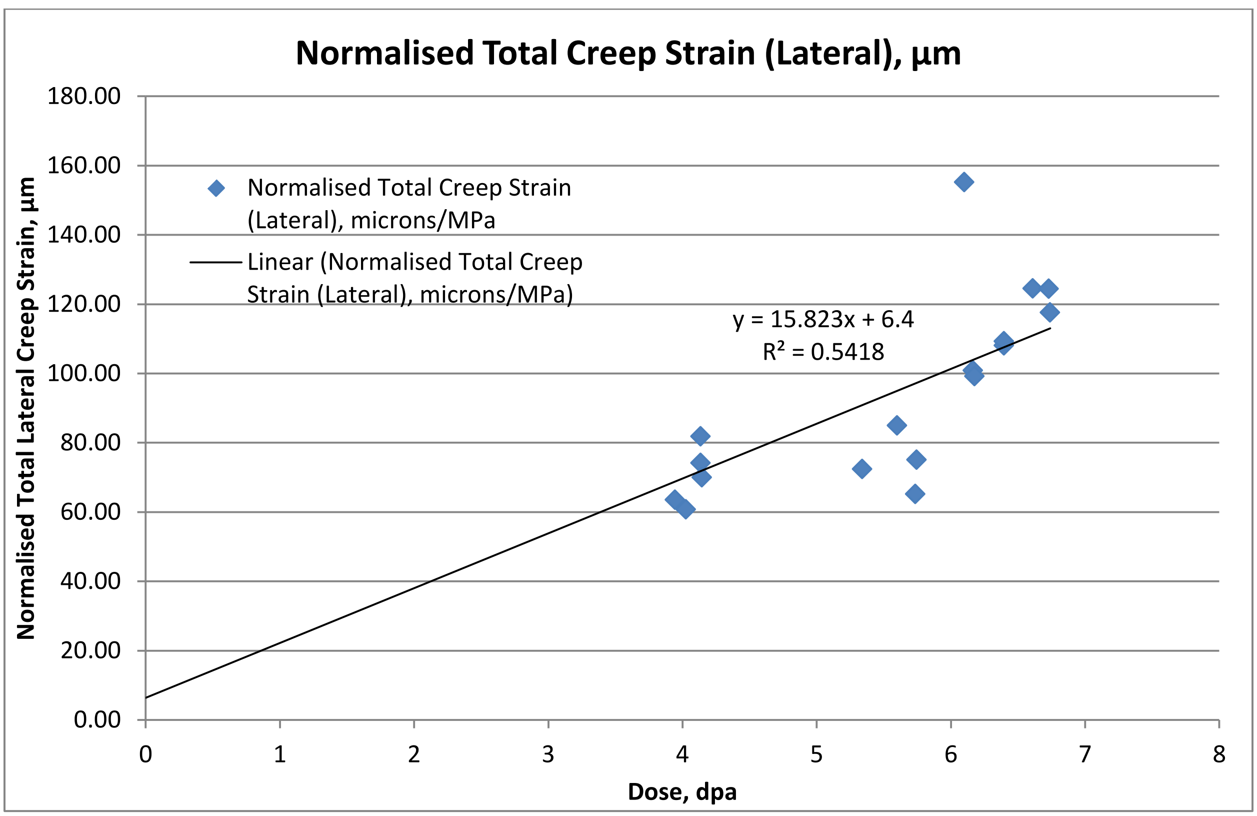

Figure 64 Normalized total lateral creep strain (microns) for PCEA

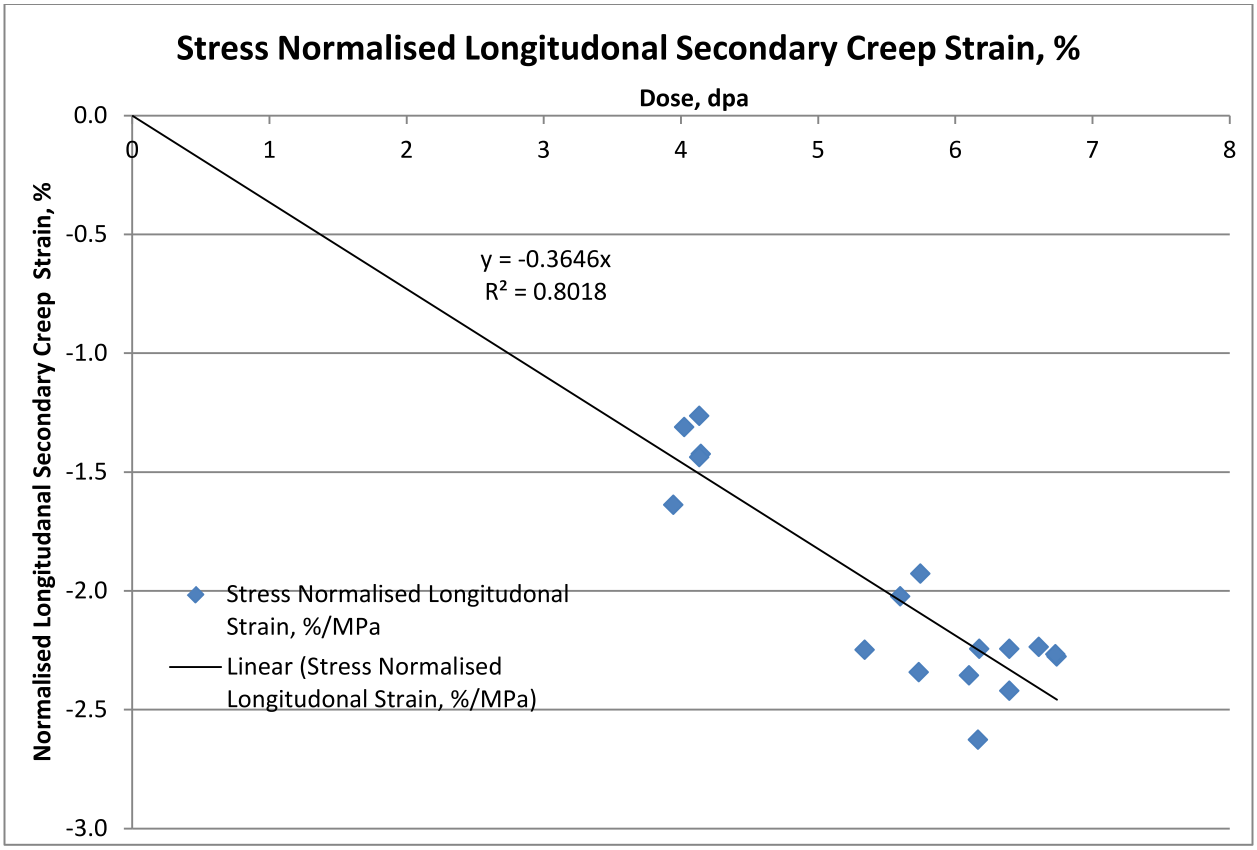

Figure 65 Normalized secondary longitudinal creep strain (%) for PCEA

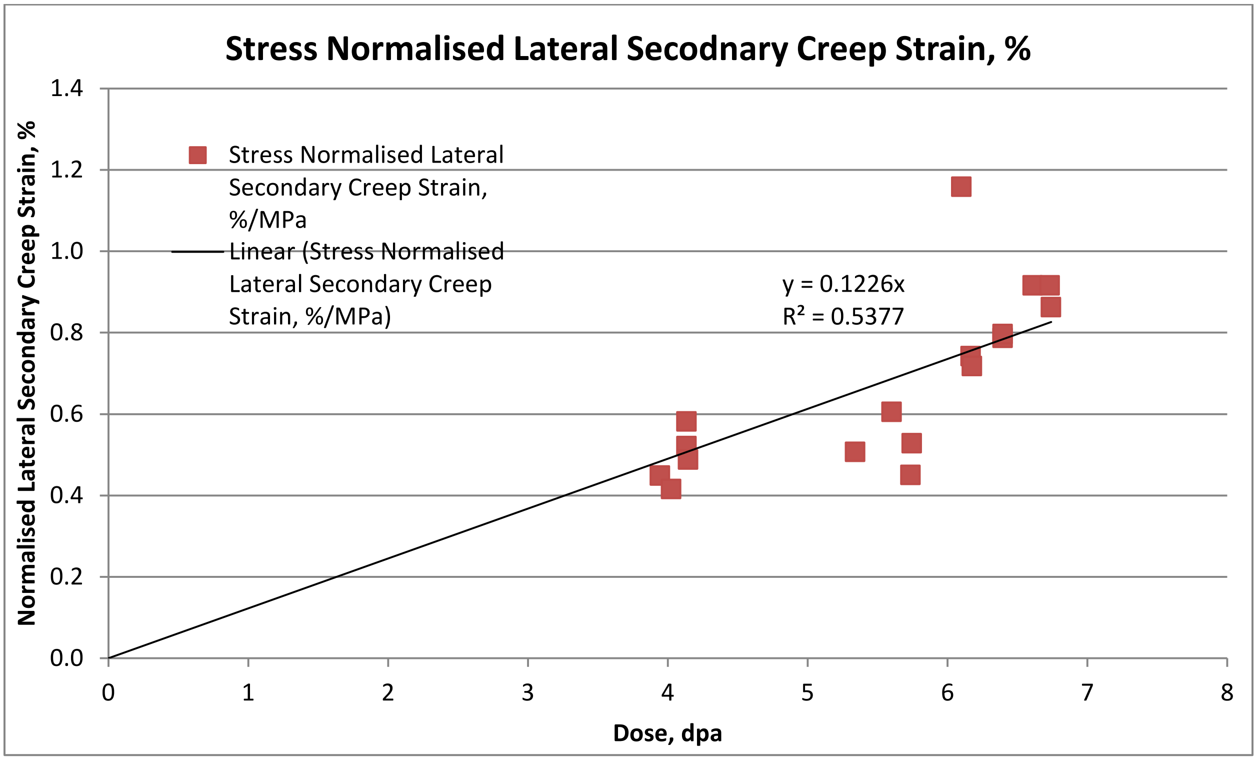

Figure 66 Normalized secondary lateral creep strain (%) for PCEA

The creep strain ratio for PCEA was calculated from the ratio of the gradients of the normalized total creep strain (Figure 63 and Figure 64). Thus, the ratio = 15.823/-90.927 = -0.174. This value of the creep strain ratio is considerably lower than both the irradiated Poisson's Ratio values of 0.268 (S.D. 0.017) all control samples, and, 0.253 (SD=0.037) for all creep samples. The PR and creep strain ratios are discussed in section 7.

The creep coefficient, K is calculated from the gradients of the normalized secondary creep plots - Figure 65 and Figure 66 divided by the normalizing stress(Equation 1 and Equation 2). Thus the longitudinal creep coefficient for PCEA was K = 0.-365/-20.0 = 0.0182 %/dpa·MPa or 0.138 ($10^{-30}cm^2$/n·Pa). The lateral value of K was 0.123/5.592 = 0.0219 %/dpa·MPa or 0.151 (10-$^{30}cm^2$/n·Pa. These K values compare well with literature values for K as discussed later in section 7.

6.5. Creep Strain Analysis for IG-110 (Code E)

The IG-110 creep strain data are reported in Table 46 and Table 47 and plotted in Figure 67 and Figure 68. The normalized total creep strain is plotted in Figure 69and Figure 70. Longitudinal and lateral normalized secondary creep strains are plotted in Figure 71 and Figure 72 .

Table 46 Derived creep strain (mm and %) for IG-110 in the longitudinal direction normalized to the peak applied stress

LONGITUDINAL STRAIN																
Specimen	I.D. Number	Companion Specimen			Compressive Creep Stress	Total Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %				
Number			Number	I.D. Number	MPa	Longitudanal		Lateral					Stress Normalised secondary creep strain	Stress Normlised total creep strain, microns	Primary Creep Strain microns	Normalized Primary Creep Strain mirons
						(mm)	%	(mm)	%				%/MPa			
EW2-02	1S9		EW2-03	1U7	-13.1868	-0.307	-1.2099	0.057	0.4474	4.56	-0.149851	-1.06000	-1.59429	-461.912	-38.0620	-57.25
EW2-01	1S7		EW2-02	1S9	-13.1865	-0.336	-1.3230	0.043	0.3381	4.74	-0.149847	-1.17319	-1.76457	-504.985	-38.0611	-57.25
EW7-01	4S9		EW8-01	4U9	-12.5827	-0.462	-1.8225	0.094	0.7429	6.28	-0.142985	-1.67956	-2.64741	-728.987	-36.3181	-57.25
EW6-03	4S4		EW7-03	4U4	-12.5880	-0.492	-1.9374	0.109	0.8570	6.56	-0.143045	-1.79432	-2.82712	-774.559	-36.3335	-57.25
EW5-01	2S7		EW5-03	2U7	-16.3545	-0.538	-2.1200	0.082	0.6418	6.00	-0.185846	-1.93412	-2.34556	-652.243	-47.2050	-57.25
EW8-03	5S13		EW9-02	5U12	-16.6516	-0.333	-1.3124	0.061	0.4799	3.57	-0.189222	-1.12322	-1.33785	-396.713	-48.0624	-57.25
EW8-02	5S1		EW9-01	5U1	-16.6254	-0.641	-2.5262	0.111	0.8717	6.70	-0.188924	-2.33730	-2.78833	-764.573	-47.9868	-57.25
EW4-01	1U9		EW6-02	3U9	-19.8067	-0.487	-1.9190	0.089	0.6972	4.47	-0.225077	-1.69396	-1.69625	-487.473	-57.1695	-57.25
EW6-01	3S9		EW6-02	3U9	-19.8166	-0.551	-2.1697	0.096	0.7528	4.65	-0.225189	-1.94453	-1.94618	-550.998	-57.1980	-57.25
EW9-03	6S14		EW10-01	6U13	-19.5946	-0.586	-2.3077	0.092	0.7237	5.43	-0.222666	-2.08505	-2.11047	-592.714	-56.5572	-57.25
EW10-02	SPARE1		EW10-03	SPARE 2	-19.8335	-0.699	-2.7558	0.143	1.1247	6.56	-0.225381	-2.53040	-2.53040	-699.338	-57.2467	-57.25
EW4-02	2S5		EW5-02	2U5	-19.5418	-0.705	-2.7784	0.111	0.8766	6.36	-0.222066	-2.55638	-2.59453	-715.515	-56.4048	-57.25

Table 47 Derived creep strain (mm and %) for IG-110 in the lateral direction normalized to the peak applied lateral stress

LATERAL STRAIN																	
Compressive Creep Stress	Specimen	I.D. Number	Companion Specimen		Piosson's	Lateral Creep Stress	Total Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress	Stress	Primary Creep Strain	Normalized Primary Creep Strain
MPa	Number		Number	I.D. Number	Ratio from PIE data	MPa	Longitudanal		Lateral					Normalised secondary creep strain	Normlised total creep strain, microns	microns	mirons
							(mm)	%	(mm)	%				%			
-13.1868	EW2-02	1S9	EW2-03	1U7	-0.1787	2.35649	-0.307	-1.2099	0.057	0.4474	4.56	0.026778	0.42064	0.65267	88.337	3.4008	5.28
-13.1865	EW2-01	1S7	EW2-02	1S9	-0.1784	2.35248	-0.336	-1.3230	0.043	0.3381	4.74	0.026733	0.31137	0.48396	66.870	3.3950	5.28
-12.5827	EW7-01	4S9	EW8-01	4U9	-0.1734	2.18183	-0.462	-1.8225	0.094	0.7429	6.28	0.024794	0.71806	1.20335	158.250	3.1488	5.28
-12.5880	EW6-03	4S4	EW7-03	4U4	-0.224	2.81971	-0.492	-1.9374	0.109	0.8570	6.56	0.032042	0.82495	1.06973	141.235	4.0694	5.28
-16.3545	EW5-01	2S7	EW5-03	2U7	-0.1642	2.68541	-0.538	-2.1200	0.082	0.6418	6.00	0.030516	0.61127	0.83228	111.126	3.8755	5.28
-16.6516	EW8-03	5S13	EW9-02	5U12	-0.1726	2.87406	-0.333	-1.3124	0.061	0.4799	3.57	0.032660	0.44721	0.56893	77.515	4.1478	5.28
-16.6254	EW8-02	5S1	EW9-01	5U1	-0.1551	2.57859	-0.641	-2.5262	0.111	0.8717	6.70	0.029302	0.84240	1.19450	157.068	3.7214	5.28
-19.8067	EW4-01	1U9	EW6-02	3U9	-0.163	3.22850	-0.487	-1.9190	0.089	0.6972	4.47	0.036687	0.66047	0.74800	100.357	4.6593	5.28
-19.8166	EW6-01	3S9	EW6-02	3U9	-0.1718	3.40450	-0.551	-2.1697	0.096	0.7528	4.65	0.038687	0.71413	0.76696	102.741	4.9133	5.28
-19.5946	EW9-03	6S14	EW10-01	6U13	-0.1866	3.65636	-0.586	-2.3077	0.092	0.7237	5.43	0.041550	0.68210	0.68210	91.903	5.2768	5.28
-19.8335	EW10-02	SPARE1	EW10-03	SPARE 2	-0.1622	3.21699	-0.699	-2.7558	0.143	1.1247	6.56	0.036557	1.08810	1.23671	162.366	4.6427	5.28
-19.5418	EW4-02	2S5	EW5-02	2U5	-0.1449	2.83161	-0.705	-2.7784	0.111	0.8766	6.36	0.032177	0.84446	1.09042	143.952	4.0865	5.28

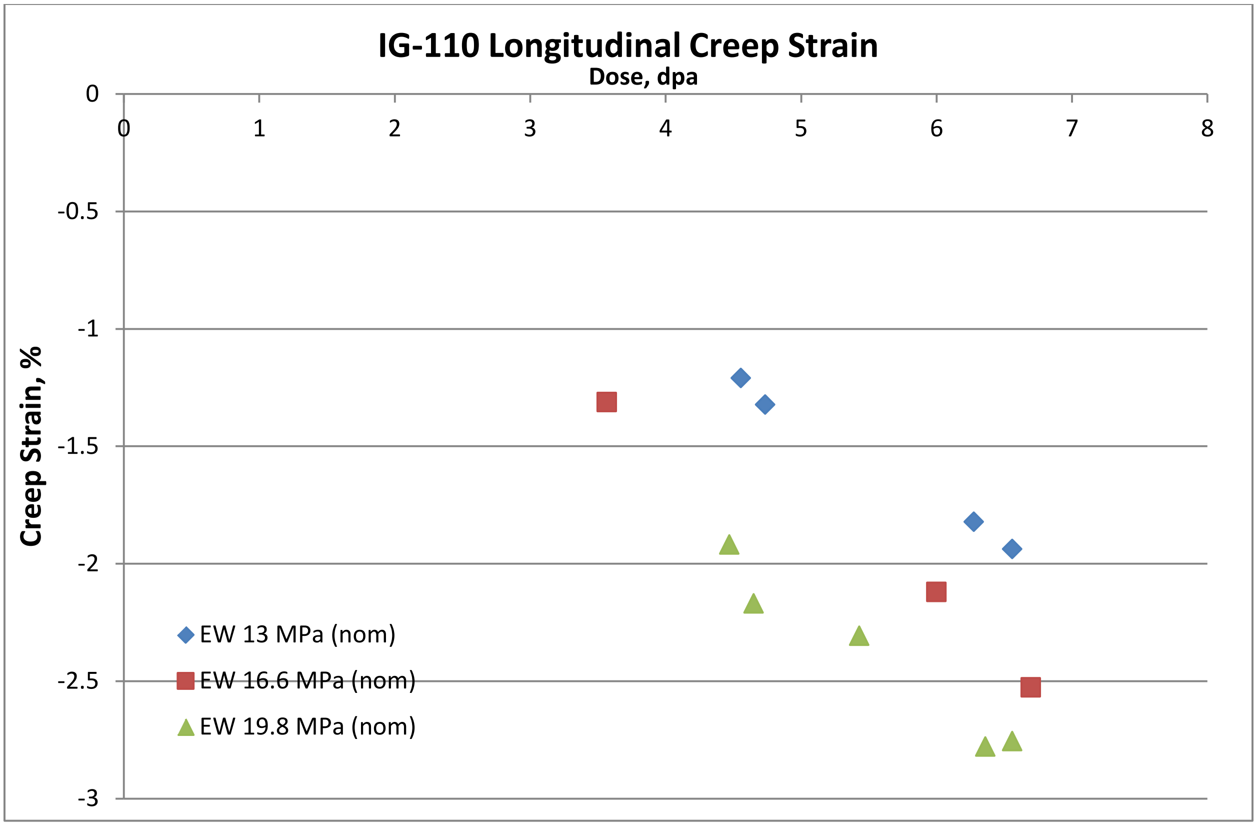

Figure 67 longitudinal creep strain (%) for IG-110

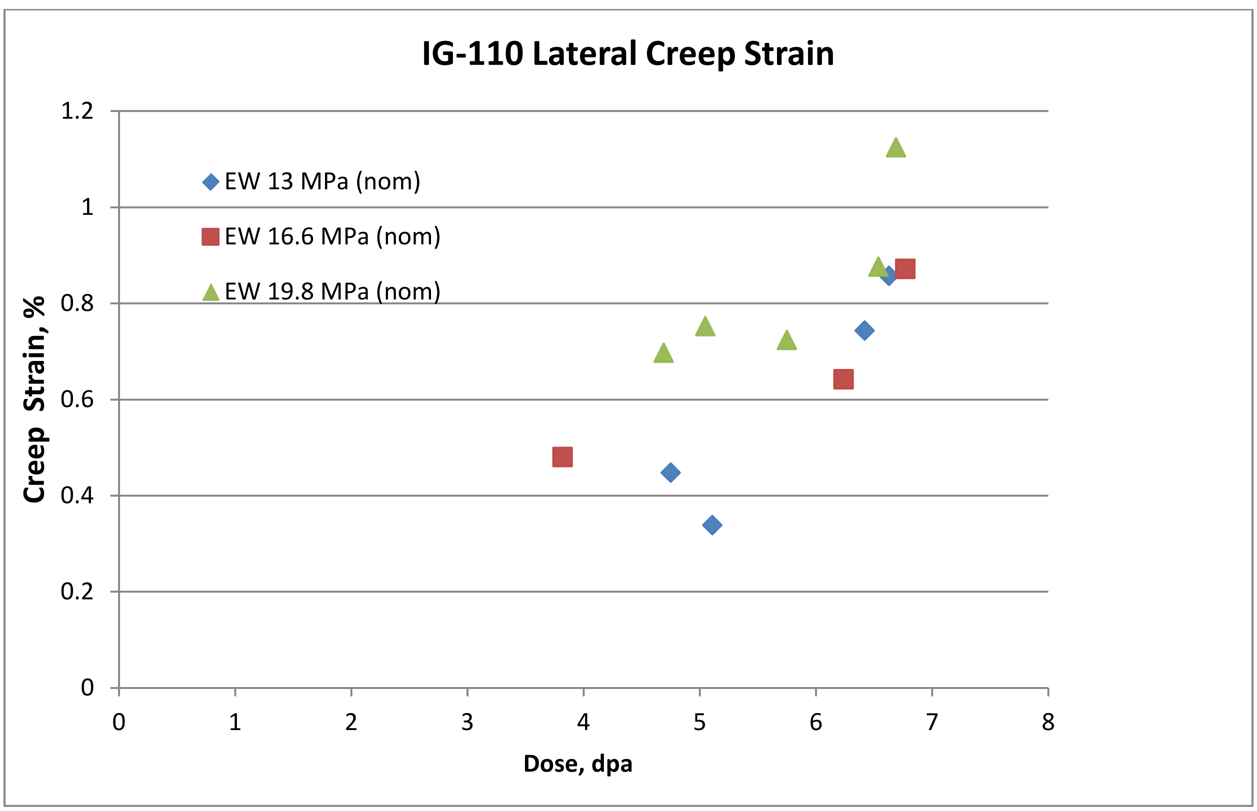

Figure 68 lateral creep strain (%) for IG-110

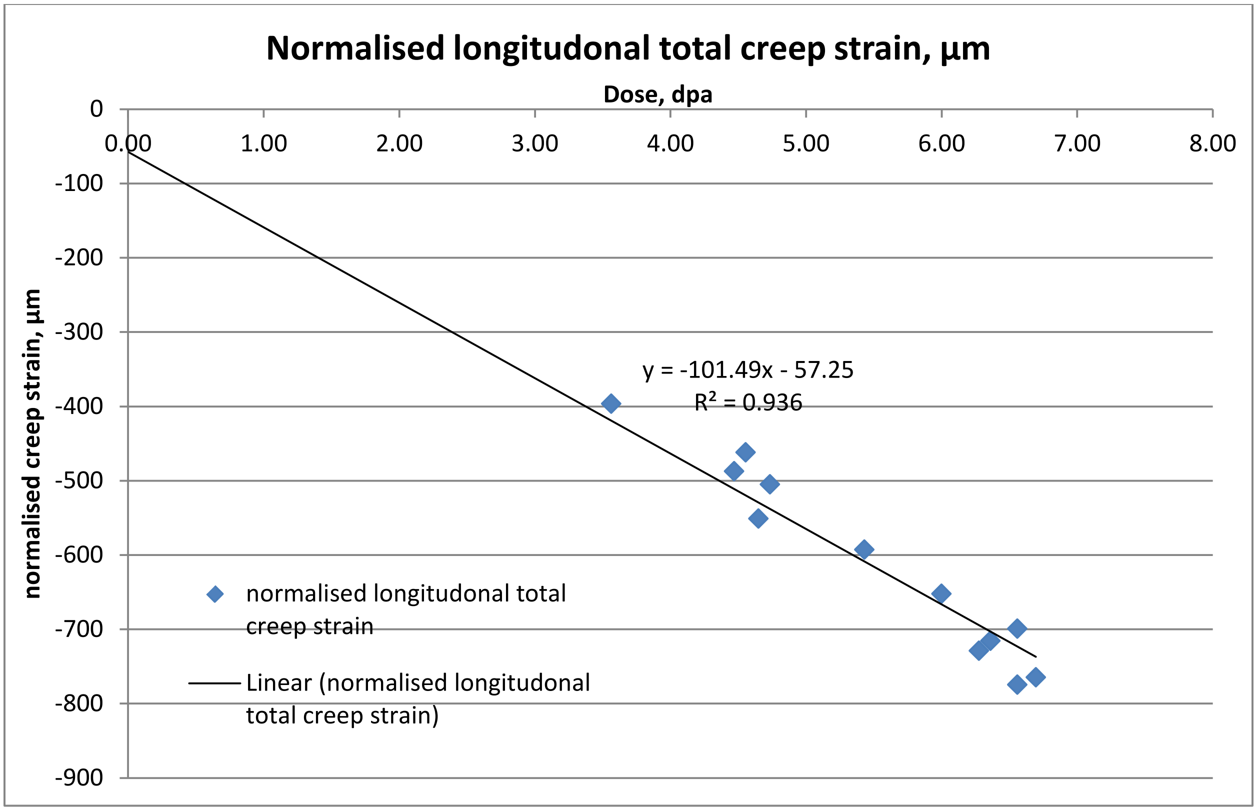

Figure 69 Normalized total longitudinal creep strain (microns) for IG-110

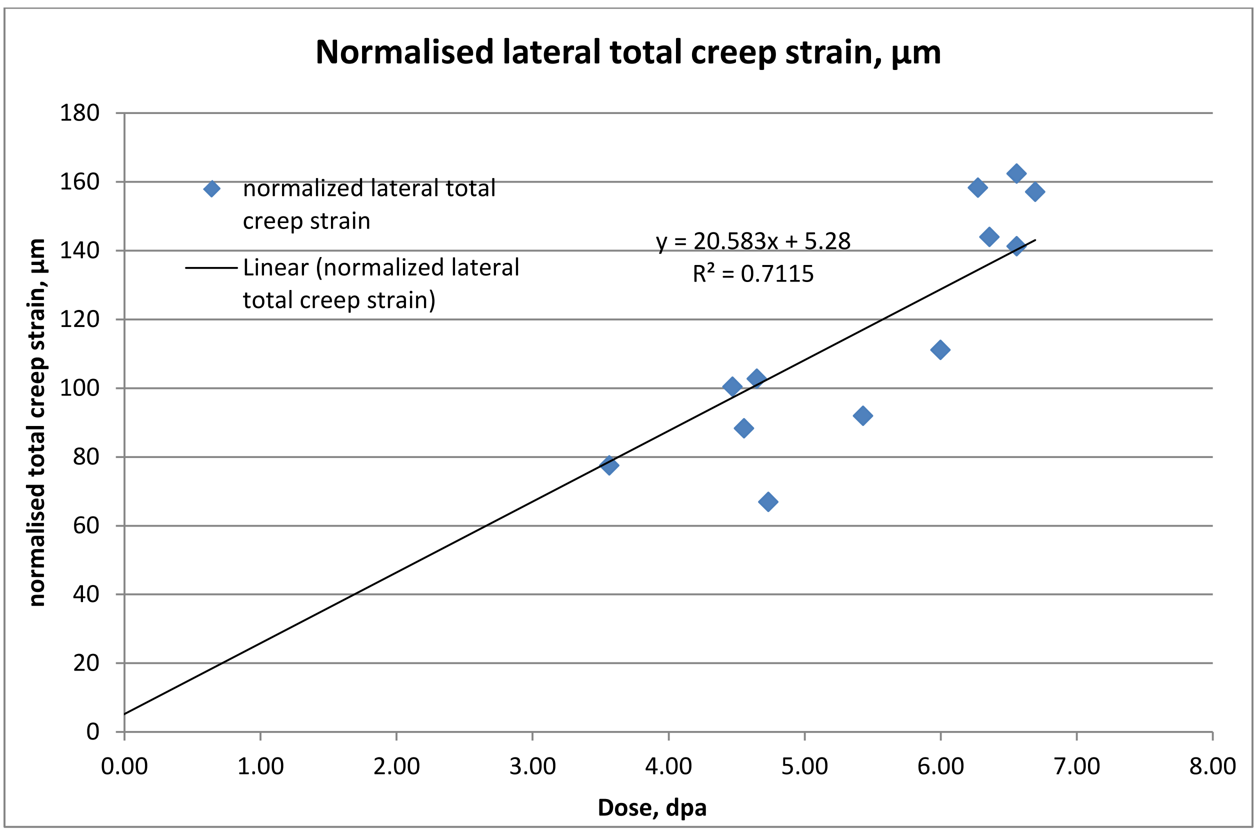

Figure 70 Normalized total lateral creep strain (microns) for IG-110

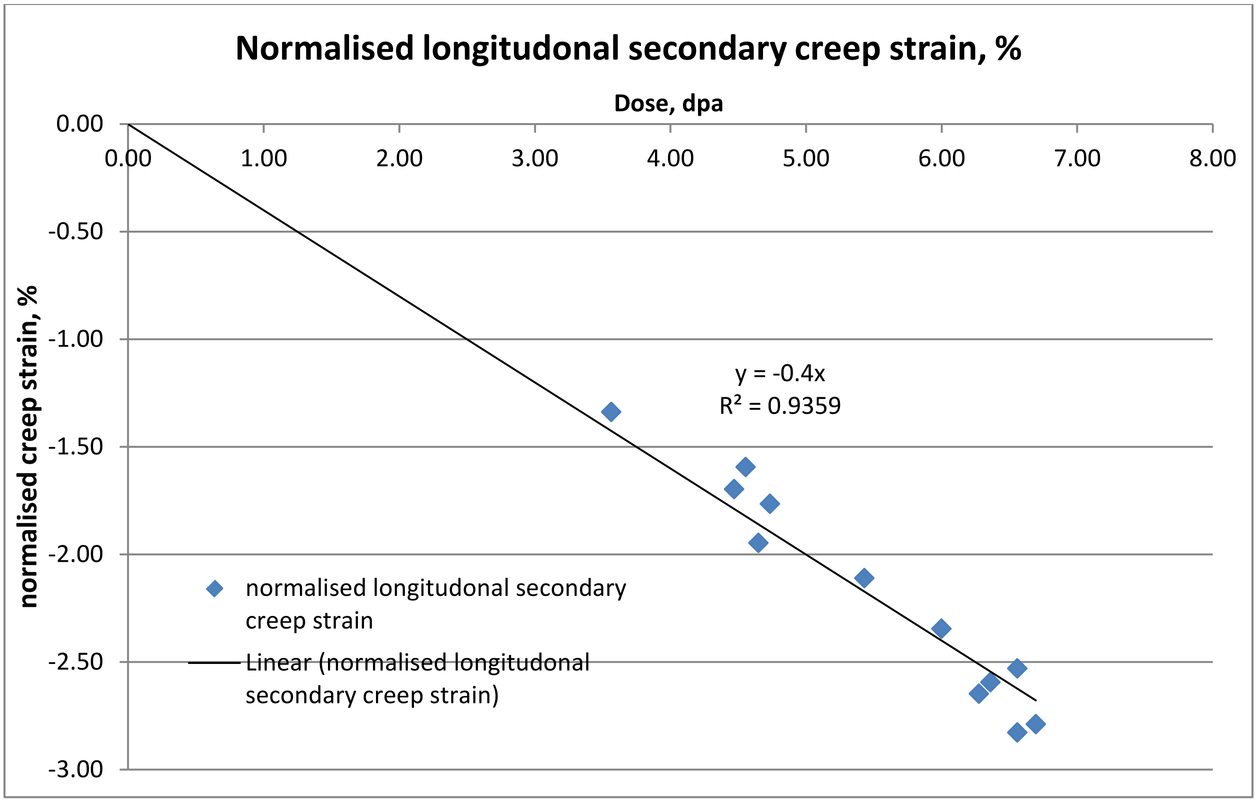

Figure 71 Normalized secondary longitudinal creep strain (%) for IG-110

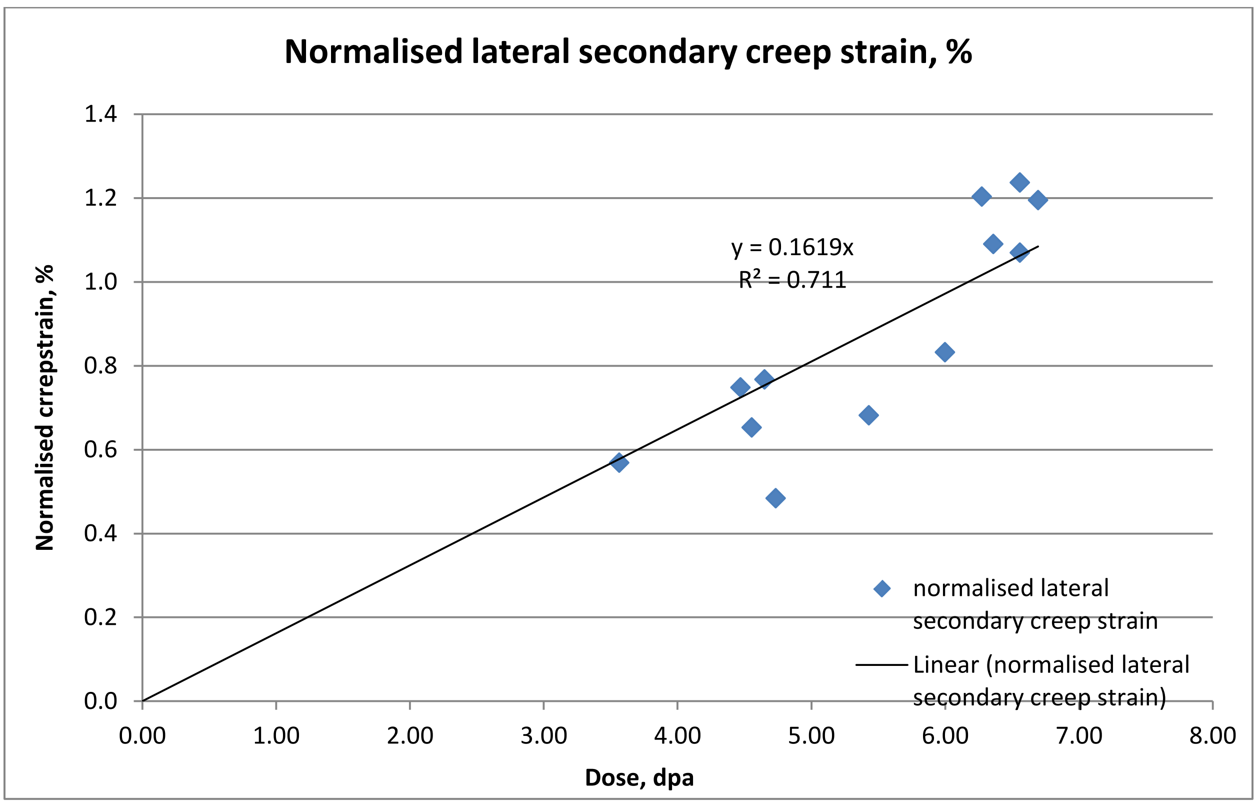

Figure 72 Normalized secondary lateral creep strain (%) for IG-110

The creep strain ratio for IG-110 was calculated from the ratio of the gradients of the normalized total creep strain (Figure 69 and Figure 70). Thus, the ratio = 20.583/-101.49 = -0.203. This value of the creep strain ratio is similar to the irradiated Poisson's Ratio values of 0.204 (S.D. = 0.092) for all control specimens but greater than the creep specimen PR of 0.169 (S.D. =0.01) for all the creep specimens. The PR and creep strain ratios are discussed in section 7.

The creep coefficient, K is calculated from the gradients of the normalized secondary creep plots (Figure 71 and Figure 72) divided by the normalizing stress (Equation 1and Equation 2). Thus the longitudinal creep coefficient for IG-110 was K = 0.-400/-19.834 = 0.0202 %/dpa·MPa or 0.137 ($10^{-30}cm^2$/n·Pa). The lateral value of K was 0.162/3.656 = 0.0443 %/dpa·MPa or 0.195 ($10^{-30}cm^2$/n·Pa). These K values compare well with literature values for K as discussed later in section 7.

6.6. Creep Strain Analysis for IG-430 (Code F)

The IG-430 creep strain data are reported in Table 48 and Table 49 and plotted in Figure 73 and Figure 74. The normalized total creep strain is plotted In Figure 75 and Figure 76Figure 64. Longitudinal and lateral normalized secondary creep strains are plotted in Figure 77 and Figure 78.

Table 48 Derived creep strain (mm and %) for IG-430 in the longitudinal direction normalized to the peak applied stress

Longitudinal creep strain																
Creep (Stressed) spec			Companion Specimen		Compressive Creep Stress	Total Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress	Stress	Primary Creep Strain	Normalized Primary Creep Strain
Specimen Number	ID Number		Number	I.D. Number	MPa	Longitudanal		Lateral					Normalised secondary creep strain	Normlised total creep strain, microns	microns	mirons
						(mm)	%	(mm)	%				%			
FW8-02	4S10		FW9-01	4U10	-12.5811	-0.2408	-1.8939	0.0608	0.4783	5.21	-0.132712	-1.7612	-2.77116	-378.8354	-33.7088	-53.04
FW4-02	3S3		FW5-03	3U3	-12.5871	-0.3002	-2.3617	0.0928	0.7305	5.95	-0.132775	-2.2290	-3.50554	-472.0830	-33.7248	-53.04
FW13-01	Spare1		FW2-01	1U10	-13.1809	-0.2769	-2.1753	0.0536	0.4214	5.42	-0.139039	-2.0363	-3.05825	-415.8198	-35.3160	-53.04
FW8-01	4S3		FW8-03	4U3	-12.5820	-0.3686	-2.8998	0.1114	0.8761	6.50	-0.132722	-2.7671	-4.35359	-579.9831	-33.7113	-53.04
FW1-01	1S5		FW1-03	1U5	-13.2248	-0.4306	-3.3890	0.0678	0.5338	6.70	-0.139502	-3.2495	-4.86410	-644.5905	-35.4335	-53.04
FW12-01	6U7		FW4-01	2U14	-16.5748	-0.2324	-1.8262	0.0353	0.2777	3.08	-0.174840	-1.6514	-1.97231	-277.5851	-44.4092	-53.04
FW3-01	2S14		FW3-03	2U9	-16.4011	-0.3400	-2.6775	0.0638	0.5024	4.38	-0.173008	-2.5045	-3.02291	-410.3986	-43.9440	-53.04
FW2-03	2S9		FW3-03	2U9	-16.3864	-0.3236	-2.5472	0.0481	0.3785	4.76	-0.172852	-2.3743	-2.86837	-390.9497	-43.9044	-53.04
FW9-03	5S10		FW10-02	5U10	-16.6021	-0.3925	-3.0866	0.1025	0.8061	6.25	-0.175128	-2.9114	-3.47153	-468.0002	-44.4825	-53.04
FW9-02	5S2		FW10-01	5U2	-16.5976	-0.4435	-3.4869	0.1000	0.7862	6.62	-0.175080	-3.3119	-3.95006	-528.9236	-44.4702	-53.04
FW2-02	2S3		FW3-02	2U3	-16.3917	-0.4648	-3.6588	0.0871	0.6858	6.40	-0.172908	-3.4859	-4.20982	-561.2865	-43.9187	-53.04
FW5-02	3S7		FW7-03	3U7	-19.7519	-0.3083	-2.4222	0.0657	0.5164	3.60	-0.208354	-2.2138	-2.21872	-308.9836	-52.9219	-53.04
FW5-01	3S5		FW7-02	3U5	-19.7875	-0.3433	-2.6998	0.0682	0.5359	4.05	-0.208729	-2.4911	-2.49216	-343.4789	-53.0170	-53.04
FW11-02	6S10		FW12-02	6U10	-19.5184	-0.3921	-3.0813	0.0692	0.5436	4.56	-0.205891	-2.8754	-2.91624	-397.6513	-52.2962	-53.04
FW11-01	6S7		FW12-02	6U10	-19.5257	-0.3914	-3.0767	0.0643	0.5054	4.74	-0.205968	-2.8707	-2.91044	-396.8385	-52.3158	-53.04
FW4-03	3S4		FW7-01	3U4	-19.7959	-0.5168	-4.0648	0.1436	1.1295	6.44	-0.208817	-3.8560	-3.85602	-516.8084	-53.0396	-53.04
FW10-03	6S2		FW11-03	6U2	-19.5282	-0.6498	-5.1081	0.1406	1.1053	6.80	-0.205993	-4.9021	-4.96933	-658.7342	-52.3223	-53.04

Table 49 Derived creep strain (mm and %) for IG-430 in the lateral direction normalized to the peak applied lateral stress

Lateral Creep Strain																	
Compressive Creep Stress	Creep (stressed) specimen		Companion Specimen		Piosson's	Lateral Creep Stress	Total Creep Strain (creep-control)				Mean Dose, DPA	Primary Creep (σ/E),%	Secondary Creep, %	Stress	Stress	Primary Creep Strain	Normalized Primary Creep Strain
MPa	Number	I.D Number	Number	I.D. Number	Ratio from PIE data	MPa	Longitudanal		Lateral					Normalised secondary creep strain	Normlised total creep strain, microns	microns	mirons
							(mm)	%	(mm)	%				%			
-12.5811	FW8-02	4S10	FW9-01	4U10	-0.1708	2.1488	-0.2408	-1.8939	0.0608	0.4783	5.21	0.02267	0.4556	0.84182	112.3424	2.8787	5.32
-12.5871	FW4-02	3S3	FW5-03	3U3	-0.1712	2.1549	-0.3002	-2.3617	0.0928	0.7305	5.95	0.02273	0.7077	1.30390	171.0443	2.8868	5.32
-13.1809	FW13-01	Spare1	FW2-01	1U10	-0.2017	2.6586	-0.2769	-2.1753	0.0536	0.4214	5.42	0.02804	0.3934	0.58744	80.0973	3.5616	5.32
-12.5820	FW8-01	4S3	FW8-03	4U3	-0.1637	2.0597	-0.3686	-2.8998	0.1114	0.8761	6.50	0.02173	0.8544	1.64690	214.6816	2.7593	5.32
-13.2248	FW1-01	1S5	FW1-03	1U5	-0.175	2.3143	-0.4306	-3.3890	0.0678	0.5338	6.70	0.02441	0.5093	0.87376	116.3454	3.1004	5.32
-16.5748	FW12-01	6U7	FW4-01	2U14	-0.1829	3.0315	-0.2324	-1.8262	0.0353	0.2777	3.08	0.03198	0.2457	0.32175	46.2781	4.0612	5.32
-16.4011	FW3-01	2S14	FW3-03	2U9	-0.1922	3.1523	-0.3400	-2.6775	0.0638	0.5024	4.38	0.03325	0.4692	0.59087	80.3532	4.2230	5.32
-16.3864	FW2-03	2S9	FW3-03	2U9	-0.1809	2.9643	-0.3236	-2.5472	0.0481	0.3785	4.76	0.03127	0.3472	0.46504	64.4022	3.9712	5.32
-16.6021	FW9-03	5S10	FW10-02	5U10	-0.1718	2.8522	-0.3925	-3.0866	0.1025	0.8061	6.25	0.03009	0.7760	1.08019	142.6842	3.8210	5.32
-16.5976	FW9-02	5S2	FW10-01	5U2	-0.1477	2.4515	-0.4435	-3.4869	0.1000	0.7862	6.62	0.02586	0.7604	1.23141	161.9363	3.2841	5.32
-16.3917	FW2-02	2S3	FW3-02	2U3	-0.1794	2.9407	-0.4648	-3.6588	0.0871	0.6858	6.40	0.03102	0.6548	0.88406	117.6194	3.9395	5.32
-19.7519	FW5-02	3S7	FW7-03	3U7	-0.201	3.9701	-0.3083	-2.4222	0.0657	0.5164	3.60	0.04188	0.4746	0.47457	65.7343	5.3186	5.32
-19.7875	FW5-01	3S5	FW7-02	3U5	-0.1984	3.9258	-0.3433	-2.6998	0.0682	0.5359	4.05	0.04141	0.4945	0.50011	68.9235	5.2593	5.32
-19.5184	FW11-02	6S10	FW12-02	6U10	-0.1882	3.6734	-0.3921	-3.0813	0.0692	0.5436	4.56	0.03875	0.5048	0.54561	74.7562	4.9211	5.32
-19.5257	FW11-01	6S7	FW12-02	6U10	-0.1896	3.7021	-0.3914	-3.0767	0.0643	0.5054	4.74	0.03905	0.4664	0.50013	68.9552	4.9595	5.32
-19.7959	FW4-03	3S4	FW7-01	3U4	-0.1521	3.0110	-0.5168	-4.0648	0.1436	1.1295	6.44	0.03176	1.0977	1.44736	189.3443	4.0337	5.32
-19.5282	FW10-03	6S2	FW11-03	6U2	-0.1767	3.4506	-0.6498	-5.1081	0.1406	1.1053	6.80	0.03640	1.0689	1.22980	161.7752	4.6227	5.32

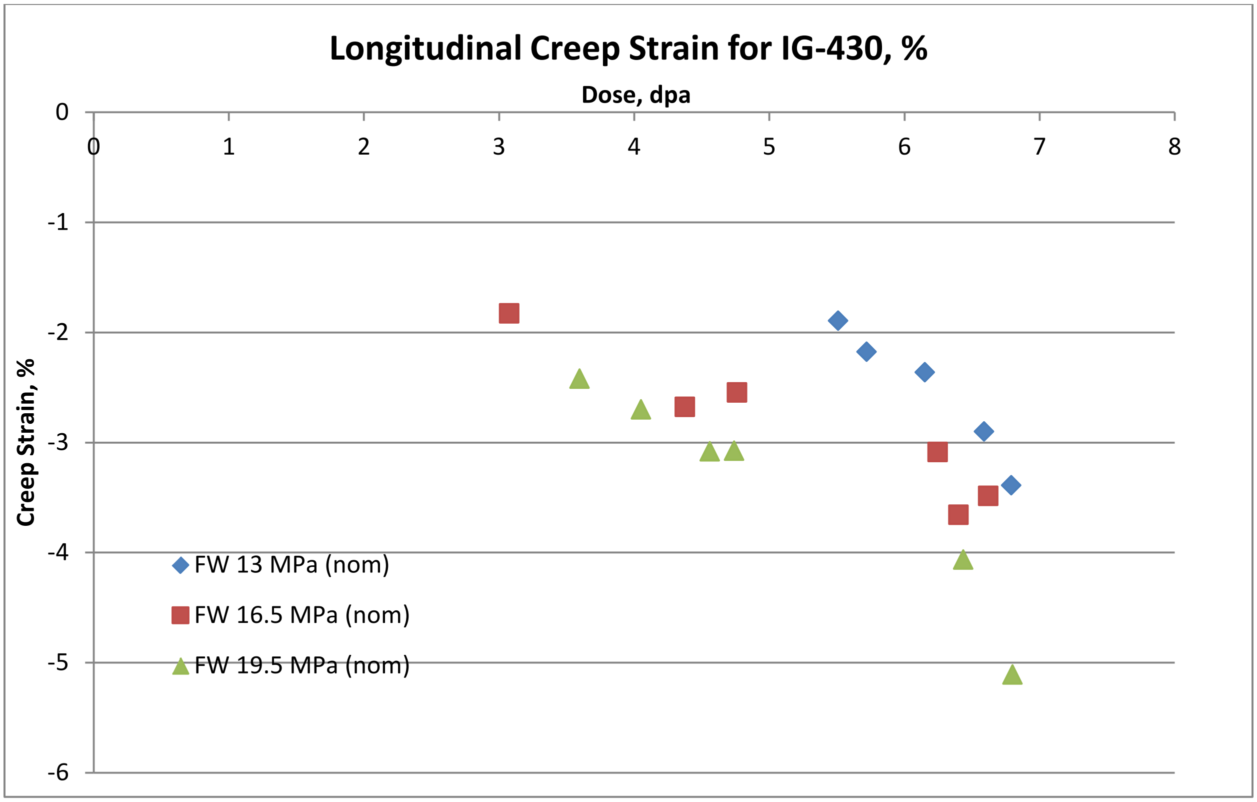

Figure 73 longitudinal creep strain (%) for IG-430

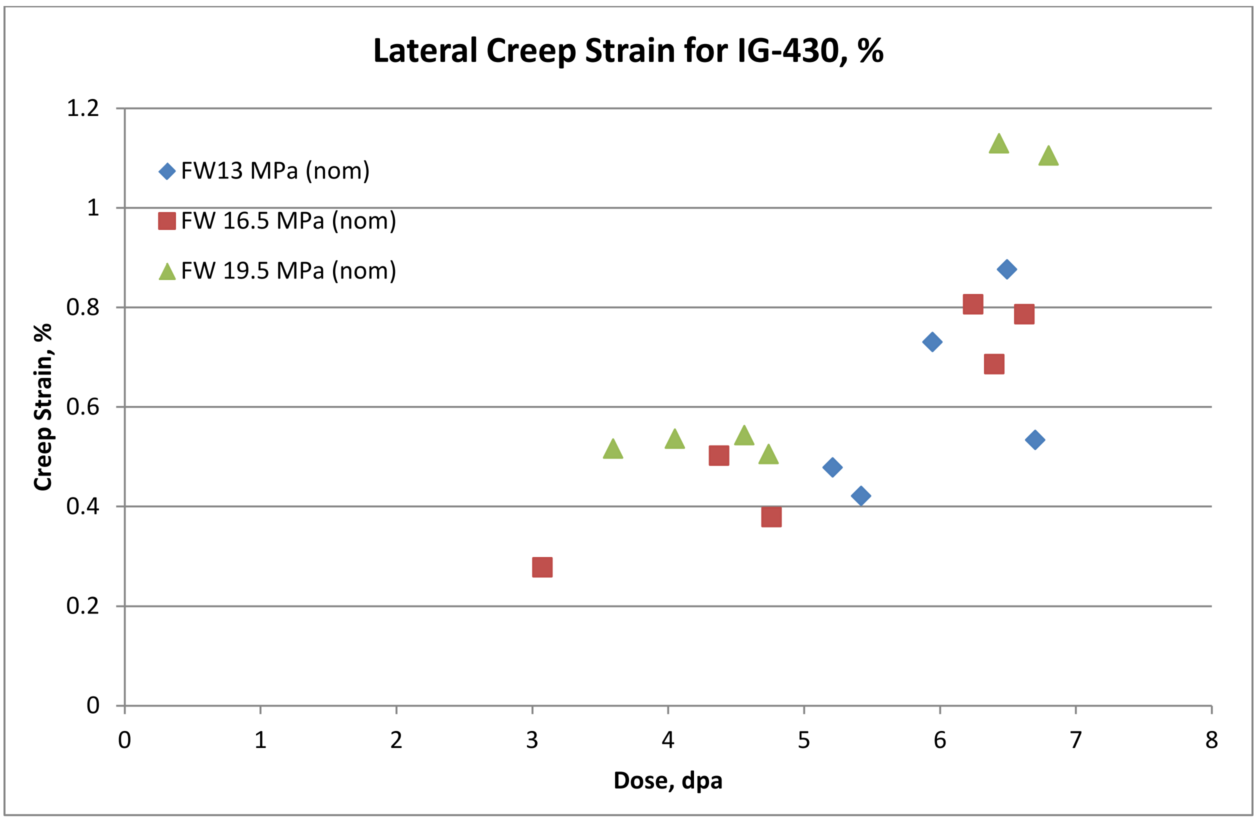

Figure 74 lateral creep strain (%) for IG-430

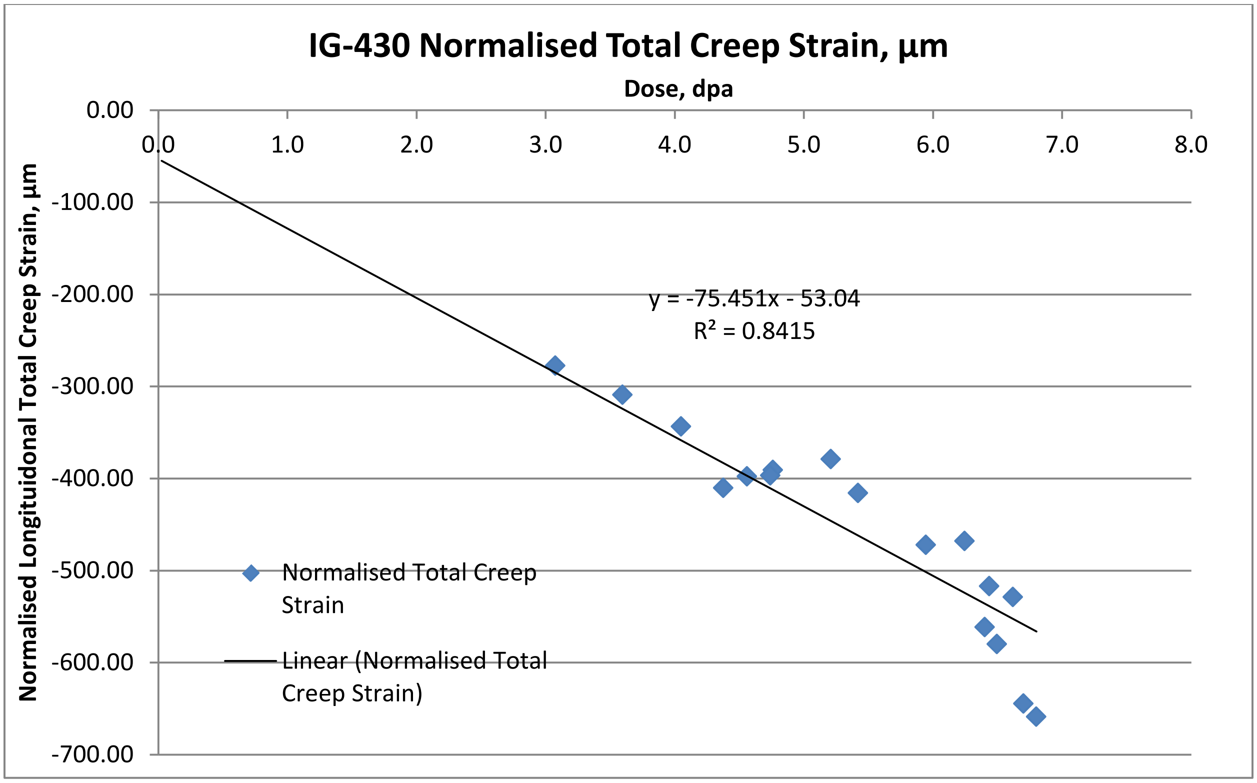

Figure 75 Normalized total longitudinal creep strain (microns) for IG-430

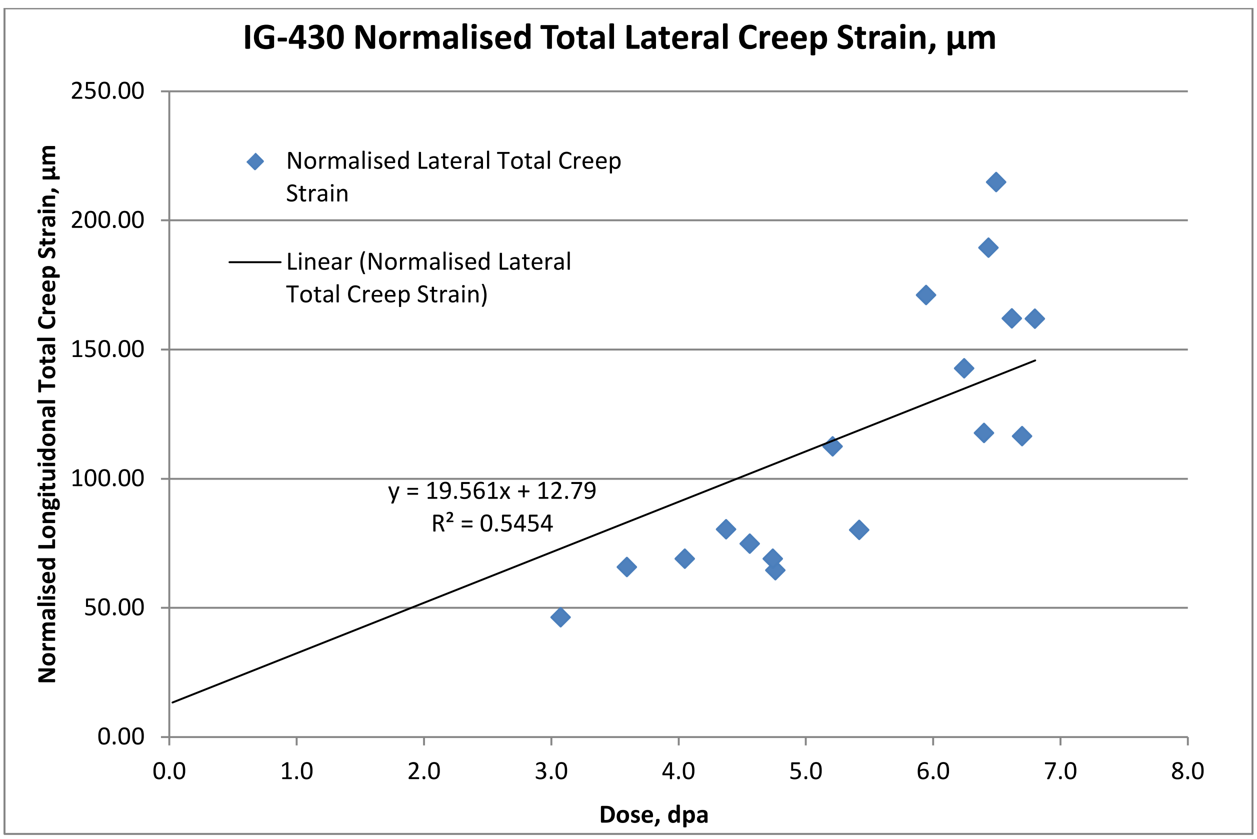

Figure 76 Normalized total lateral creep strain (microns) for IG-430

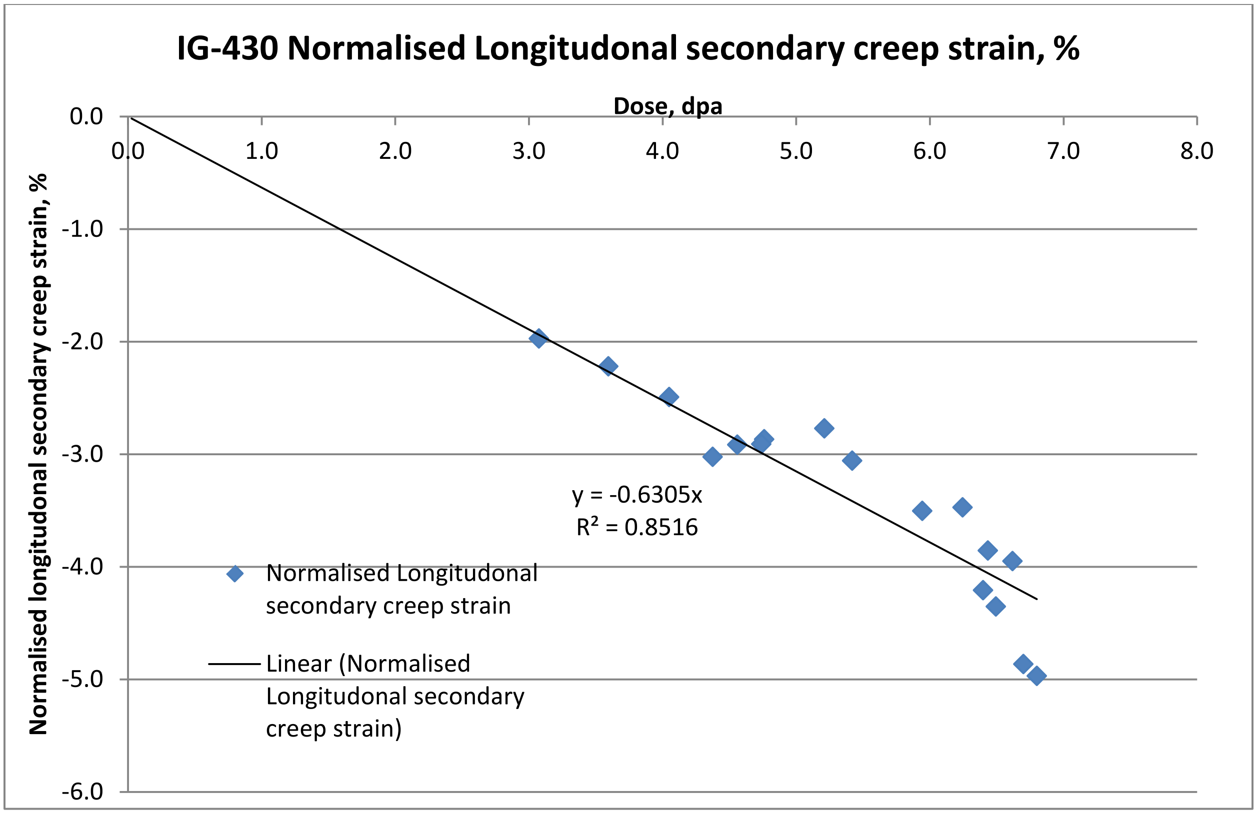

Figure 77 Normalized secondary longitudinal creep strain (%) for IG-430

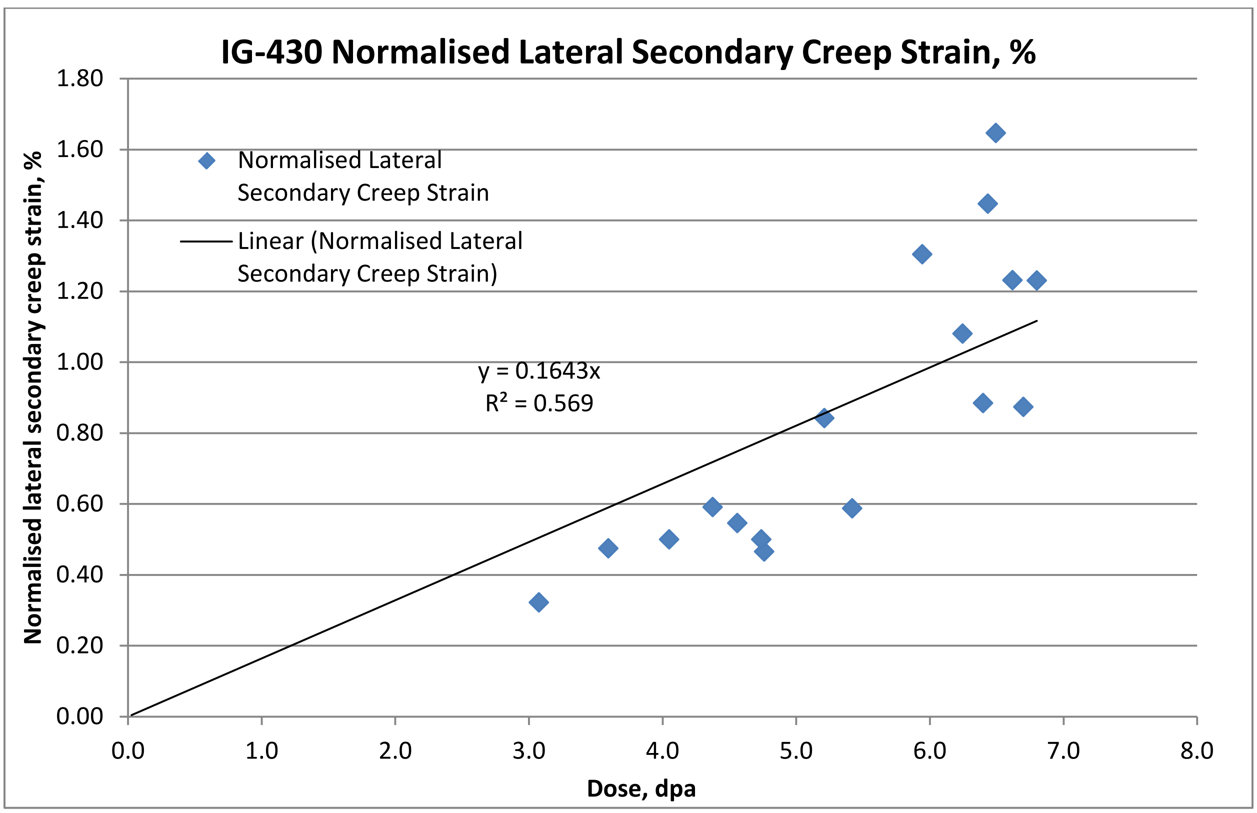

Figure 78 Normalized secondary lateral creep strain (%) for IG-430

The creep strain ratio for IG-430 was calculated from the ratio of the gradients of the normalized total creep strain (Figure 75 and Figure 76). Thus, the ratio = 19.561/-75.431 = -0.259. This value of the creep strain ratio was larger than both the irradiated control specimen Poisson's Ratio value of 0.192 (S.D. = 0.017) and the creep specimen PR of 0.194 (S.D. = 0.067). The PR values appear to be increased by irradiation (Table 30)[6], which is at odds with the other graphites. The PR and creep strain ratios are discussed in section 7.

The creep coefficient, K, is calculated from the gradients of the normalized secondary creep plots (Figure 77 and Figure 78) divided by the normalizing stress (Equation 1 and Equation 2). Thus the longitudinal creep coefficient for IG-110 was K = 0.-400/-19.834 = 0.0202 %/dpa·MPa or 0.137 ($10^{-30}cm^2$/n·Pa). The lateral value of K was 0.162/3.656 = 0.0443 %/dpa·MPa or 0.195 ($10^{-30}cm^2$/n·Pa. These K values compare well with literature values for K as discussed later in section 7.

7. General Discussion

The above reported creep coefficient data are compared to historic and literature data in an attempt to establish their credibility. Data trends and correlations are sought. The important derived creep parameters for each grade of graphite examined are in Table 50 and Table 51.

7.1. A Comparison of Creep and Control Volume Change for AGC-1 Graphite Grades

As evidenced by the data in Figure 16, Figure 21, Figure 25, Figure 30, Figure 34 and Figure 41 the volume change on irradiation for each grade was very similar for the creep and control specimens within that grade, despite the creep and control specimens having very different dimensional changes. Volume conserving creep[11,12] such as observed here would suggest that we are in a creep regime where crystal dimensional change mechanisms are is in control and it is assumed that a-axis dimensional change, X_a, is twice the c-axis dimensional change, X_c, ($2X_a=X_c$).

It is also noted the PCEA volume change tends to behave similarly to the proven historic grade H-451. For example the volume change characteristics of the two extruded grades are compared in Figure 35. Cleary the creep and control specimens exhibit similar behavior for both grades.

This similarity is further explored by comparing the creep behavior of PCEA and H-451. Figure 57 and Figure 58 (H -451) and Figure 63 and Figure 64 (PCEA) yield creep-strain ratios of 0.18 and 0.17 for H-451 and PCEA, respectively. The creep coefficient, K, for PCEA and H-451 are derived from Figure 59 and Figure 60 (H-451), and Figure 65 and Figure 66 (PCEA). $K_{(longitudinal)}$ values of 0.138 and 0.124 are obtained for H-451 and PCEA, respectively (Equation 1 and Equation 2). $K_{(lateral)}$ values of 0.176 and 0.151 were derived for H-451 and PCEA, respectively. On the basis of this single temperature creep-data PCEA graphite appears to be very similar to H-451 graphite.

Note also that for PCEA, NBG-17 and NBG-18 the creep data set contains both WG and AG orientation specimens. Examination of the creep data showed that within each of these grades the AG/WG directions behaved similarly with respect to irradiation creep. Consequently, all the creep data (i.e., AG and WG) has been combined here for each grade.

7.2 A Comparison of the Creep Strain Ratio and Poisson's Ratio

The calculated creep strain ratios are tabulated along with Poisson's ratio values for the unirradiated specimens[6,7] and the irradiated creep and control specimens are reported in Table 50.

Table 50 Comparison of Poisson's ratio and creep strain ratio

Graphite Grade	Grade Letter	Piosson's Ratio			Creep Strain Ratio
		Unirradiated	Control	Creep	
NBG-17	A	0.33	0.26	0.24	0.24
NGB-18	B	0.32	0.27	0.25	0.20
H-451	C	0.31	0.28	0.27	0.18
PCEA	D	0.25	0.27	0.25	0.17
IG-110	E	0.25	0.20	0.17	0.20
IG-430	F	0.17	0.19	0.19	0.26

Irradiation lowers the value of Poison's ratio (with the exception of IG-430). PCEA appeared to undergo no apparent change. The Poison's ratio determined on the creep specimens was lower than that determined from the control specimens (again, with the exception of IG-430). The Creep Strain Ratio does not agree with the irradiated (creep or control) value and is generally lower (again with the exception of IG-430). The creep strain ratio evidently does not agree with unirradiated or the irradiated Poisson's Ratio value. This observation the creep strain ratio does not equal the irradiated creep value may prove contentious.

7.3 A comparison of the obtained K values with literature values

The calculated values of the longitudinal and lateral creep constants, K, are reported in Table 51 (Equation 1 and Equation 2). These values are plotted along with literature values[12,13,14,15,16,17,18,19,20,21] in Figure 79 and Figure 80 . The temperature range of AGC-1 Capsule is in also indicated by the horizontal line. The AGC-1 data has been plotted at the mean temperature for the creep and control specimen of each grade in AGC-1. The horizontal line potted in Figure 79 and Figure 80 indicates the variation observed in the creep and control or central section of the capsule. The degree to which temperature varied along the capsule length was excessive and probably accounts for some of the data spread. The means and standard deviations of the specimen temperatures are given by grade in Table 52.

It must be remembered that AGC-1 was the prototype capsule and such problems were not unexpected.

Lines are added to Figure 79 and Figure 80 simply for guidance, they are not fitted lines. The derived values of $K_{(longitudinal)}$ and K_{later} fall between the lines and are in reasonable agreement with the literature values for K. This agreement supports the assumption that the creep at these doses can be satisfactorily described by the linear visco-elastic creep model. The lateral values of K are more unreliable, as indicated by the poorer linear fits (lower R^2 values) to the lateral creep data. The data for K suggests that the capsule operated at a higher temperature, which is broadly in line with our observations and capsule thermal models.

Table 51 creep strain ratios and K data for the six grades in AGC-1

GRADE	CODE	Total creep strain coefficient micron/dpa		Creep strain Ratio	Normalized secondary creep strain coefficient', %/dpa		Normalizing stress, σ_{max}, (MPa)		Secondary creep strain coefficient K, %/dpa.MPa		Secondary creep strain coefficient, $10^{-30}cm^2/n.Pa$	
		Longitudinal	Lateral		Longitudinal	Lateral	Longitudinal	Lateral	Longitudinal	Lateral	Longitudinal	Lateral
NBG-17	A	-72.5410	17.602	-0.243	-0.287	0.148	-19.730	5.893	0.0145	0.0250	0.099	0.170
NGB-18	B	-70.9680	15.281	-0.215	-0.280	0.120	-19.723	5.613	0.0142	0.0213	0.096	0.145
H-451	C	-102.1800	18.11	-0.177	-0.403	0.142	-19.809	5.491	0.0203	0.0259	0.138	0.176
PCEA	D	-90.9270	15.823	-0.174	-0.365	0.123	-20.000	5.592	0.0182	0.0219	0.124	0.151
IG-110	E	-101.4900	20.583	-0.203	-0.400	0.162	-19.834	3.656	0.0202	0.0443	0.137	0.195
IG-430	F	-75.431	19.561	-0.259	-0.631	0.164	-19.776	3.970	0.0319	0.0414	0.219	0.281

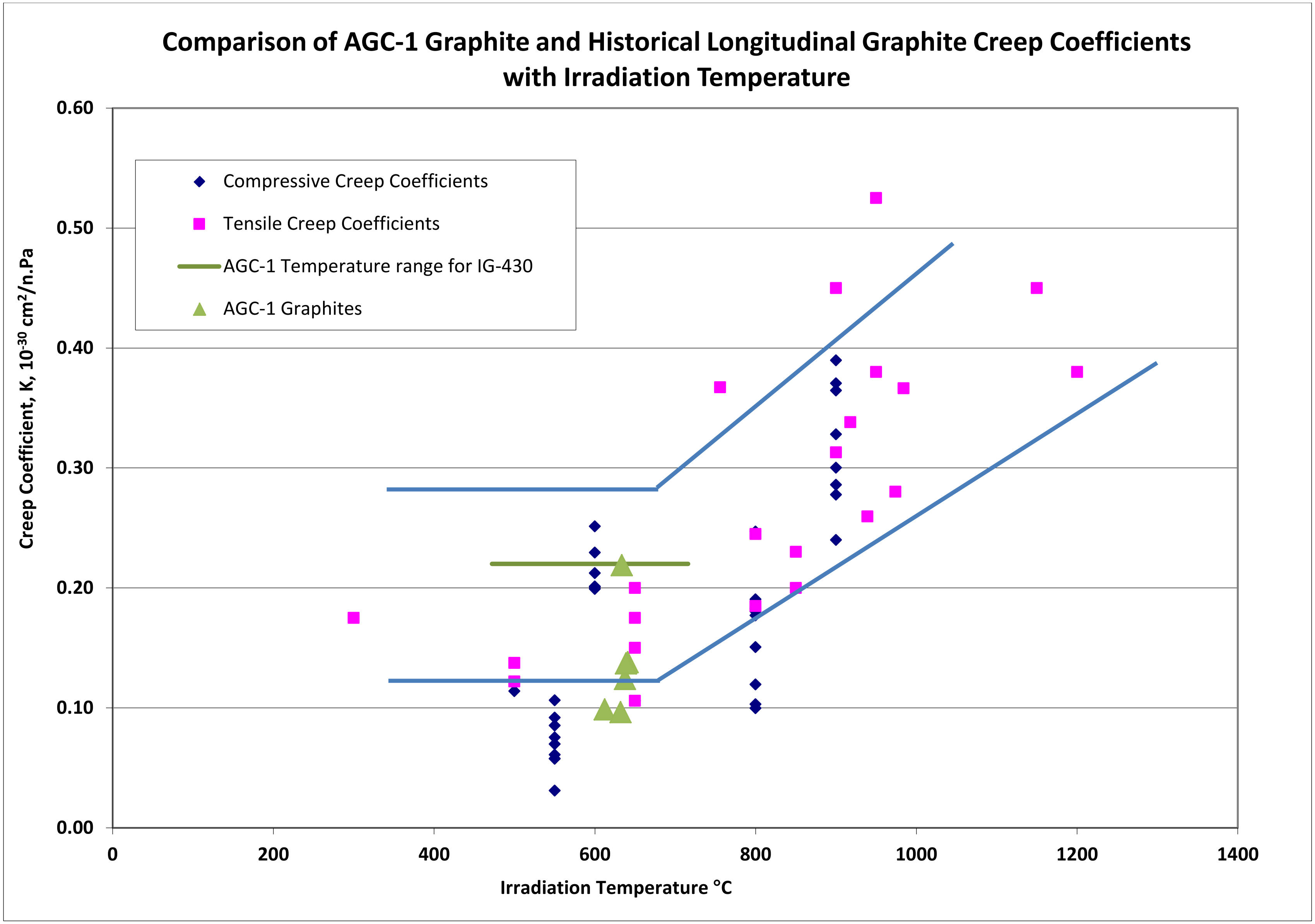

Figure 79 Comparison of AGC-1 Graphite's and Longitudinal Graphite Creep Coefficients (from the Literature) with Irradiation Temperature

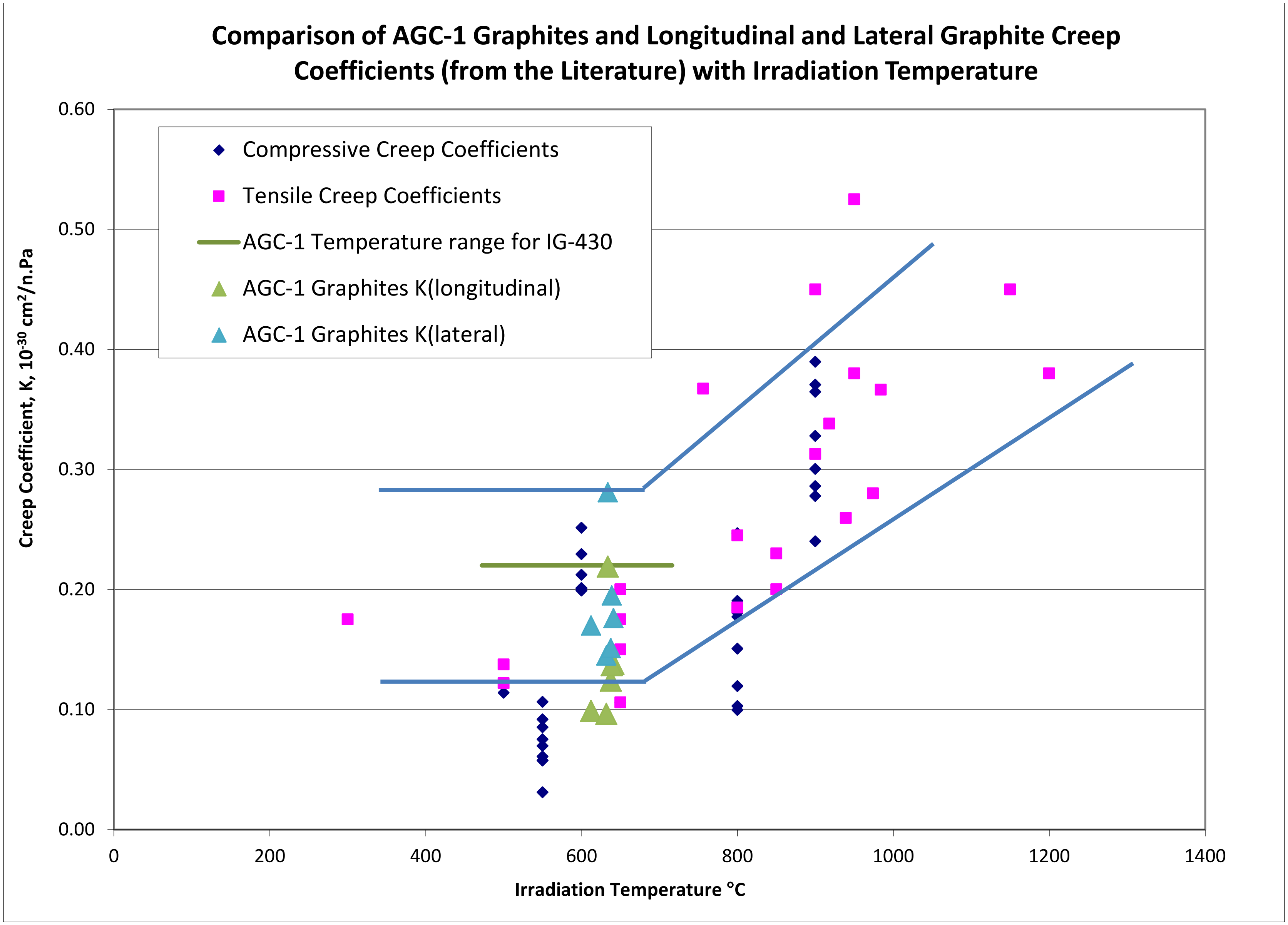

Figure 80 Comparison of AGC-1 Graphite's and Longitudinal and Lateral Graphite Creep Coefficients (from the Literature) with Irradiation Temperature

Table 52 Mean and standard deviation for the grades in the center (creep/control) section of capsule AGC-1

GRADE	GRADE I.D. LETTER	NUMBER OF SPECIMENS	MEAN TEPERATURE,°C	STANDARD DEVIATION, °C
NBG-17	A	32	612.3	73.98
NBG-18	B	34	632.0	61.59
H-451	C	22	641.0	41.91
PCEA	D	34	637.6	56.92
IG-110	E	24	638.8	58.14
IG-430	F	34	633.7	63.10

The large standard deviations seen in the creep/control specimen temperatures (see also Section 5.7) observed in Table 52 indicate the large temperature spread that was observed in AGC-1. The standard deviations were particularly large for grades NBG-17 and IG-430. As shown by the temperature analysis in section 5.7 theses two graphites had a large number of data point which would not have met our criteria as T_{creep} - $T_{control}$ <100°C, and 500°C < T_{irr} < 700°C had we applied them. Consequently the data for NBG-17 and IG-430 remains suspect.

This discrepancy becomes obvious for IG-430 and somewhat less obvious for NBG-17 if the product of K and unirradiated modulus (E_0) (Table 53) is compared for the various grades (Figure 81 and Figure 82). Most of the AGC-1 graphite grades have $K{\cdot}E_0$ values between 1.0 and 2.0 x 10^{-21} cm^2/n [E>50keV]. The IG-430 data greatly exceed these values while the NBG-17 data are at the low and high end respectively for longitudinal and lateral data, respectively.

Table 53 E_0, $K_{long}{\cdot}E_0$ and $K_{lat}{\cdot}E_0$ for the six graphite grades in AGC-1

AGC-1					E_0, GPa			
Graphite	K_{long}, 10^{-30} cm^2 / n·Pa [E>50 KeV]	K_{lat}, 10^{-30} cm^2 / n·Pa [E>50 KeV]	Assumed T_{irr}	Std. Dev.	WG	AG	$K_{long}{\cdot}E_0$, 10^{-21} cm^2/n [E>50 KeV]	$K_{lat}{\cdot}E_0$, 10^{-21} cm^2/n [E>50 KeV]
NBG-17	0.10	0.17	612.3	73.98	11.58	11.19	1.105	1.969
NGB-18	0.10	0.145	632	61.59	12.46	12.17	1.173	1.807
H-451	0.14	0.176	641	49.91	7.2	8.84	1.220	1.267
PCEA	0.12	0.151	637.6	56.92	8.89	10.98	1.362	1.342
IG-110	0.14	0.195	638.8	58.14	8.88	8.88	1.217	1.732
IG-430	0.22	0.281	633.7	63.1	9.48	9.48	2.076	2.664

GA design literature value

Note that the appropriate value of E_0 has been used for the longitudinal and lateral creep strain orientations[22].

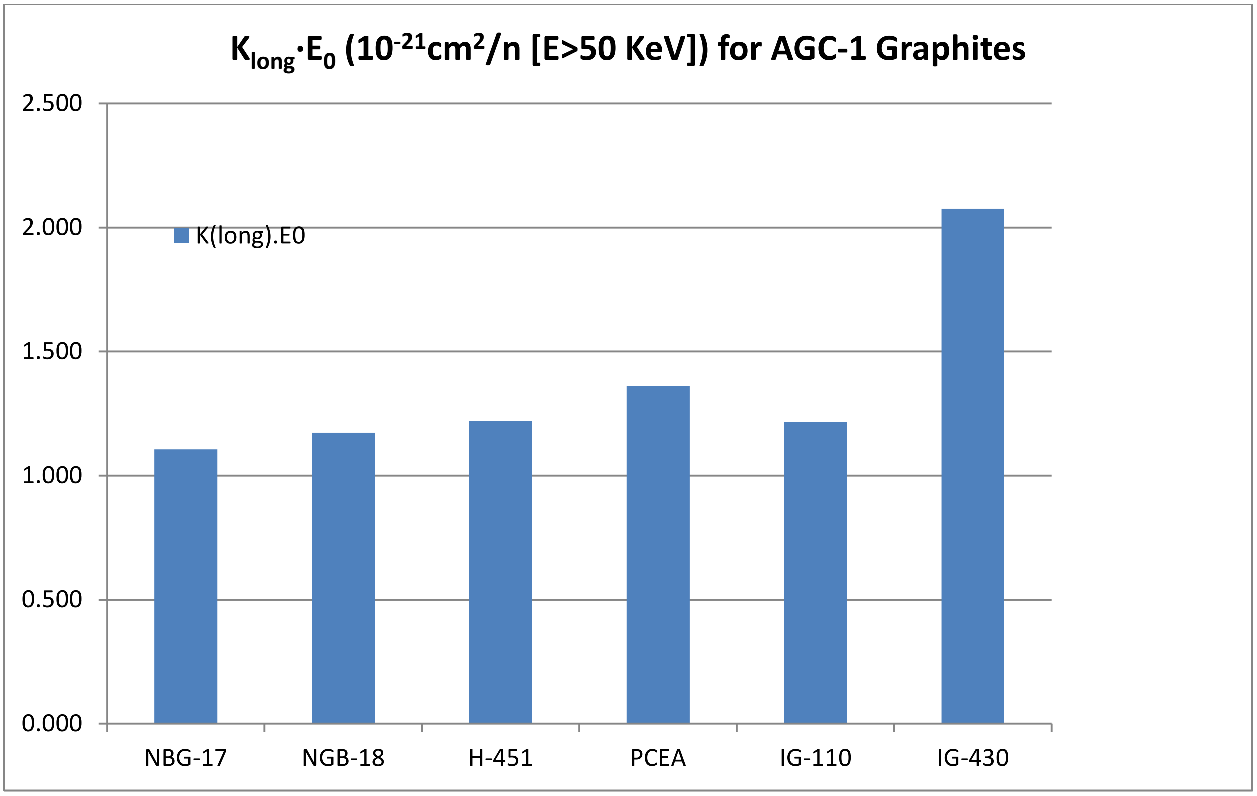

Figure 81 The variation of the product $K_{(Long)}.E_0$ for the six graphite grades in AGC-1

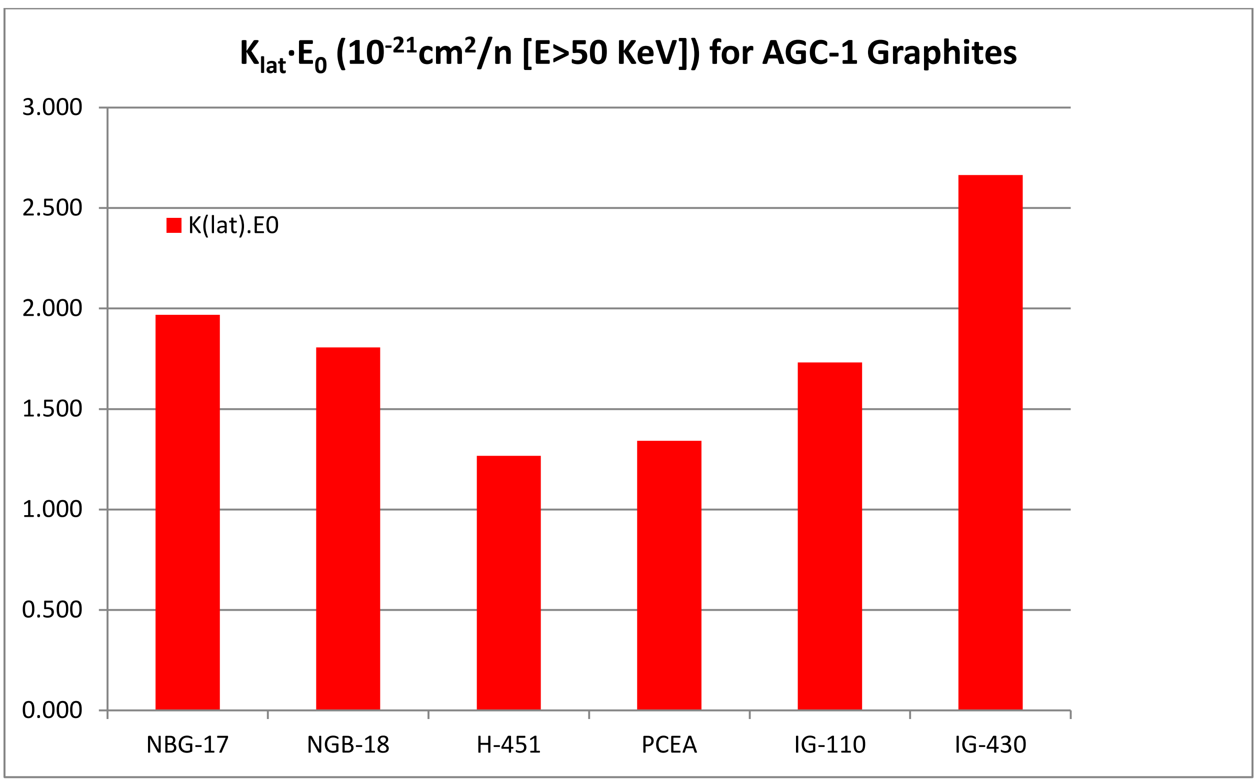

Figure 82 The variation of the product $K_{(Lat)}.E_0$ for the six graphite grades in AGC-1

7.4. The variation of K with graphite structural features

An obvious correlation to K variations would be with the graphite bulk density. Many physical properties are known to correlate with density. However, here is no obvious relationship between density and the creep strain coefficient, K (Figure 83).

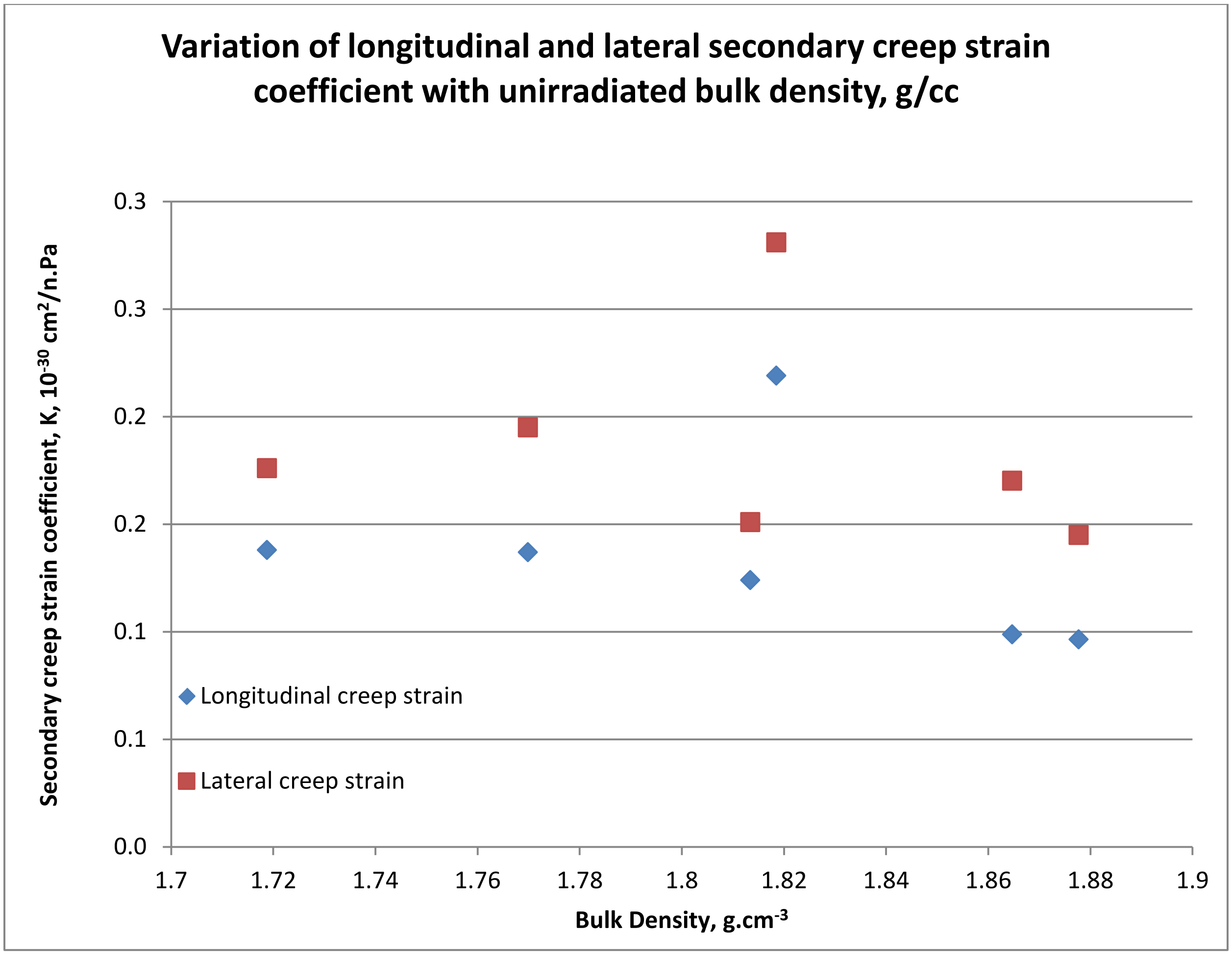

Figure 83 Variation of longitudinal and lateral secondary creep strain coefficient with unirradiated bulk density, g/cc

If it is assumed that the lower dose portion of the creep behavior curve (2nd creep stage) is linear and dominated by the in-crystal changes (not pore generation), we might expect K to correlate with crystal parameters. Figure 84 and Figure 85 show the relationships between L_a and L_c, respectively with the creep coefficients, K (both longitudinal and lateral). The creep constant K appears to increase as the crystallite coherence length (L_a) increases (Figure 84). Similarly, K increases with increasing crystallite coherence height L_c (Figure 85). This correlation would substantiate a predominantly crystallite-dislocation mechanism for the observed stage II (linear) creep.

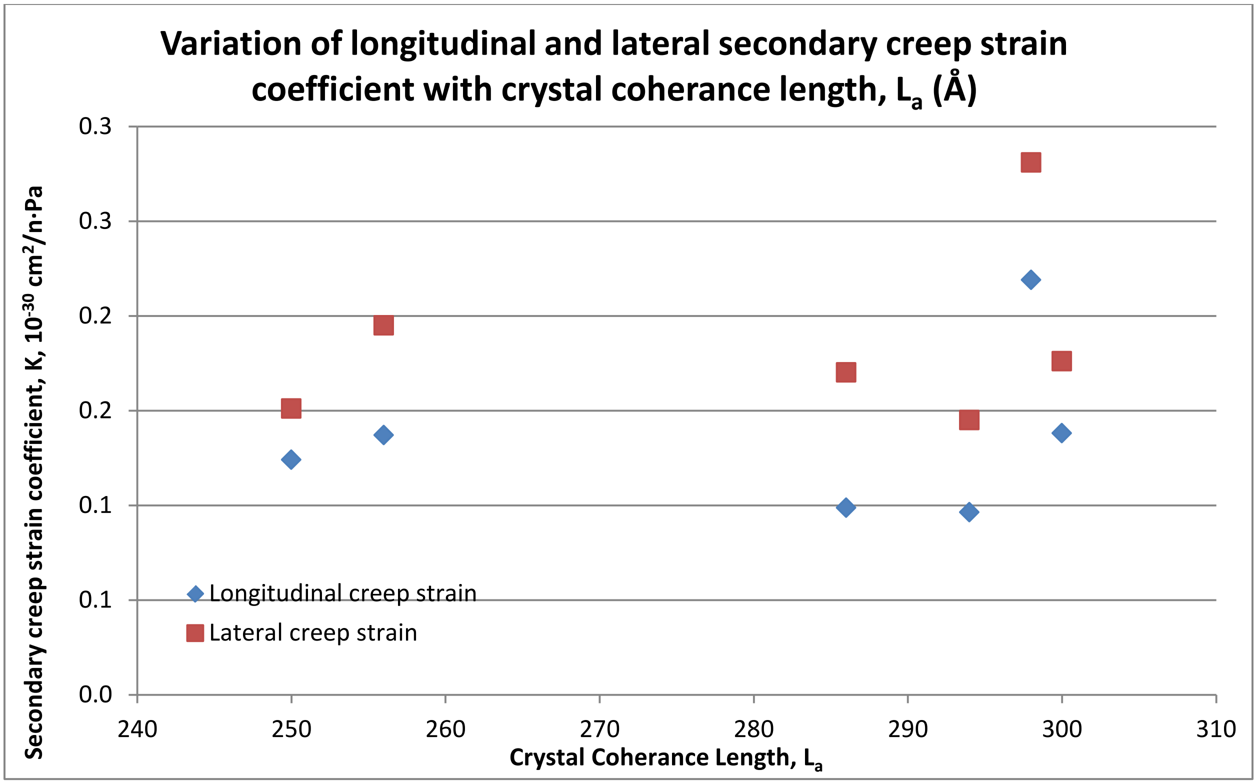

Figure 84 Variation of longitudinal and lateral secondary creep strain coefficient with crystal coherance length, La (Å)

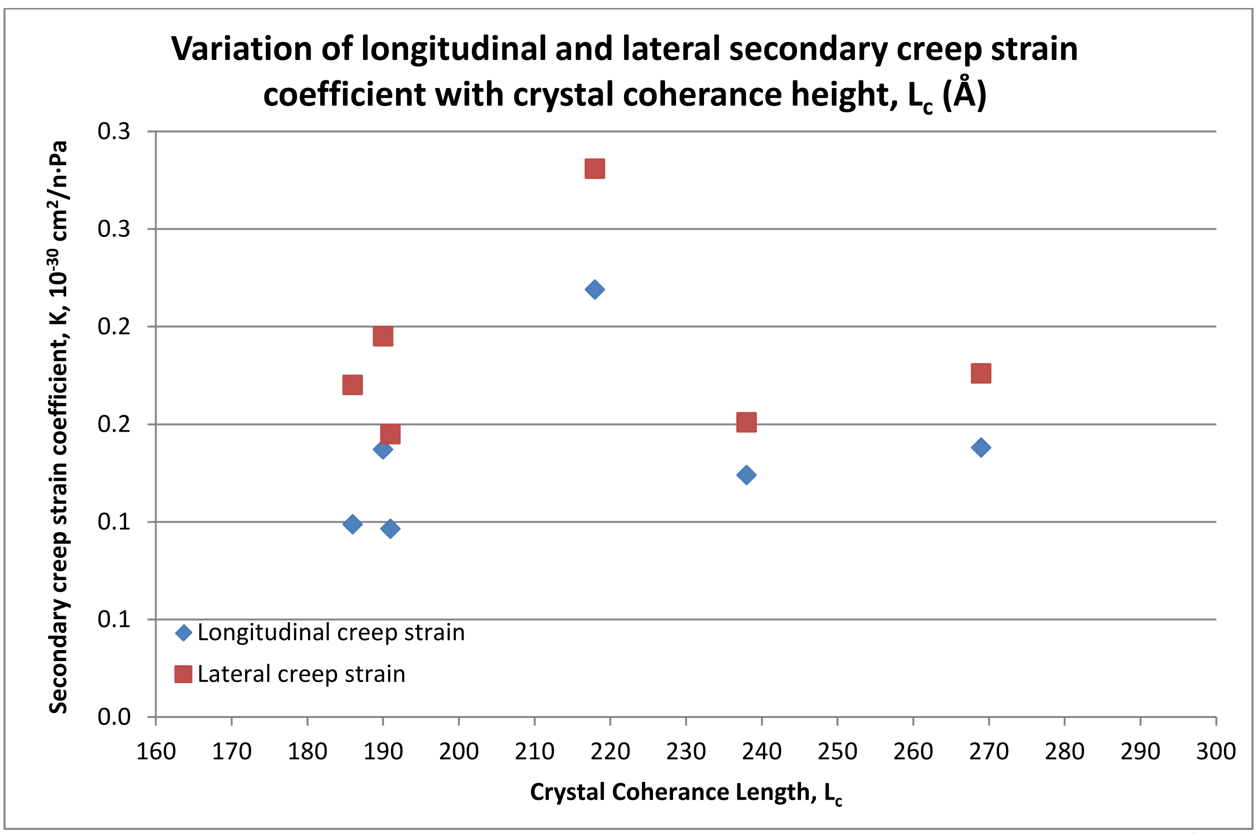

Figure 85 Variation of longitudinal and lateral secondary creep strain coefficient with crystal coherence height, Lc (Å)

The final correlation explored here was between the filler particle size and the secondary creep constant (Figure 86). There appears to be a correlation between the two parameters with the creep coefficient becoming smaller as the grain size increases. This may be a reflection of the weak connection between filler particle size and crystallite coherence length (Table 54 and Figure 87).

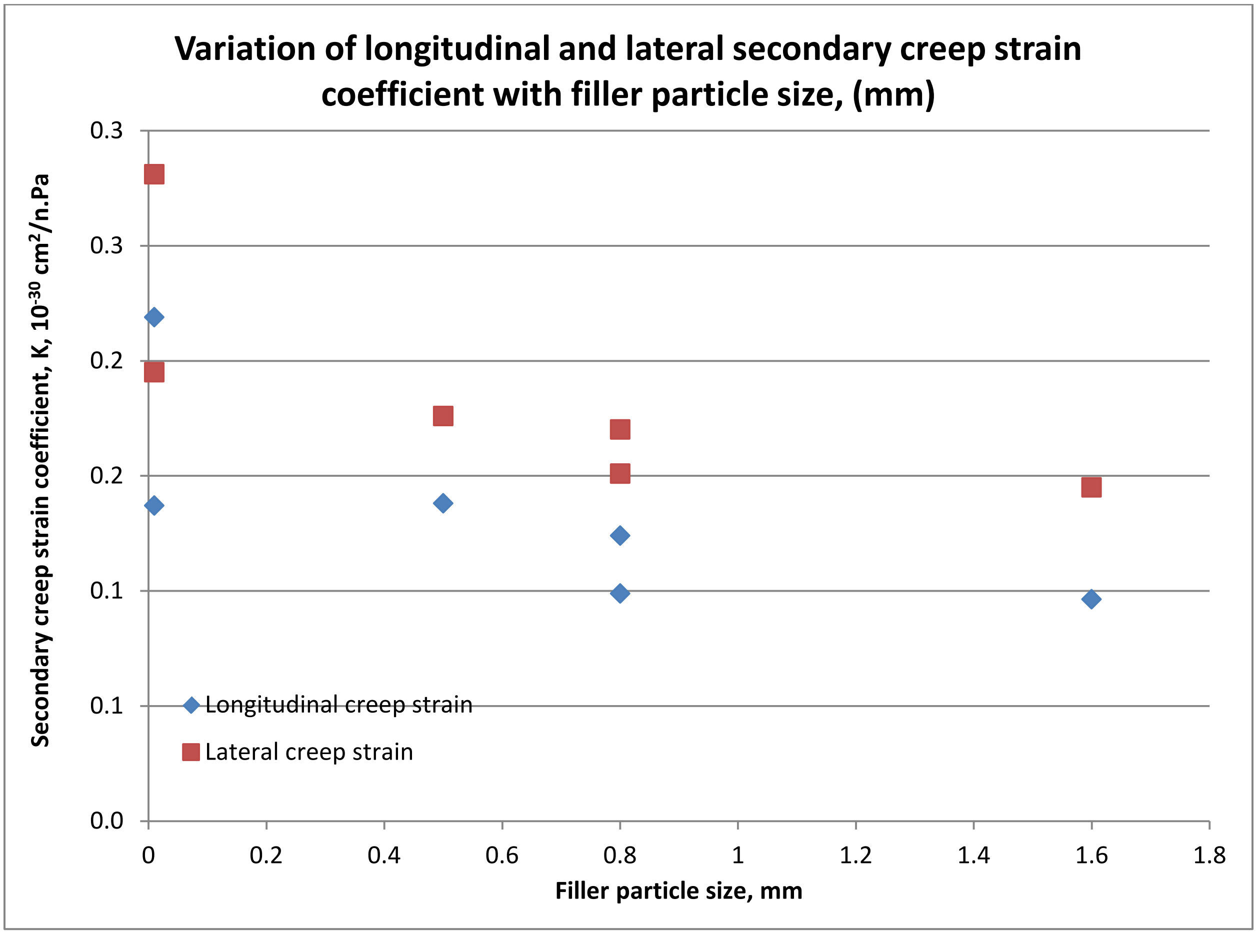

Figure 86 Variation of longitudinal and lateral secondary creep strain coefficient with filler particle size, (mm)

Table 54 filler particle and crystal parameters for the grades examined in AGC-1

GRADE	Unirradiated density	Crystal coherence length L_a	Crystal coherence hieght L_c	Maximum Filler Particle size*	Young's modulus*** (fundamental frequency), E	Secondary creep strain coefficient,K, $10^{-30}cm^2/n.Pa$	
	g/cc	Å	Å	mm	GPa	Longitudonal	Lateral
NBG-17	1.8647	286	186	0.8	11.19	0.099	0.170
NGB-18	1.8777	294	191	1.6	12.17	0.096	0.145
H-451**	1.7188	300	269	0.5	8.84	0.138	0.176
PCEA	1.8134	250	238	0.8	10.98	0.124	0.151
IG-110**	1.7699	256	190	0.01	8.88	0.137	0.195
IG-430**	1.8185	298	218	0.01	9.48	0.219	0.281

* From ORNL/TM-2009/025

***From ORNL/TM-2010/285

**mean grain size

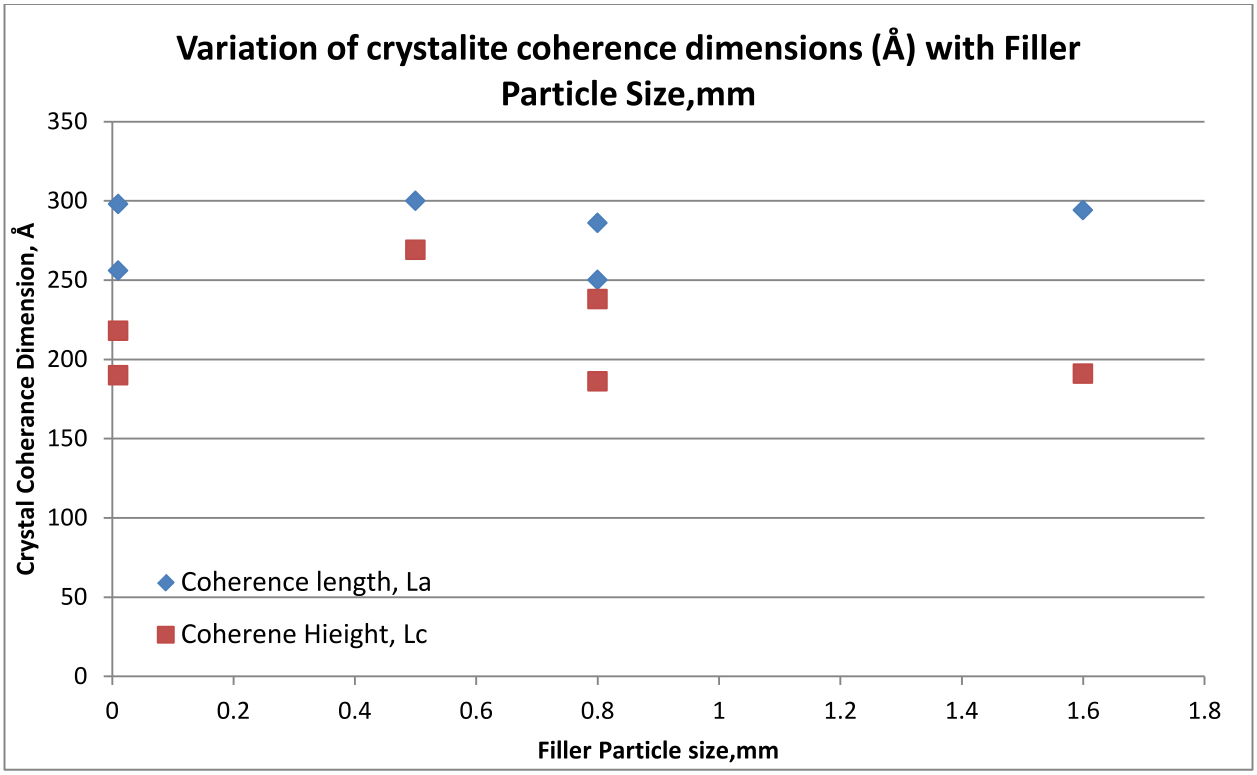

Figure 87 Variation of Crystallite coherence dimensions with filler particle size

We would generally expect the crystallite coherence length to be reduced by the repetitive grinding that occurs as the filler particle size is reduced by mechanical attrition[23,24]. Hence a slight drop in crystallinity with filler size is not unexpected.

8 Quality Assurance

The activities described here were conducted in accordance with the applicable requirements of the ASME/NQA-1-2000 national standard entitled Quality Assurance Requirements for Nuclear Facility Applications. Project and activity-specific information concerning ORNL's application of the standard's requirements is provided in Document #QAP-ORNL-NGNP-01 titled Quality Assurance Plan for the Next Generation Nuclear Plant Materials Program at Oak Ridge National Laboratory

9 Summary and Conclusions

An analysis of the creep response for the AGC-1 major graphite grades has been completed. Irradiation induced creep is a complex phenomenon and requires sophisticated experiments to achieve accurate data for analysis. The main conclusions resulting from this analysis are captured in a brief list which will be followed by a brief discussion of these conclusions.

9.1 Summary of results

All AGC-1 dimensional change data have been analyzed and the creep strain data calculated and analyzed. The following are the main conclusions from this analysis:

1. For the AGC-1 dose range the magnitude of the dimensional changes for the major graphite grades is of the correct order compared to previous H-451 dimensional changes data.
2. The IG-110 volume change data from AGC-1 agree reasonably well with previous HTK-7 volume change data for IG-110 graphite.
3. Only grade IG-430 shows signs of the onset of turnaround. All other AGC-1 graphite grades show no signs of the onset of turnaround. (Note, we are in a dose range where anisotropy would likely not become apparent sine the behavior is dominated by the initial crystal contraction).
4. When the creep strain data set for a particular graphite grade is normalized to the maximum applied stress the data falls on a reasonable straight line.
5. The analyzed creep strain appears to be linear with neutron dose and the creep strain is proportional to the applied creep stress.
6. The creep data appears to fit a linear creep law (stage II creep).
7. The volume change curves for the irradiated (crept and uncrept) specimens are very similar at lower doses (>6 dpa) supporting the hypothesis that irradiation creep in this region is at constant volume (as reported elsewhere in the literature).
8. Large thermal variations along the length of the capsule meant that the matched pairs where not at the same temperature as called for in the original design. Moreover, for given graphite grade the specimens were not at a common temperature.
9. The temperature variations (lower temperatures) correlate with the lower γ-dose in the core.
10. Despite the large temperature variations the AGC-1 creep data are useful with the possible exception of grades IG-430 and NBG-17.
11. Thermal assessment of the data suggests it might be beneficial to reanalyze certain data applying the temperature criterion discussed in Section 5.7.
12. When comparing the dimensional change behavior for both iso-molded grades, IG-430 and IG-110, it is seen that the behavior of IG-110 appears superior compared to IG-430 over the dose and temperature range of AGC-1.
13. Despite the large difference in grain size between NBG-17 (0.8 mm) and NBG-18 (1.6 mm) both vibrationally molded grades behave dimensionally in a very similar fashion. Both are very isotropic at AGC-1 doses and temperatures
14. PCEA and H-451 were less isotropic than the other major graphite grades as would be expected from extruded grades. However, PCEA was substantially more isotropic than H-451.
15. The longitudinal creep data is always a better linear fit than the lateral creep strain data
16. The Creep Coefficients determined for the six major grades are in reasonable agreement with literature values for the creep coefficient for other grades.
17. The calculated values for the creep coefficients for the graphite grades (excluding IG-430) were shown to range between ~0.1 and ~0.2 X 10^{-30} $cm^2/n\cdot Pa$.

18. The creep strain ratio does not agree with the irradiated Poisson's ratio (creep or control).
19. Poisson's ratio is consistently smaller in the irradiated condition, and typically smaller in the stressed (crept) samples than in the unstressed (control) samples.
20. Both IG-110 and IG-430 have Poisson's ratio values lower than the other grades examined
21. The parameter $K \cdot E_0$ showed a discrepancy in the IG-430 data. Other graphite grades have $K \cdot E_0$ values ranging from1.0 to 1.5 cm^2/n [E>50keV] (longitudinal) and 1.5-2.0 cm2/n [E>50keV] (lateral), whereas the value for IG-430 were >2.0 (longitudinal) and >2.5 (lateral).
22. NBG-17 was also anomalous in that its longitudinal $K \cdot E_0$ value is larger than the other graphite grades with the exception of IG-430.
23. The creep coefficient, K, does not correlate with the bulk density, but does correlate with the crystal parameters L_a and L_c supporting the hypothesis that the creep strain at mechanism at these temperatures and doses is related to the crystals behavior, i.e., an in-crystal deformation mechanism for creep.
24. A correlation between K and grain size was observed.

9.2 Discussion of results

The calculated values for the creep coefficients for the graphite grades (excluding IG-430) were shown to range between ~0.1 and ~0.2 X $10^{-30} cm^2/n \cdot Pa$. The Creep Coefficients determined for the six major grades are in reasonable agreement with literature values for the creep coefficient for other grades. However, the AGC-1 data has been plotted at the mean temperature for the creep and control specimens of each grade in AGC-1. The degree to which temperature varied along the capsule length was excessive and probably account for some of the data spread.

IG-430 was noted to enter into volume turn-around at lower doses than expected. This has been observed within the European program and is apparent in the volume change data reported here.

Both of the iso-molded grades examined here exhibited lower Poisson's ratio value after irradiation than either the extruded or vibrationally molded grades. A similar trend was noted in the Pre-irradiation data measurements.

The ultimate completion of the entire AGC series of experiments will allow the creep coefficient, K, to be correlated with irradiation temperature for the first time!

Attempts were made to correlate the creep coefficient with various structural parameters. The creep coefficient, K, does not correlate with the bulk density, unlike many mechanical and physical properties.

The creep coefficient, K, correlates with the crystal parameters L_a and L_c supporting the hypothesis that the creep strain at mechanism at these temperatures and doses is related to the crystals behavior, i.e., an in-crystal deformation mechanism for creep.

A weaker correlation was observed between K and grain size which probably reflect the known correlation between smaller grain size and improved crystalinity due to grinding.[23,24]

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11. Distribution

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