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I am submitting herewith a dissertation written by Amir Sassan Mobasheran entitled "Examination of Experimental Data for Irradiation-Induced Creep in Nuclear Graphite." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Nuclear Engineering.

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EXAMINATION OF EXPERIMENTAL DATA FOR IRRADIATION-INDUCED CREEP IN NUCLEAR GRAPHITE

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Amir Sassan Mobasheran

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ABSTRACT

The objective of this dissertation was to establish credibility and confidence levels of the observed behavior of nuclear graphite in neutron irradiation environment. Available experimental data associated with the OC-series irradiation-induced creep experiments performed at the Oak Ridge National Laboratory (ORNL) were examined.

Pre- and postirradiation measurement data were studied considering "linear" and "nonlinear" creep models. The nonlinear creep model considers the creep coefficient to vary with neutron fluence due to the densification of graphite with neutron irradiation. Within the range of neutron fluence involved (up to 0.53×10^{26} neutrons/m^2, E > 50 KeV), both models were capable of explaining about 96% and 80% of the variation of the irradiation-induced creep strain with neutron fluence at temperatures of 600°C and 900°C, respectively.

Temperature and reactor power data were analyzed to determine the best estimates for the actual irradiation temperatures. It was determined according to thermocouple readouts that the best estimate values for the irradiation temperatures were well within ±10°C of the design temperatures of 600°C and 900°C.

The dependence of the secondary creep coefficients (for both linear and nonlinear models) on irradiation temperature was determined assuming that the variation of creep coefficient with temperature, in the temperature range

studied, is reasonably linear. It was concluded that the variability in estimate of the creep coefficients is definitely not the results of temperature fluctuations in the experiment.

The coefficients for the constitutive equation describing the overall growth of grade H-451 graphite were also studied. It was revealed that the modulus of elasticity and the shear modulus are not affected by creep and that the electrical resistivity is slightly (less than 5%) changed by creep. However, the coefficient of thermal expansion does change with creep.

The consistency of calculated Poisson's ratios for primary and secondary creep with volume change, caused by irradiation-induced creep, was also investigated. It was determined that these ratios were consistent with the volume change.

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CHAPTER 1

INTRODUCTION

1.1 Statement and Importance of the Problem

The confident design of a nuclear reactor core requires knowledge and accurate prediction of the strains that develop in the core components during their service lives. This is in view of the structural integrity and dimensional stability of the core.

The total strain experienced by a solid material when under applied stress and subjected to a neutron irradiation environment is described by its constitutive equation. For nuclear graphite this equation is:

$$\epsilon_T = \epsilon_e + \epsilon_p + \epsilon_s + \epsilon_g + \epsilon_t \quad , \tag{1-1}$$

where

ϵ_T = total strain,

ϵ_e = elastic strain,

ϵ_p = primary creep strain,

ϵ_s = secondary creep strain,

ϵ_g = irradiation growth,

ϵ_t = thermal strain.

Determination of the components of the constitutive equation requires understanding of the physical and mechanical properties of this material as affected by neutron irradiation and creep.

Fast-neutron irradiation-induced creep has emerged as one of the critical properties of graphites utilized in high-temperature gas-cooled nuclear reactors (HTGR's). While thermally-induced creep-strain in graphite is not significant for temperatures below 1800°C, in a fast-neutron irradiation environment creep is manifest as an important phenomenon at temperatures as low as 300°C [1, 30]. The strain-to-failure of graphite, when subjected to a purely external load and no creep, is generally 0.25-0.5%. In a fast-neutron irradiation environment, under applied loads, creep strains of up to 5% or more have been observed [2].

Irradiation-induced creep in graphite is a result of stress relaxation caused by temperature and neutron flux gradients present in the core. Without this relaxation process, graphite could rapidly disintegrate due to irradiation induced distortion and its temperature dependence. In other words, the internal stresses in graphite, arising from the differential irradiation-induced shrinkage and differential thermal strains, are reduced significantly by fast-neutron irradiation induced creep [3].

Considering the behavior of graphite in a neutron irradiation environment, relaxation is a dominant parameter in the HTGR core designer's analysis. This relaxation must be well known or well predicted for the proper design for safety and operation of HTGR's.

The objective of this work is to critically examine the available irradiation-induced creep data, obtained at Oak Ridge National Laboratory (ORNL), to establish credibility and confidence levels of observed behavior of nuclear graphite. Moreover, the coefficients for the constitutive equation mentioned above will also be derived.

1.1.1 Organization of the Dissertation

Following sections of this chapter introduce the phenomenon of creep and some properties of solid materials.

Chapter 2 provides information on nuclear graphite and its peculiarities. Technological significance of the irradiation induced creep is also discussed in this chapter.

Experimental techniques involved in conducting irradiation experiments for creep studies are discussed in Chapter 3.

The description of the OC-series experiments is included in Chapter 4.

Chapter 5 is devoted to the analyses of temperature data and reactor power.

Chapter 6 talks about the different approaches to creep characterization. The nonlinear creep model is introduced in this chapter.

Chapter 7 covers the statistical methods employed in the analysis of experimental data. Descriptive statistics as well as inferential statistics (regression analysis) are discussed in this chapter.

Examination of the nonlinear creep model as well as the linear model are covered in Chapter 8.

Chapter 9 contains a discussion on constitutive equation for graphite and the determination of the coefficients for this equation.

Chapter 10 provides a summary of the research performed, the conclusions drawn, and then the recommendations made.

Appendix A provides more information regarding the creep phenomenon in solid materials. Appendix B contains the data reading and converting program. Appendices C and D contain the figures related to temperature analyses that were not included in the main text. Three SAS programs, written for temperature analysis, have been included in Appendix E. A SAS code written for detailed temperature analysis is contained in Appendix F. Two SAS programs for reactor power analysis are included in Appendix G.

1.2 Deformation in Solid Materials and Creep Phenomenon

Mechanical properties of solid materials that cause their deformation fall into two classes: short-term and long-term properties. Figure 1-1 indicates the short-term properties of an "ideal" solid whose specimen has been

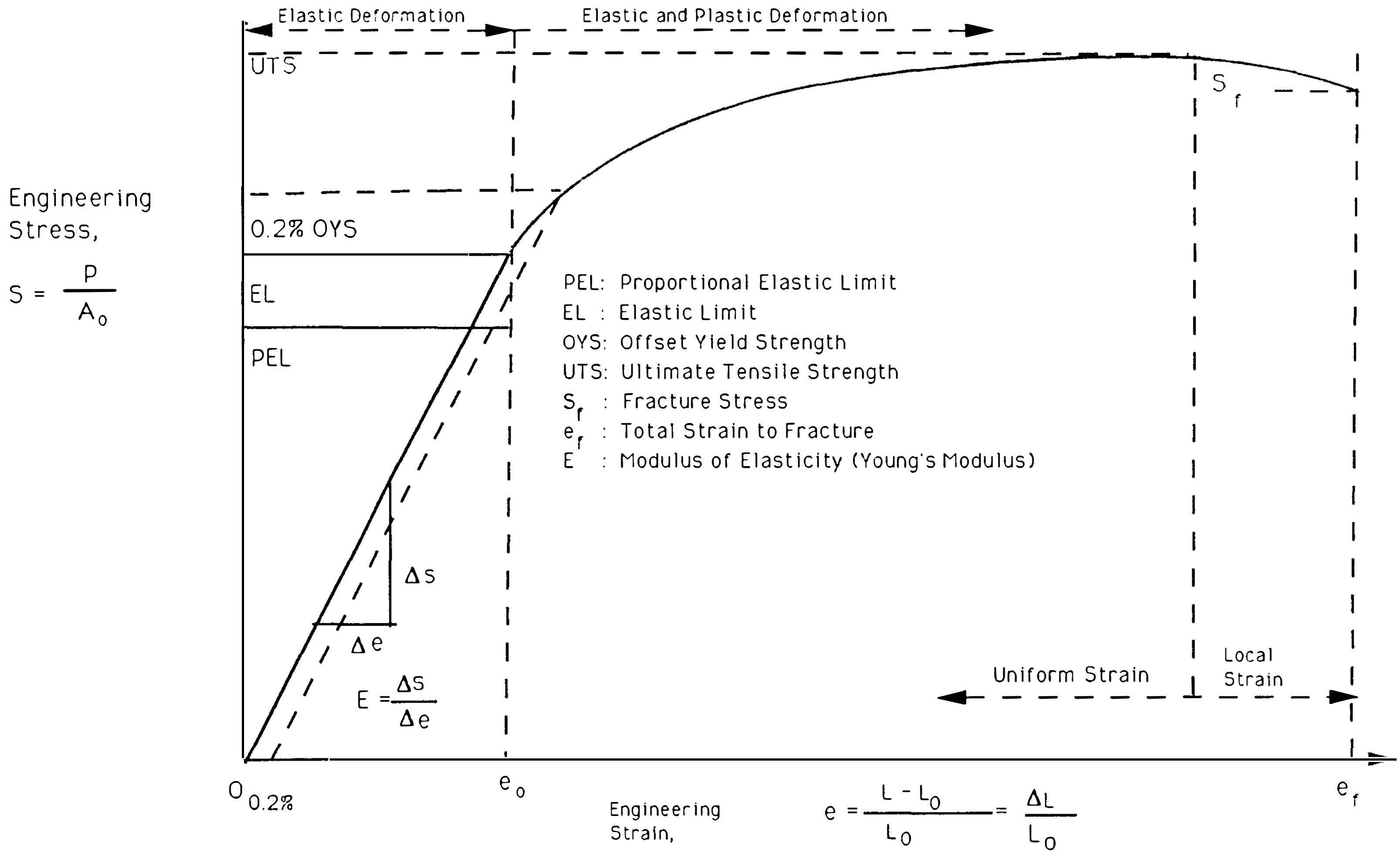

Figure 1-1. Engineering stress-strain behavior of an "ideal" solid.

subjected to uniaxial tensile stress [4]. The shape of the stress-strain curve depends on the material and the test conditions.

Appendix A provides more information regarding the creep phenomenon. However, it should be noted that these discussions on creep are for creep phenomenon in the absence of neutron irradiation.

Short-term properties of a solid material such as ultimate tensile strength (UTS), yield strength, modulus of elasticity (Young's modulus), etc., although very important material characteristics, provide little information in regard to the behavior of material when subjected to stresses and high temperatures for long periods of time. Therefore, for such applications, it is important that the time-dependent behavior of the material be known [5].

A property that falls into the category of long-term properties of materials is important because of creep phenomenon in solid materials. Creep is defined as the time-dependent plastic deformation of a solid subjected to a fixed load at constant temperature. A typical creep curve is depicted in Figure 1-2. As indicated in Figure 1-2, the creep behavior of most materials consists of three main stages. The trend of creep rate during each stage is different from the other two stages as shown in Figure 1-3. In general, immediately upon loading, an instantaneous elongation is experienced by the material. This elongation is mainly elastic in nature. When the load is fully

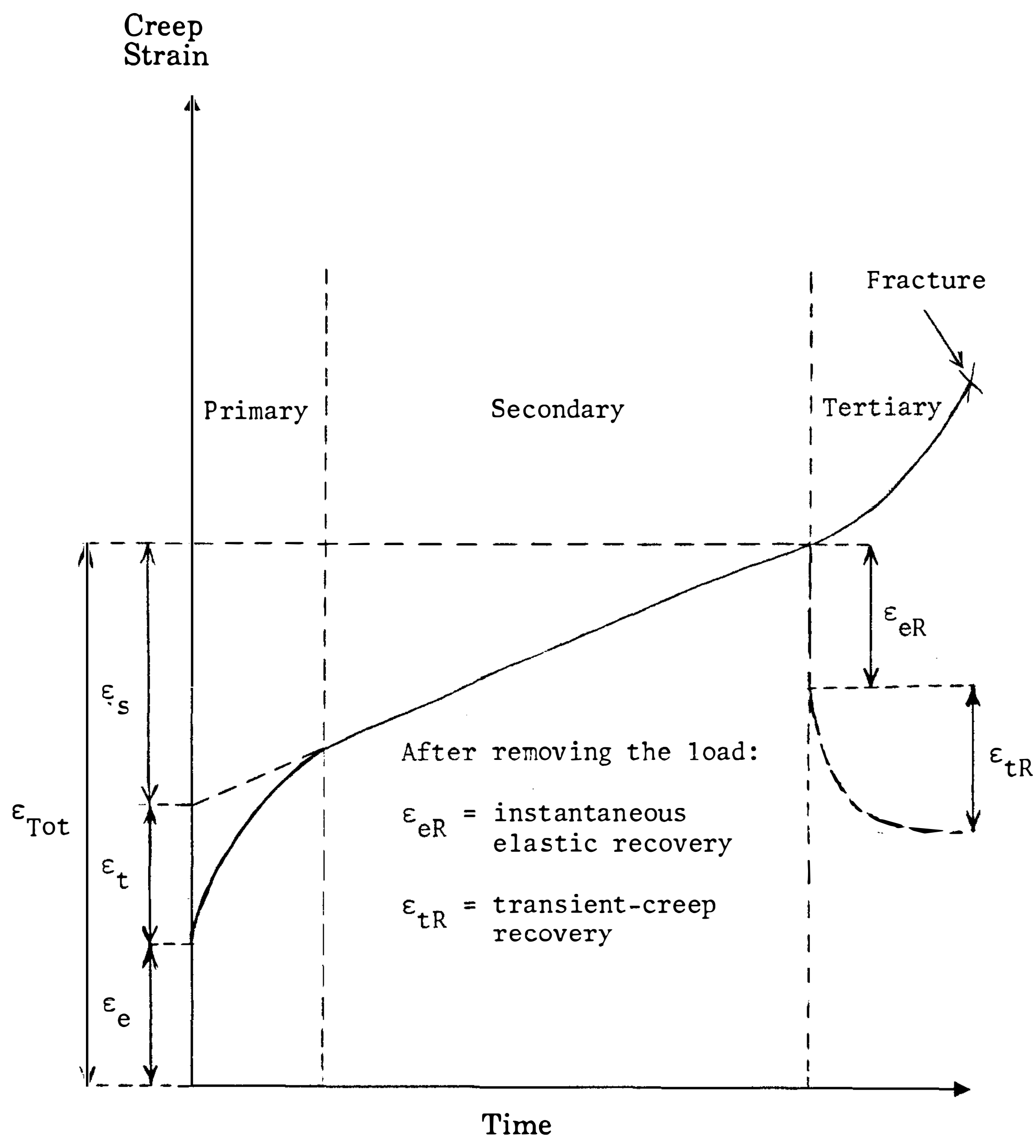

Figure 1-2. Typical creep curve.

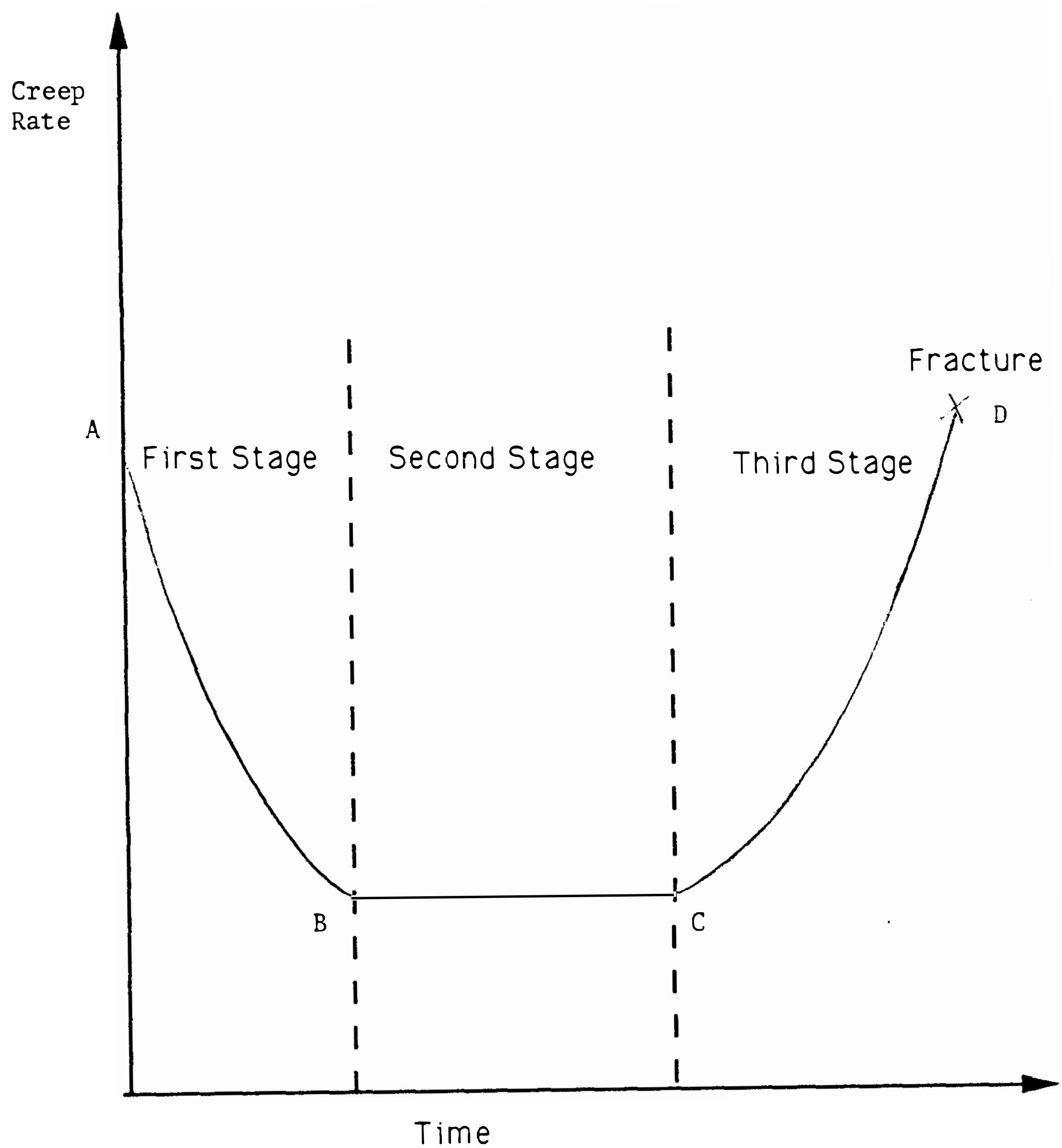

Figure 1-3. Creep rate versus time behavior.

applied (point A), the creep rate is fairly large but gradually decreases with time. This time-dependent creep rate is the main characteristic of the first stage of the creep. This stage is also called primary or transient creep.

The second stage of the creep phenomenon commences when the rate of plastic deformation reaches a constant or steady state value (point B in Figure 1-3). During this stage (from point B to point C in Figure 1-3), the creep rate remains constant. This constant creep rate is the minimum creep rate manifested by the material under the test. The second portion of the creep curve is also referred to as secondary creep, linear creep, or steady state creep.

The third stage creep or tertiary creep, visible in a constant load test but not in a constant stress test, is reached when the creep rate begins to increase in a manner that is usually exponential with time. This stage (from point C to point D in Figure 1-3) eventually ends with the fracture of the material.

It should be noted that the shape of the creep curve depends on the material under consideration and the test conditions. At higher temperatures and/or higher stresses, creep occurs at faster rates. If the specimen is unloaded during the test some of the strain recovers, as shown by the dashed line in Figure 1-2. Therefore, the creep phenomenon includes both permanent and recoverable strain [6].

1.3. Stress-Relaxation Phenomenon

Relaxation is a mechanical phenomenon associated with creep. This occurs as a time-varying decrease in stress in a solid material that is held in a fixed external configuration. In other words, relaxation is the relief of stress by internal creep. If a material is susceptible to creep, it is also susceptible to relaxation. Figure 1-4 shows a schematic relaxation curve. As with creep, relaxation is more common and is manifested at a faster rate at high temperatures [7].

1.4 Creep-Time Analysis

It is important to note that the creep-time relationship allows various material characteristics to be identified. Not only is the fracture time obtained, but also the following information can be identified [8]:

1. the initial elongation on loading;
2. the strain or time corresponding to the end of first and/or second stages of creep;
3. the time spent in the second and/or third stages of creep;
4. the instantaneous creep rate as a function of strain or time the primary creep;
5. the secondary creep rate (this is inversely proportional to for rupture time);
6. the time to exhibit a certain amount of strain for particular stress and temperature levels;

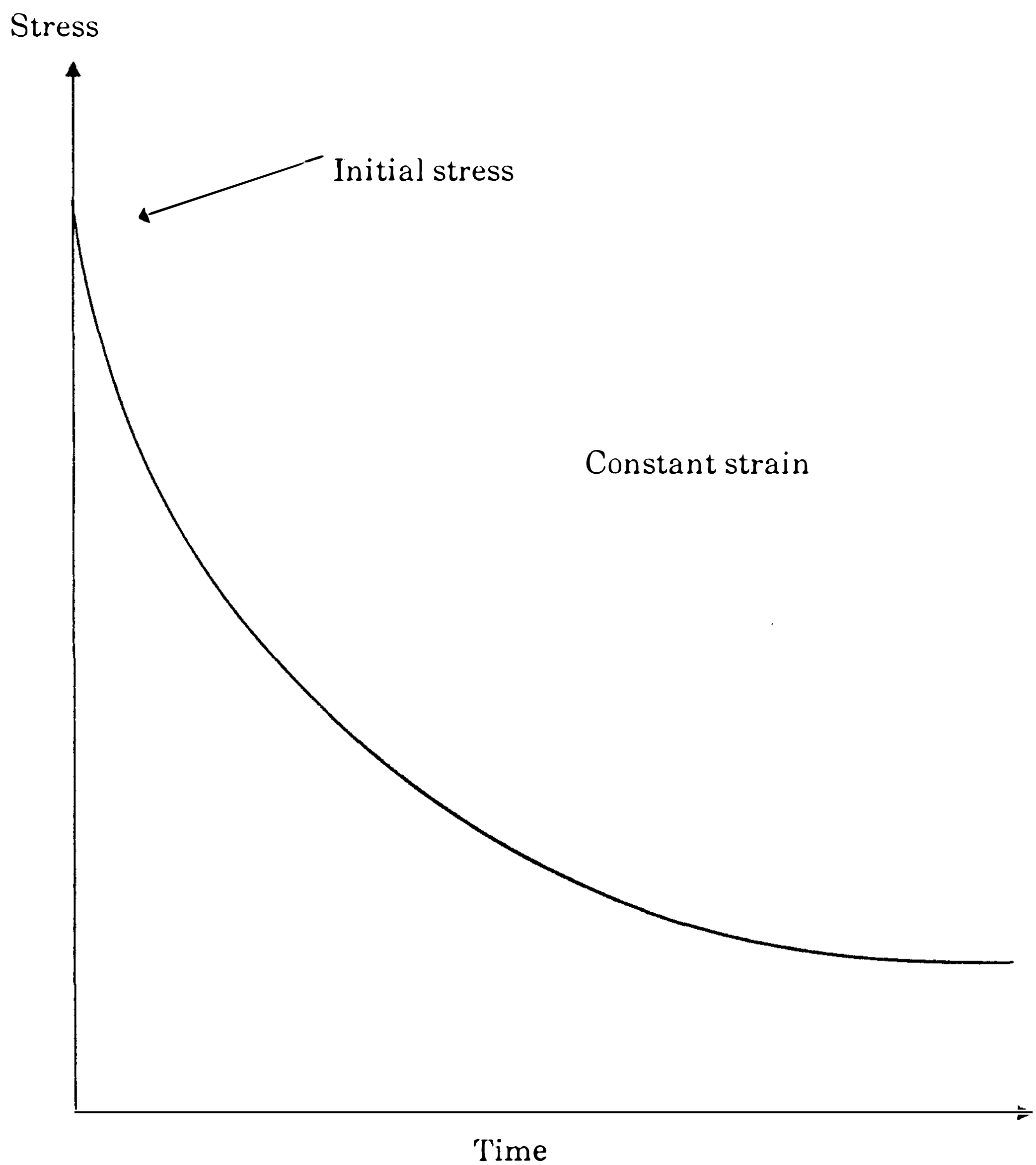

Figure 1-4. Reduction of stress with time due to relaxation phenomenon.

7. data sufficient to allow for the development of an empirical model (functional relationship) describing either various portions of or the entire creep curve.

The following associated considerations are also very important in understanding the basic fundamentals of material behavior [8]:

1. How can creep and rupture behavior be related to crystal structure and microstructure?
2. What factors control the creep-rupture behavior of materials?
3. What pretreatments can be applied to alter materials behavior?
4. How can creep-rupture data for a given material be used to predict the behavior to be expected of related materials?
5. How accurately can data obtained within a given range of test conditions be interpolated and/or extrapolated to other stresses and temperatures?

These questions must be answered with an accuracy and confidence level required by the designers. The answers can be found by extensive studies of material behavior and through the correlation of associated experimental data.

In this work the main interest is in the behavior of secondary creep of nuclear graphite in an irradiation environment.

In examining the experimental data for irradiation-induced creep in nuclear graphite, the general objective of this work, a newly proposed nonlinear empirical equation (a secondary creep-rate model) is studied to determine whether it has any conflict with the short-term irradiation data available for analysis. The results will be compared with those obtained when a linear model is considered.

CHAPTER 2

GRAPHITE

2.1 Graphite Structure [9]

Graphite is an allotropic form of the element carbon. It consists of layers of hexagonally arranged carbon atoms in a planar condensed ring system. These layers are then stacked "vertically" to produce the three-dimensional structure. Within the layers, the chemical bonds are of covalent type whereas between the layers, the bonds are of the Van Der Waals type. The latter type of bond is much weaker than the former one. Considering the stacking arrangements of the layers in graphite, two allotropic forms are distinguished: Hexagonal and Rhombohedral.

The hexagonal graphite is the thermodynamically stable form of graphite when the temperature and pressure are below approximately 2600 K and 60 kbar, respectively. The layers are arranged in an ABAB stacking sequence, as shown in Figure 2-1. The unit cell constants are: $\underline{a}$ = 245.6 pm and $\underline{c}$ = 670.8 pm (pico meter = 10^{-12} meters). The distances $\underline{a}$ and $\underline{c}$ in the graphite crystal are depicted in Figure 2-1. According to the International Committee for Characterization and Terminology of Carbon (ICCTC), "The use of the term Graphite instead of the more exact term Hexagonal Graphite may be tolerated in view of the minor importance of Rhombohedral Graphite, the other allotropic form."

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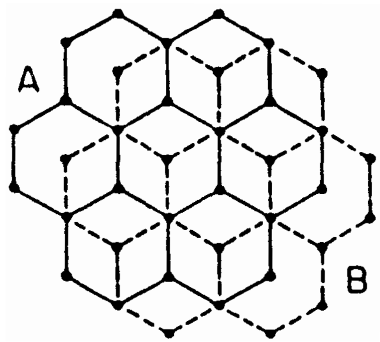
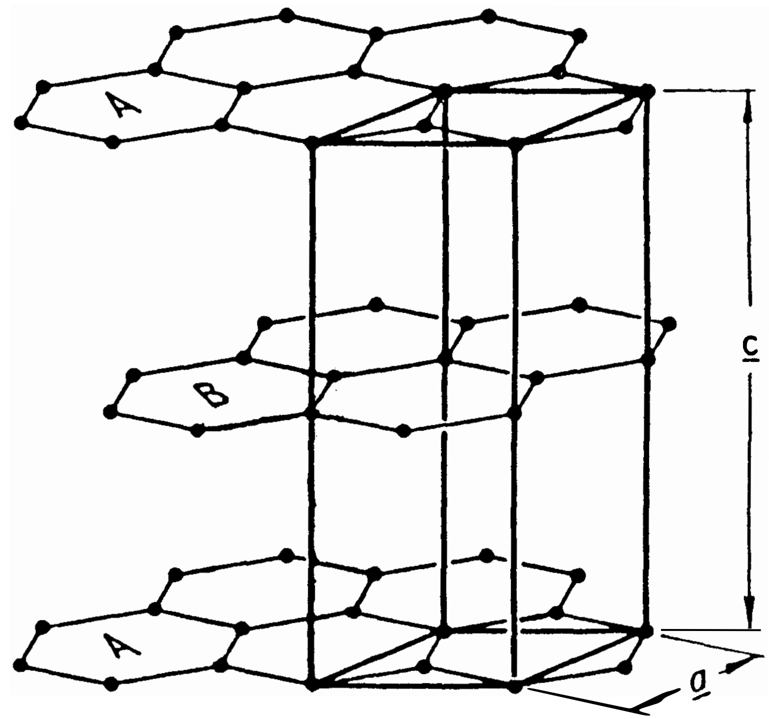




SPACE GROUP: C6/mc(D_{6h}^{4})
UNIT CELL:
$\underline{a}$ = 2.4612 ± 0.0001 A
$\underline{c}$ = 6.7079 ± 0.0007 A
VOLUME = 35.190 A^3
ATOMS PER UNIT CELL = 4
CRYSTAL DENSITY = 2.266 g/cm^3

Figure 2-1. Graphite structure [2].

The Rhombohedral graphite is a thermodynamically unstable form of graphite. The layers are arranged in an ABCABC stacking sequence. The unit cell constants are: $\underline{a}$ = 256.6 pm and $\underline{c}$ = 1006.2 pm. This allotropic form of graphite cannot be isolated in pure form. It is produced by shear deformation of Hexagonal graphite and, on heating above 1600 K, transforms progressively to the hexagonal (ABAB) form. More details on graphite can be obtained from the literature [26].

2.2 Nuclear Graphite

Following the definition of Nuclear Graphite given below, for the sake of brevity the simple term graphite will appear instead of Nuclear Graphite in this work. The following definitions, provided by ICCTC, are quoted directly from reference [9].

> Nuclear Graphite is a Polygranular Graphite material for use in nuclear reactor cores consisting of Graphitic Carbon of very high chemical purity. High purity is needed to avoid absorption of low-energy neutrons and activation of the impurities.
>
> Notes. Besides the absence of neutron absorbing impurities, modern Reactor Graphites are also characterized by a high degree of graphitization and no preferred bulk orientation. Such properties increase the dimensional stability of the Nuclear Graphite at high temperatures and in a high flux of neutrons. The term Nuclear Graphite is often, but incorrectly, used for any Graphite Material in a nuclear reactor even if it serves only for structural purposes.

The terms: "Polygranular Graphite," "Graphitic Carbon," and "graphitization," involved in the above definition, are defined by ICCTC as follows [9]:

Polygranular Graphite:	A Graphitic Material composed of grains which can be clearly distinguished by optical microscopy. From the view point of crystallinity, a Polygranular Graphite is always a Polycrystalline Graphite but not vice versa.
Graphitic Carbon:	Graphitic Carbons are all varieties of substances consisting of the element Carbon in the allotropic form of Graphite irrespective of the presence of structural defects.
Graphitization:	Solid state transformation of thermodynamically unstable Non-Graphitic Carbon into Graphite by thermal activation.

2.3 Peculiarities of Nuclear Graphite

A few peculiarities of graphite are briefly explained in this section. These will help to understand the necessity of having a good knowledge of irradiation-induced creep in graphite.

Graphite has been labeled "the most fascinating nuclear material," and as an old and wry joke amongst people involved in the design of graphite moderated gas-cooled reactors: "The only property that does not change when it is exposed to the neutron irradiation is its color" and some have added that, "that, appropriately, is black" [10].

Like diamond, graphite is crystallized carbon. However, the bonding between the carbon atoms in diamond are all of covalent type and the atoms bond in tetrahedral fashion (four directions in three dimensions) to three nearest neighbors. But, as seen before (Figure 2-1), in graphite, the carbon atoms covalently bond in three directions to three nearest neighbors in the same plane. Although these three-directional covalent bonds are strong in the plane, the atoms can slide by each other (basal slip) due to the weak Van Der Waals binding force between the layer planes. Thus, in a sense, graphite is both harder and softer than diamond [11].

The rest of the current section has been obtained from references [12, 30]. Graphites and carbons, as used in nuclear technology, are:

* synthetic materials
* hallogen gas-purified because of neutronic and oxidation resistance requirements
* The following characteristics must be considered as they significantly affect the physical properties of graphite:
    1. distribution of grain size and shape,
    2. grain orientation,
    3. pore size and shape,
    4. proportion of poorly graphitized carbon, etc.

Unirradiated graphite:

1. can be described as having a nonlinear stress-strain behavior,
2. is reasonably strong but generally fractures at strains as low as 0.2(±0.1)%,
3. has negligible thermal creep for temperatures up to 1800°C,
4. is very resistant to thermal shock (due to low elastic modulus, high thermal conductivity, and low coefficient of thermal expansion (CTE)).

Under irradiation:

1. the material hardens and the stress-strain relationship becomes more linear,
2. the coefficient of thermal expansion does not change very much with neutron fluence in the absence of an applied force (less than 10% for a fluence of up to 10^{24} n/m^2 [30]),
3. the coefficient of thermal conductivity decreases rapidly and drastically to some quasi-stationary value which is lower for lower irradiation temperatures,
4. the material experiences dimensional changes.

At the microscopic level:

1. The changes in physical dimensions are due to the expansion of crystallites in the c-axis direction and their contraction in the a-axis direction.

2. Crystallite growth is due to the formation of interstitials, interstitial clusters, vacancies and the collapse of vacancy lines.

3. The anisotropic growth causes severe shear strains at the crystallite and interparticle boundaries. Initially, the shear strains are accommodated by microcrack closure and by some plastic deformation. Eventually, the microcrack closure is exhausted and boundary fracture is initiated due to the intensified shear strains on the crystallite boundaries. The closure of microcracks and the creation of new cracks are manifested by the material under irradiation. This is illustrated by densification during the microcrack closure and the eventual decrease in density as the internal shear strains are accommodated by new cracking [30].

2.4 Irradiation-Induced Creep

Under an external stress and in an irradiation environment, a graphite specimen undergoes a permanent change in dimensions. This is in addition to the dimensional changes which would occur without stress. Irradiation-induced creep strain is defined as the difference of the dimensional change of the stressed specimen in the direction of the stress and that of the similar unstressed specimen in the same direction.

It has been found that the irradiation-induced creep strain in graphite can be at least an order of magnitude larger than any strain found in graphite in the absence of irradiation.

In other words, if, for example, two identical cylindrical specimens of nuclear graphite are involved in an irradiation-induced creep test, mathematically, the creep definition is:

$$\varepsilon_C = \frac{l'-l_0}{l_0} - \frac{l-l_0}{l_0} = \frac{l'-l}{l_0} \qquad (2.4\text{-}1)$$

where,

ϵ_c = irradiation-induced creep (unit length/unit length)

l_0 = preirradiation length (unit length)

l = postirradiation length of control (unstressed) specimen (unit length)

l' = postirradiation length of creep (stressed) specimen (unit length)

It should be noted that the definition is based on the following assumptions:

1. The specimens have been at the same irradiation temperature.
2. The creep specimen has been kept under a constant uniaxial stress.
3. The specimens have received equal amount of neutron fluence (neutrons/(unit length)^2).
4. The dimensional measurements have been performed at the same hot cell (temperature).

A more practical definition of irradiation-induced creep can be given as:

$$\varepsilon_c = (\frac{\Delta l}{l_o})_{creep} - (\frac{\Delta l}{l_o})_{growth} \qquad (2.4\text{-}2)$$

where

$(\frac{\Delta l}{l_o})_{creep}$ = change in length of creep specimen (unit length/unit length),

$(\frac{\Delta l}{l_o})_{growth}$ = change in length of control specimen (unit length/unit length).

2.5 Technological Significance

Considering the peculiarities of graphite and the definition of the irradiation-induced creep in graphite, the technological significance of the creep phenomenon for this material hardly needs any further explanation. Transfer of heat from the coated fuel particles to coolant, considering the geometry of the graphite core, creates temperature and thermal stress patterns. Moreover, neutron irradiation causes dimensional changes, with varying spatial rates throughout the graphite core. These rates depend on temperature and neutron flux density distributions [12].

Irradiation-induced creep in graphite relaxes the high internal stresses that are developed at locations of large strain gradients. Otherwise, in the absence of creep, these stresses would lead to fracture.

In short, for the structural integrity and dimensional stability of the graphite core, the irradiation-induced creep in graphite must be studied.

CHAPTER 3

EXPERIMENTAL TECHNIQUES [12,13]

The experimental techniques employed in obtaining irradiation- induced creep data are generally of three types: fully instrumented creep tests, restrained shrinkage, and controlled load tests with out-of-reactor strain measurement. This chapter provides a brief description of each method and its advantages and disadvantages.

3.1 Fully Instrumented Creep Tests

A fully instrumented creep test is the most fundamental, but also the most difficult, method for in-reactor creep measurement. In this type of creep test, a single specimen is subjected to a controlled load at a controlled temperature, as the stressed (test) specimen. A similar specimen is kept in the irradiation capsule at the same temperature but under no stress as the unstressed (control) specimen. The irradiation-induced creep, the difference between the strains experienced by the stressed and the control specimens, is recorded as a function of neutron fluence. The irradiation-induced creep tests conducted in the Siloé reactor, Grenoble, France, and in the High Flux Reactor, Petten, The Netherlands, have incorporated this technique.

The advantages of this type of creep experiment are as follows:

1. Strain measurements at short time intervals can be made with high precision (displacements of a few microns can be reliably recorded).
2. The load is known and changeable at will.
3. The temperature can be changed over a limited range.
4. The thermal expansion and stress-strain measurements can be made in situ.

The disadvantages of this technique are listed below:

1. high cost and complexity;
2. limitation to virtually a single specimen per capsule (extremely high cost of the data per specimen);
3. vulnerability of the single test specimen to fracture from an accidental overload;
4. correction requirements for irradiation effects on sensor materials (systematic errors);
5. prohibitive expense for investigating a range of materials under a range of temperatures, flux densities, and stresses (not suitable for obtaining statistical results).

The uncertainty in the absolute value of the steady-state creep coefficient in these measurements could reach ± 25% [13].

3.2 Restrained Shrinkage Tests

This type of experiment is entirely different from the previous one. This technique takes advantage of the differences in the irradiation-induced contraction rates of graphites in the temperature range of 400-1400°C. A dumbbell-shaped tensile specimen, fitted with split cylindrical graphite pads or split sleeves of less shrinkage rate are utilized in this technique. The difference in the contraction rates of the specimen and the pads (or split sleeves) imposes a tensile strain on the specimen and a compressive strain on the restrainers. To stress a specimen in compression, a modified version of the compound specimen (restrained shrinkage assembly) can be used.

The difference in shrinkage between the test specimen and a control specimen (irradiated at the same temperature), measured after the test, determines the irradiation-induced creep under tensile stress. After the irradiation, the measurements must be done to deduce the end-of-life stress (the stress at temperature at the end of the irradiation). This stress can be estimated by heating the specimen assembly to the irradiation temperature and measuring the specimen expansion, and then repeating the test with just the specimen itself. The difference in the thermal strains obtained gives the strain of the specimen at the end of irradiation. The corresponding stress can be obtained from the tensile stress-strain curve. Additional data can be obtained by reirradiating the restrained shrinkage assembly.

This method, developed by the ECN, Petten, The Netherlands, has been used extensively to generate creep data in that laboratory.

The advantages of this type of creep experiment are as follows:

1. No external loading device is needed (self actuating);
2. The experiment is fairly inexpensive;
3. Up to 50 specimens can be included in one capsule; this can provide many results for a range of conditions and materials.

The disadvantages of this technique are listed below:

1. The load on the specimen is not constant.
2. The varying load is only known at the end of life by an indirect out-of-reactor measurement.
3. Data analysis requires some specific creep model established by more refined experiments.
4. The method cannot be used at high fluences due to "turn around" phenomena.
5. This technique is limited at low temperatures (below 500-600°C) due to low shrinkage rates.
6. The cumulative effects of the sources of error could be large.

No formal error analysis has been published, but it has been claimed that an accuracy of ± 20% for the steady-state creep coefficient can be obtained [13].

3.3 Controlled Load Tests with Out-of-Reactor Strain Measurement

This method is an isostress isothermal irradiation-induced creep test which incorporates strings of tensile or compressive specimens together with their matching unstressed (control) companions. Creep strains are determined by measuring the difference of the dimensions of the stressed specimens in the direction of the stress and those of the matching unstressed specimens in the same direction. These measurements are performed out of the reactor after disassembling the irradiation capsule. Repeated encapsulation and reirradiation of the same specimens provide creep strain versus fluence curves.

This type of irradiation technique has been incorporated in the OC-series irradiation experiments at ORNL and in the DISCREET series of experiments at the Euratom Joint Research Center, Petten, The Netherlands.

Since the strain measurements are performed directly in the laboratory, the measuring precision is good. But, since this is done periodically, after accumulation of some fluence, data points for one specimen are measured only at wide fluence intervals. This is the main disadvantage of this technique compared to the creep experiments with continuous strain registration. However, more data points can be obtained after each irradiation interval if several specimens of the same grade of graphite are present in the specimen columns. Finally, the irradiation-induced changes in thermal expansivity and Young's modulus require the strain measurements to be corrected.

The ability to control the load and to incorporate a large number of specimens are the main advantages of this technique.

No formal error analysis for this technique has been performed.

CHAPTER 4

IRRADIATION-INDUCED CREEP EXPERIMENTS AT ORNL [14]

4.1 Characterization and Standardization of Graphite

As one of the gas-cooled reactor programs at ORNL, the high-temperature gas-cooled reactor base-technology program requires the characterization and standardization of graphite. The existing creep data, collected in the 1970's, for a number of graphites of different origins were scattered over a factor of 3 to 5, and the graphites did not correspond to the coarser isotropic graphite grades now being considered for HTGR's. Evaluation of the irradiation-induced creep characteristics of the graphites of interest was among the studies to be performed at ORNL.

The design of a series of irradiation tests, referred to as the OC-series tests, was initiated at ORNL in the mid-seventies. The main objective of this series of tests was to evaluate the creep characteristics at elevated temperatures and to high fast fluences of various graphites of interest to HTGR designers. The other physical/mechanical property data required for the constitutive equations for these graphites were also to be determined.

The Oak Ridge Research Reactor (ORR) was the source of fast neutrons for the irradiation capsules. Specimens of different grades of graphite were exposed to fast neutrons ($E>0.18$ MeV) at temperatures of 600°C and 900°C for accumulated fluences of approximately 4.35×10^{21} neutron/cm^2 and 4.49×10^{21}

neutron/cm^2, respectively. The original plan was to also consider temperature of 1250°C and reach accumulated fluences of at least 8 x 10^{21} neutron/cm^2 (8 x 10^{25} neutron/m^2), the full design fluence for the HTGR. This required the design and construction of a flux-trap irradiation facility in the ORR.

4.2 OC-Series Irradiation Capsules [3,14]

The OC-series irradiation capsules were utilized to perform creep experiments of the type explained in Section 3.3 (Controlled Load Tests With Out-of-Reactor Strain Measurement). The general features of the first capsule, OC-1, which are shared by OC-2, OC-3, OC-4, and OC-5 capsules, are explained here. The nominal specimen temperature for OC-1, OC-3, and OC-5 was 900°C and that for OC-2 and OC-4 was 600°C. The cross-sectional views of the in-core portion of the capsule are shown in Figures 4-1 and 4-2.

The OC-1 capsule was designed to irradiate a few graphite specimens at a constant temperature and under two constant compressive stress levels. The capsule contained two test columns and two control columns as indicated in Figure 4-1. The specimens in each column had identical companions in a control column. The test columns were designated as the east and west columns and the control columns as north and south columns.

Some detailed features of the capsule which were used in the final creep analysis tests are summarized in the following subsections:

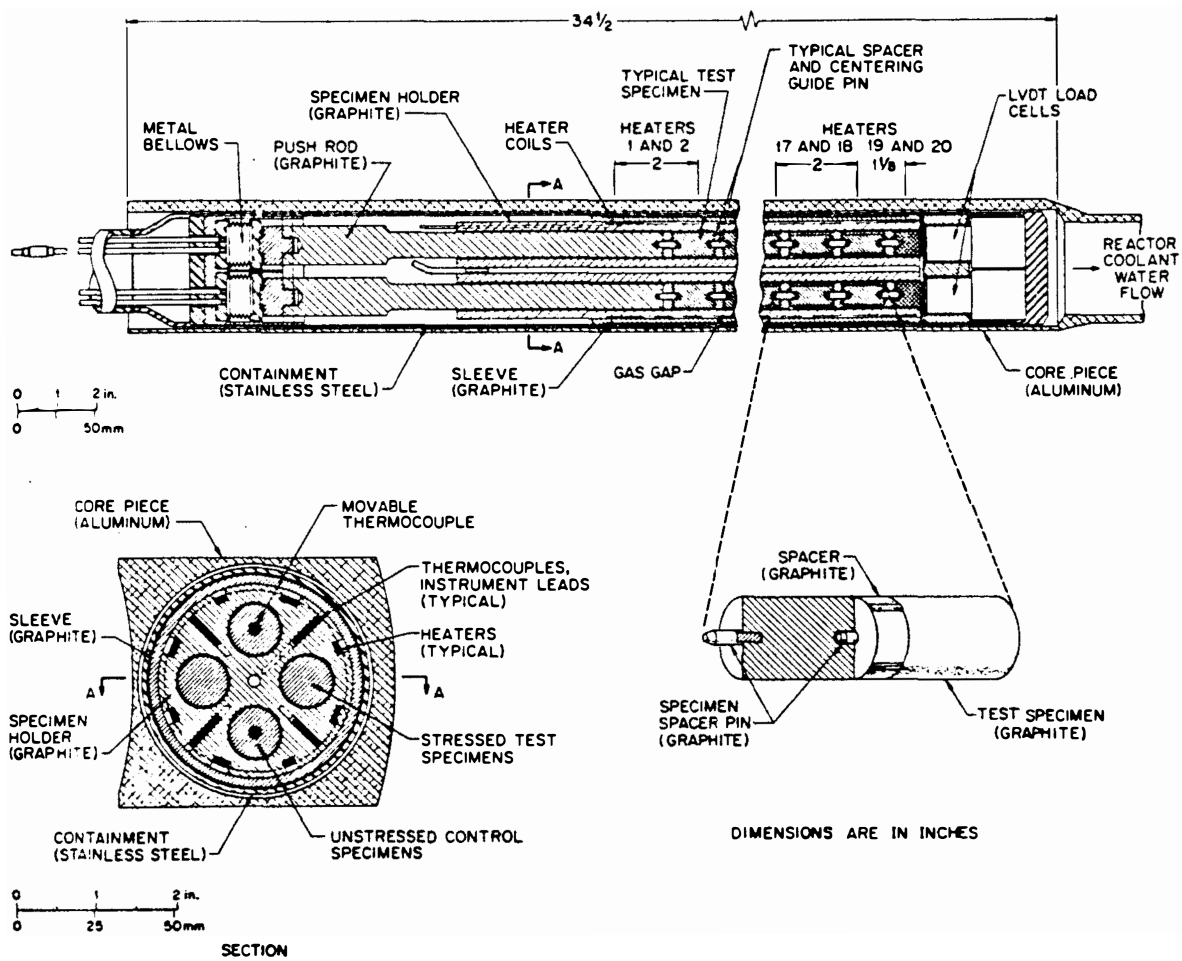


Figure 4-1. A cross-sectional view of the in-core portion of the ORR capsule OC-1 showing the stressed columns.

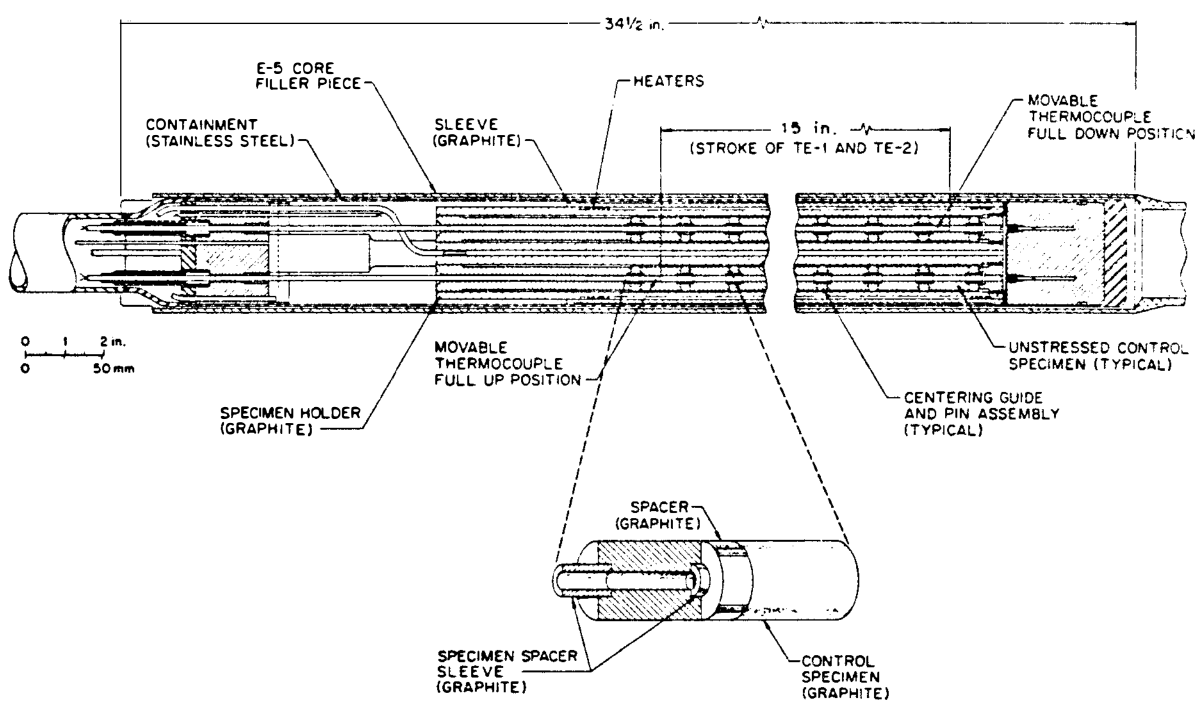


Figure 4-2. A cross-sectional view of the in-core portion of the ORR capsule OC-1 showing the unstressed columns.

4.2.1 Specimen Columns

Total number of stressed (test) specimens = 28

Total number of unstressed (control) specimens = 28

Number of stressed (test) columns = 2

Number of unstressed (control) columns = 2

Number of specimens in each column = 14

4.2.2 Specimen Geometry and Dimensions

Geometry = Cylindrical

Diameter = 15.24 mm (0.6 in.) for the low-stress specimens,

12.44 mm (0.49 in.) for the high-stress specimens

Length = 25.4 mm (1.0 in)

The stressed specimens each have shallow holes in each end for connection to one another and centering by the use of small pins and spacers, respectively, as indicated in Figure 4-1. The assembly of the control columns is very similar to that of the stressed columns except for a small-diameter cylindrical hole along the axis of each column as the passage for a moveable thermocouple (MTC) as depicted in Figure 4-2.

4.2.3 Compressive Stress Levels

1. 13.79 MPa (2000 psi), applied to 22 of the specimens;

2. 20.68 Mpa (3000 psi), applied to 6 of the specimens in the two stressed columns. These specimens had smaller geometrical cross sections than those in (1).

In the OC-1 experiment, the first creep experiment conducted at 900°C, the compressive stresses were achieved by pressurized metal bellows placed on the top of the east and west columns. The bellows were pressurized with helium gas to 5.89 Mpa (854 psig), providing a load of 2515 N (565.4 lb). This force was transmitted through a push-rod and sensed by an LVDT load cell. This device was designed to measure up to 3115 N (700 lb) at 480°C. Even if the load cell was expected to suffer radiation damage and decalibration at exposures exceeding 3 x 10^{20} neutron/cm^2 (E>0.18 MeV), this provided valuable information in regard to the transmission of force through the specimen column during the initial stages of capsule operation. In this experiment, a sticking or binding occurred in one of the stressed columns which resulted in an overloading of the specimens in that column. Data from those specimens will not be used in the creep analysis.

The load measuring system was modified for the subsequent experiments. This was done to prevent any sticking or binding in the load train which induced uncertainty and to avoid the decalibration experienced in the OC-1 experiment. In the new load measuring system a bellows was put at the opposite end of each loaded column. To verify the amount of load and its transmission through the specimen columns, every day, these new bellows were pressurized to push the loaded columns upward. Each new bellows upon reaching a pressure slightly exceeding that of the upper bellows would break an electrical contact indicating the amount of load and its transmission through the stressed column.

The specimen columns were in a cylindrical graphite specimen holder separated from a graphite sleeve by a gas gap. The whole assembly was in a stainless steel containment, as shown in Figures 4-1 and 4-2.

4.2.4 Heat Source

Gamma heating was the major source of thermal energy in the specimens. In order to achieve the required nominal constant temperature on the surface of the specimens, the gas gap surrounding the specimen holder was changed in different axial steps along the test section of the capsule (0.508 m (20 in.)). This is due to the fact that gamma heating profile in the reactor core is not uniform. A typical gamma-heating profile of the ORR core [39] is depicted in Figure 4-3. In addition to the gamma heating, Ohmic heating was also provided to the specimens for more temperature control. This was accomplished by wrapping high resistance heater wires around the specimen holder.

It should be noted that because of the upward shifting of the gamma heating profile, due to core aging and shifting of control rods, a capsule later designed for 1200°C experiment was planned to be shifted upward by about

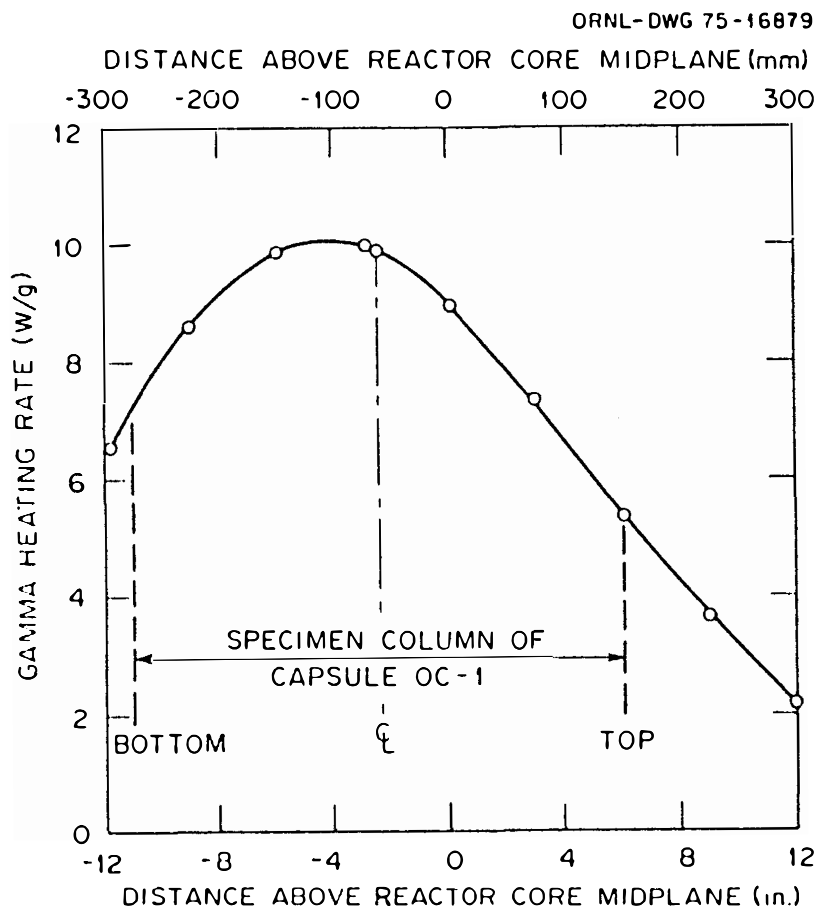


Figure 4-3. A typical gamma-heating profile of the ORR core (position E-5).

76 mm in order to keep the same section of the capsule exposed to the maximum gamma heating rate. Otherwise, a "uniform" temperature distribution along the surface of the specimens could not be achieved. More information on the high-temperature capsule, the sources of gamma heating, as well as the determination of the upward shift mentioned here can be found in reference [15].

4.2.5 Temperature Measurement

Temperature of the specimens is measured by two different sets of thermocouples (TC's): moveable thermocouples (MTC's) and fixed thermocouples (FTC's).

Two MTC's, one for each control specimen column, are responsible for measuring the temperature of the control specimens that should be very close to the temperature of the corresponding stressed specimens (of the same elevation). This is due to the four-fold symmetry incorporated in the design and construction of the irradiation capsules. Each MTC moves through the axial hole of its corresponding column and reports its elevation in the column and the associated temperature to the Oak Ridge Research Reactor Data Acquisition and Control System (ORRDACS).

The FTC's, located in the graphite specimen holder at different axial locations, report the temperatures of their locations to ORRDACS. The decalibration of TC's, considering their type, is not of any concern during the conduction of each experiment [40, August 1990]. A computer algorithm, written by the Instrumentation and Control Division of ORNL, "deduces" the temperature of the stressed specimens from these reported temperatures.

The temperatures reported by MTC's while "scanning" the control columns (performing the so called "z-trace") and those reported by the two FTC's for the zone being traced were utilized to make corrections to the Ohmic heating. These corrections were required to keep the specimens at the nominal constant design temperature of 900°C. The adjustment to each heater power was performed automatically or by the experiment operator after each z-trace by making corrections to the setpoint value associated with that heater. This and similar corrections are based on the differences between the mean values of MTC reports and the nominal temperature. The z-trace for the control columns was performed, on average, every twenty-four hours. Each zone takes about five minutes to be scanned. Five temperature measurements (MTC reports) are recorded for each zone of each control column. These temperatures are averaged and the obtained value is the best estimate of the temperature of the zone under consideration. After each complete z-trace, the MTC's are moved to the top of the capsule to be kept far from the high flux region of the reactor core until the following z-trace time. This prevents the MTC's from being considerably damaged or decalibrated by neutron bombardments. The decalibration of these TC's, considering their type, is not of any concern during the conduction of each experiment [40, August 1990]. More detailed description of the z-trace and setpoint adjustment and the roles of MTC's and FTC's are included in Chapter 5.

Figure 4-4 depicts the enlargement of the axial cross sections of the test columns and the control columns. The zone numbers, heater numbers, the names of the FTC's, and the names of the MTC's are also indicated in this figure. Each zone has two heaters and two FTC's, except for zone number five which has five FTC's. The FTC's designated T11A, T27A, and T28A were installed to monitor other temperatures of interest. For more details, the instrument application diagram for OC capsules, reference [16], can be consulted.

The number and characteristics of the TC's are summarized below:

<u>MTC's</u>:

MTC's are 3.2-mm-diam. (1/8-in.) stainless-steel-sheathed Chromel vs. Alumel thermocouples;

One MTC is installed in each control column;

Each MTC can be moved through a 0.413 m ($16\frac{1}{4}$ in.) stroke;

The speed is 0.83 mm/s (2 in./min).

TC positions can be controlled to less than ±3.2 mm (±⅛ in.).

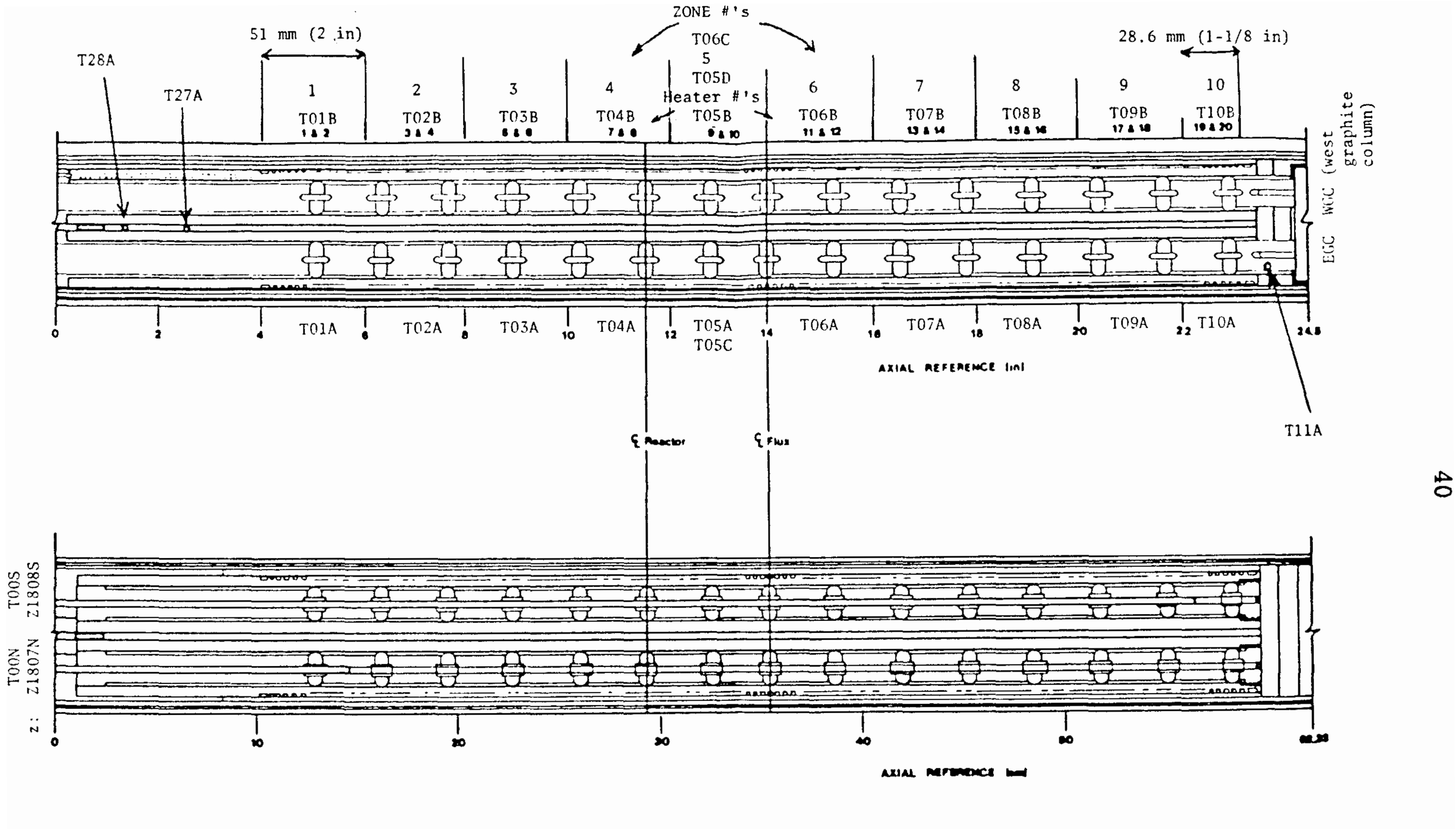


Figure 4-4. 900 °C irradiation creep capsule test specimen and control specimen axial cross section enlargement.

FTC's

FTC's are 1.6-mm-diam. (1/16-in.) stainless-steel-sheathed MgO-insulated Chromel vs. Alumel thermocouples; 28 FTC's are involved of which 24 are located within the graphite specimen holder close to the test specimens at various elevations.

It was required to maintain a ±10°C temperature control which corresponds to ±3% change in apparent creep coefficient as indicated in the literature [12].

4.2.6 Flux Measurements [17]

To measure the neutron flux along the capsule, flux monitors were put inside the thermocouple grooves (in the graphite specimen holder) at different axial and azimuthal positions. The monitors are made of an approximately 25-mm long segment of 1.6-mm stainless-steel tubing. Various monitor wires are contained in each tube.

For the OC-2 experiment (a 600°C experiment with basically the same design as the OC-1 experiment), the time-averaged total neutron fluxes and the time-averaged fast neutron fluxes (E>0.18 MeV) were calculated as discussed below.

The experiment involved 20 dosimeters at five axial and four azimuthal positions. Monitor wires made of Fe, Ti, V-Co, and V-Fe were contained in stainless-steel tubes. The flux magnitudes were computed by using the activities resulting from the following nuclear reactions.

$^{58}Fe\ (n,\gamma)^{59}Fe$ - total flux,

$^{59}Co\ (n,\gamma)^{60}Co$ - total flux,

$^{46}Ti\ (n,p)^{46}Sc$ - fast flux,

$^{54}Fe\ (n,p)^{54}Mn$ - fast flux.

The average flux magnitude at each axial position was obtained by computing the arithmetic average of the fluxes obtained at the corresponding four azimuthal positions. Then, a least-squares fit was performed to obtain a third degree polynomial with two different sets of coefficients for the total flux and the fast flux. For more details, reference [17] can be consulted.

The accumulated fast-neutron fluence (E>0.18 MeV) at the E-5 position of ORR during one cycle of the reactor (about 55 days) is about 1.0×10^{21} n/cm^2. To achieve an accumulated fast neutron fluence of about 8.0×10^{21} n/cm^2, the full design fluence of an HTGR, a total residence time (in the operating ORR) of about 15 months was required.

A summary of OC-series experiments that were performed at ORNL is presented in Table 4-1.

Table 4-1. A Summary of the OC-Experiments Performed at ORNL

Experiment	Nominal Design Temperature (°C)	Gross Irradiation Duration	Peak Accumulated Fast Fluence (n/cm^2, E>0.18 MeV)	Reactor Power (MW)
OC-1	900	April 1, 1976- May 22, 1976 (1139 hr.)	1.3×10^{21}	30
OC-2	600	June 30, 1978- October 15, 1978 (2 ORR cycles) (110 days)	2×10^{21}	28
OC-3	900	Feb. 28, 1979- July 8, 1979 (2 ORR cycles)	3.2×10^{21} $((1.3+1.9) \times 10^{21})$	*
OC-4	600	Nov. 25, 1980- Aug. 20, 1981 (2 ORR cycles)	4×10^{21} $((2+2) \times 10^{21})$	*
OC-5	900	Dec. 17, 1981- March 8, 1982 (64.6 full-power days (fpds) or 46,521 MW(h) of irradiation)	4.45×10^{21} $((3.2+1.25) \times 10^{21})$	30

*Reactor power varied during this period.

CHAPTER 5

EXAMINATION AND ANALYSIS OF THE EXPERIMENTAL DATA

This chapter explains the way that experimental data were recorded and then read and the procedures followed to critically examine and analyze the temperature data.

5.1 Data Acquisition and Control System

A Digital Equipment Corporation (DEC) PDP 11/40 computer with the required ancillary equipment was employed to operate the capsule heaters and monitor and record the data from the experiment. The thermocouple readings were related to the specimen temperatures by various algorithms developed by the I&C Division of ORNL. This permitted the computer to adjust the heaters to maintain the required temperatures. The ORR Data Acquisition and Control System (ORRDACS) operated successfully with data logging, data processing, and control and alarm functions. The periodic listing of all experiment parameters being monitored was performed automatically. This listing and the demand logs of any of the experiment parameters as required by the experiment operators provided valuable and essential data bases for the operation and monitoring records of the experiments [14,18].

5.2 Experimental Databases

The experimental data were recorded by ORRDACS with a density of 800 bits per inch (BPI) on about 200 magnetic tapes. The data were written on these tapes by a DEC PDP 11/40 computer in free format.

There are two different kinds of databases on the ORRDACS tapes: 128-point database and 600-point database. These databases contain the reports made by the sensors involved in the experiment(s) at ORR. The data recorded before 1979 are in 128-point database. The ORRDACS magnetic tape record format for these databases are shown in Figure 5-1 [19].

5.3 Reading of the ORRDACS Data Tapes and Their Translation

As the first major step toward performing analysis on the data obtained from the OC-series experiments, devising an efficient procedure to read the experimental data from the ORRDACS magnetic tapes turned out to be a very time-consuming task. Considering the vast amount of data to be read, the extensive data analysis procedures to be employed, the relatively low speed of minicomputers for input/output operations and number processing, involved in the required extensive statistical analysis, it was decided to invoke a mainframe computer to perform the required tasks.

The IBM mainframe computer at X-10 was chosen to read the experimental data from the ORRDACS magnetic tapes. This required a bit-pattern conversion from the DEC PDP 11/40 formats (Radix-50 and ASCII)

ID	RECORD CONTENTS	LENGTH (BYTES) 12-Pt. DB	600-Pt. DB	TYPE
1	RECID (record unique ID number)	1	1	INTEGER*2
	Spare	1	1	
	TIME (time record was logged)	8	8	CHARACTER*1
	DATE (date record was logged)	9	9	CHARACTER*1
	Spare	1	1	
	PNTNUM (number of points used)	2	2	INTEGER*2
	MAXPNT (max. no. of pt.'s allowed in the system)	2	2	INTEGER*2
	EXPNAM (name of exp. with which each point is associated)	512	1200	INTEGER*2
	Record padding	508	1196	CHARACTER*1
2	RECID	1	1	INTEGER*2
	Spare	1	1	
	TIME	8	8	CHARACTER*1
	DATE	9	9	CHARACTER*1
	Spare	1	1	
	PTNAME (point names in RAD50)	1024	2400	REAL*4
3	RECID	1	1	INTEGER*2
	Spare	1	1	
	TIME	8	8	CHARACTER*1
	DATE	9	9	CHARACTER*1
	Spare	1	1	
	ICHAN (gain and chan. codes)	512	1200	INTEGER*2
	PNTFLG (flag word)	512	1200	INTEGER*2
4	RECID	1	1	INTEGER*2
	Spare	1	1	
	TIME	8	8	CHARACTER*1
	DATE	9	9	CHARACTER*1
	Spare	1	1	
	ALPHSQ (aLpha sequence table)	512	1200	INTEGER*2
	SENSOR (sensor type)	512	1200	INTEGER*2
5-10	Reserved for future database records			
11	RECID	1	1	INTEGER*2
	Spare	1	1	
	TIME	8	8	CHARACTER*1
	DATE	9	9	CHARACTER*1
	Spare	1	1	
	RDATA (real data values)	1024	2400	REAL*4
12	RECID	1	1	INTEGER*2
	Spare	1	1	
	TIME	8	8	CHARACTER*1
	DATE	9	9	CHARACTER*1
	Spare	1	1	
	IDATA (raw data values)	512	1200	INTEGER*2
	PNTFLG (flag word)	512	1200	INTEGER*2
13-20	Reserved for future records			

Figure 5-1. ORRDACS magnetic tape record format for 128-point and 600-point databases [19].

to the IBM format (EBCDIC). A computer program in IBM-Assembly and FORTRAN-IV had already been written for this purpose [20], but the outputs of some runs (on sample data) revealed that the program needed some modifications. These modifications are explained in Section 5.4.

As a sample of data for reading, a portion of the OC-2 experimental data was obtained from the Instrumentation and Control (I&C) Division of ORNL [19]. The contents of the magnetic tape obtained were the copies of 6 original data tapes. The data were copied on the target tape with a density of 800 bits per inch (BPI). The contents of this data tape were composed of 128-point data bases. Examination (reading) of the beginning portion of the OC-2 data tape on the IBM 370 computer at X-10 indicated that the data acquisition and recording for the OC-2 experiment commenced at 13:34:28 on June 30, 1978. One hundred and seventeen out of the then 128 channels of the ORRDACS were utilized to send signals from sensors to the computer. Data were recorded every 5 minutes. Each complete set of data, as was previously shown in Figure 5-1, was composed of 20 records, of which, records 5-10 and 13-20 were reserved for future use. The record size for the 128-point database is 1044 bytes and that for the 600-point database is 2420 bytes. To facilitate the characterization of the experimental points, channels, sensors, and also to show typical reported numerical values, the contents of a typical complete data set for OC-2 experiment are arranged and shown in Table 5-1. The explanation for each column in this figure is given below.

Table 5-1. A Typical Complete Data Set of the 128-Point Database (for OC-2) Recorded at 19:14:16 on 30-Jun-78.

Seq No.	Point Name	Gain and Chan. Code	Flag Word	Alpha Seq. No.	Sensor Type	Real Data	Raw Data
1	$$$$$	-12288	97	1	V0	0.0	0
2	T01A	-16381	511	104	T2	0.5297463E 03	3398
3	T01B	-16380	511	103	T2	0.5271519E 03	3380
4	T02A	-16379	511	114	T2	0.5231160E 03	3352
5	T02B	-16378	511	76	T2	0.5130256E 03	3282
6	T03A	-16377	511	115	T2	0.4954360E 03	3160
7	T03B	-16376	511	39	T2	0.4913982E 03	3132
8	T04A	-16375	511	74	T2	0.4795701E 03	3050
9	T04B	-16374	10751	40	T2	0.4584968E 03	2904
10	T05A	-16373	511	41	T2	0.4680254E 03	2970
11	T05B	-16372	511	42	T2	0.4665820E 03	2960
12	T06A	-16368	511	43	T2	0.4544531E 03	2876
13	T06B	-16367	511	44	T2	0.4628286E 03	2934
14	T07A	-16366	511	45	T2	0.4579192E 03	2900
15	T07B	-16365	10751	46	T2	0.4321963E 03	2722
16	T08A	-16364	511	47	T2	0.4564751E 03	2890
17	T08B	-16363	511	48	T2	0.4596521E 03	2912
18	T09A	-16362	511	49	T2	0.4720667E 03	2998
19	T09B	-16361	10751	50	T2	0.4602297E 03	2916
20	T10A	-16360	511	51	T2	0.4960129E 03	3164
21	T10B	-16359	511	52	T2	0.4916865E 03	3134
22	T00N	-16383	353	53	T2	0.5842148E 03	3776
23	T00S	-16382	353	54	T2	0.5914294E 03	3826
24	Z1807N	4140	353	55	Z1	0.1527100E 02	2502
25	Z1808S	4141	353	56	Z1	0.8728027E 01	1430
26	.TREF1	-12259	373	57	T1	0.2926997E 02	1208
27	P1703D	1280	427	58	P1	-0.1000000E 01	-1
28	P1703H	1024	427	59	P1	-0.1000000E 01	-1
29	P1704D	1792	427	78	P2	-0.1000000E 01	-1
30	P1704H	1536	427	116	P2	-0.1000000E 01	-1
31	P1705D	2304	427	117	P3	-0.1000000E 01	-1
32	P1705H	2048	427	60	P3	-0.1000000E 01	-1
33	P1706D	2816	299	73	P4	-0.1000000E 01	-1
34	P1706H	2560	299	66	P4	-0.1000000E 01	-1
35	P1805D	0	427	106	P1	-0.1000000E 01	-1
36	P1805H	256	427	107	P1	-0.1000000E 01	-1
37	P1806D	512	427	65	P1	-0.1000000E 01	-1
38	P1806H	768	427	108	P1	-0.1000000E 01	-1
39	F1812	3072	299	109	F1	-0.1000000E 01	-1
40	I01	0	321	94	J1	0.6789339E 00	695
41	I02	770	321	110	J2	0.8317977E 00	851
42	I03	512	321	111	J3	0.1000000E 01	1022
43	I04	768	321	105	J4	0.4018843E 00	411
44	I05	1	321	112	J5	0.9090542E 00	930
45	I06	257	321	113	J6	0.6483464E 00	663
46	I07	513	321	61	J7	0.3619403E 00	370
47	I08	769	321	27	J8	0.1000000E 01	1022
48	I09	2	321	28	J9	0.3593398E 00	367
49	I10	258	321	62	JA	0.9116648E 00	933
50	J01	-28640	353	29	J1	0.105971oE 04	2532
51	J02	-28639	353	30	J2	0.4522168E 03	1076
52	J03	-28638	353	63	J3	0.1515080E 04	3620
53	J04	-28637	353	31	J4	0.6033386E 03	1438
54	J05	-28636	353	32	J5	0.2318242E 04	5516
55	J06	-28635	353	64	J6	0.2263412E 04	5408
56	J07	-28634	353	33	J7	0.9492109E 03	2240
57	J08	-28633	353	34	J8	0.1842101E 04	4356
58	J09	-28632	353	35	J9	0.2032437E 03	482

Table 5-1. (continued)

Seq No.	Point Name	Gain and Chan. Code	Flag Word	Alpha Seq. No.	Sensor Type	Real Data	Raw Data
59	J10	-28631	353	36	JA	0.1105175E 04	2592
60	OC1BKU	768	395	378	BK	0.1000000E 01	-1
61	P1703	-12237	511	38	P1	0.7375488E 03	6042
62	P1704	-12240	511	68	P2	0.7392578E 03	6056
63	P1705	-12236	511	67	P3	0.8105469E 03	6640
64	P1706	-12239	511	79	P4	0.8029785E 03	6578
65	P1504	-12233	511	69	PO2	0.7626953E 03	6248
66	P1503	-12234	511	70	P1	0.7590332E 03	6218
67	REAPWR	53	483	22	JBV	0.3032048E 08	5000
68	P1814	-12238	511	23	P5	0.5725098E 02	4690
69	STOON	514	320	2	I1	0.0	0
70	STOOS	514	320	3	I1	0.0	0
71	T04SET	514	320	95	J4	0.4790000E 03	0
72	T03SET	514	320	85	J3	0.4950000E 03	0
73	PWRWDG	3840	427	4	MO	-0.1000000E 01	0
74	F1813	47	353	5	F1	0.1420898E 03	1164
75	T27A	-16357	353	96	T2	0.9327898E 02	426
76	F1803	42	353	84	I1	0.1108398E 03	454
77	T28A	-16356	353	6	I1	0.4445734E 02	106
78	NUMHRS	514	320	7	T2	0.2040000E 03	0
79	STDATE	514	320	72	T2	0.7613412E 07	0
80	T11A	-16358	353	86	T2	0.1662454E 03	910
81	T06C	-16369	353	8	T2	0.4570527E 03	2894
82	T05D	-16370	353	9	J2	0.4631172E 03	2936
83	T05C	-16371	353	71	J1	0.4818782E 03	3066
84	T02SPT	514	320	87	J3	0.6000000E 03	0
85	T01SPT	514	320	10	J4	0.6000000E 03	0
86	T03SPT	514	320	11	J5	0.6000000E 03	0
87	T04SPT	514	320	83	J6	0.6000000E 03	0
88	T05SPT	514	320	82	J7	0.6000000E 03	0
89	T06SPT	514	320	97	J8	0.6000000E 03	0
90	T07SPT	514	320	88	J9	0.6000000E 03	0
91	T08SPT	514	320	12	JA	0.6000000E 03	0
92	T09SPT	514	320	13	P3	0.8076172E 03	0
93	T10SPT	514	320	81	J1	0.5280000E 03	0
94	P1505	-12232	511	98	J2	0.5160000E 03	6616
95	T01SET	514	320	89	J5	0.4680000E 03	0
96	T02SET	514	320	14	J6	0.4590000E 03	0
97	T05SET	514	320	15	J7	0.4580000E 03	0
98	T06SET	514	320	99	J8	0.4600000E 03	0
99	T07SET	514	320	9	J9	0.4720000E 03	0
100	T08SET	514	320	16	JA	0.4940000E 03	0
101	T09SET	514	320	17	I1	0.1000000E 02	0
102	T10SET	514	320	100	I1	0.2000000E 02	0
103	CAULIM	514	320	91	P4	0.8005371E 03	0
104	ALMLIM	514	320	18	P1	-0.1000000E 01	0
105	P1506	-12231	511	19	P1	-0.1000000E 01	6558
106	P1503D	3328	427	101	P2	-0.1000000E 01	-1
107	P1503H	513	427	92	P2	-0.1000000E 01	-1
108	P1504D	3584	427	20	P3	-0.1000000E 01	-1
109	P1504H	769	427	21	P3	-0.1000000E 01	-1
110	P1505D	1	427	102	P4	-0.1000000E 01	-1
111	P1505H	1025	427	93	P4	-0.1000000E 01	-1
112	P1506D	257	427	80	F1	-0.7324219E 00	-1
113	P1506H	1281	427	75	F1	0.1318359E 03	-1
114	F1802	43	353	77	DO	0.1000000E 01	-6
115	F1804	46	353	24	MU	0.1000000E 01	1080

Table 5-1. (continued)

Seq No.	Point Name	Gain and Chan. Code	Flag Word	Alpha Seq. No.	Sensor Type	Real Data	Raw Data
116	OCSBDO	512	267	25		0.0	-1
117	OCSBMU	256	267	26		0.0	0
118		0	0	0		0.0	9629
119		24151	0	24151		0.0	16512
120		3661	0	3661		0.0	0
121		26877	0	26877		0.0	17720
122		-16216	0	-16216		0.0	25376
123		26877	0	26877		0.0	17720
124		-16176	0	-16176		0.0	-12160
125		26877	0	26877		0.0	17738
126		-16136	0	-16136		0.0	-23808
127		26877	0	26877			17736
128		-16096	0	-16096			-16736

Seq. No.: Sequence number for sensors.

Point Name: Name of the sensor.

Gain and Channel Code: A code used for each channel.

Flag Word: A code associated with each point name.

Alpha Sequence Number: A sequence number for a point name.

Sensor Type: Type of sensor.

Real Data: The actual data.

Raw Data: The data before conversion.

The point names of interest were the ones associated with temperature measurements (sensor type of T2) and the setpoints (the point names ending with "SP" and corresponding to sensor types starting with "J") and the values (Real Data) associated with them.

5.4 Modifications to Data-Reading Program

In Winter 1987, some software problems were experienced which called for conduction of a "facelift" on the statements of the IBM Job Control Language (JCL) and the FORTRAN-IV program/subroutines which were being used for reading the contents of the data tape on X-10 computers. This was required considering the fact that the program/subroutines had been written in FORTRAN-IV, an old dialect of the FORTRAN language, which necessitated having access to an old in-house developed special IBM compiler/system library. This non-standard compiler was no longer in use. It was desired to have an efficient computer code for reading and analyzing the vast amount of experimental data available.

Having consulted the applications/systems consultants at the Computing and Telecommunications (C&T) Division of ORNL and The University of Tennessee Computing Center (UTCC) at Knoxville, it was decided to modify the old program and the required JCL statements. By replacing the LOGICAL statements of the old code with the CHARACTER statements of FORTRAN-77 and by performing some other changes to the code and its JCL, the modified program was successfully test run on the IBM 3090 at UTCC [21]. Before reading the data tape, the density of its contents had to be changed from 800 BPI to 1600 BPI or 6250 BPI because the tape drives for 800 BPI tapes were no longer in use at UTCC. For this reason, the contents of the OC-2 sample data tape were copied onto another tape with a density of 6250 BPI.

Running the new program, included in Appendix B, and reading the whole contents of the 6250-BPI data tape revealed that there were data for just 20 days. The data on that tape started on June 30, 1978, and ended on July 20, 1978. There were 5517 different times recorded. It is noted that the complete experimental data for the OC-2 experiment was recorded from June 30, 1978, through October 15, 1978, (for about 110 days). The 20-day data available on the data tape were sufficient for performing some preliminary data analysis and representing some portion of the experimental data graphically [41]. It should be noted that the remaining portion of the OC-2 data was not available for analysis and besides performing temperature analysis for OC-3 and OC-4 experiments were of main interest (each being the second experiment at 900°C and 600°C, respectively.

5.5 Data Analysis

Having performed preliminary partial data scanning analysis on a portion of OC-2 data, experimental data for OC-3 and OC-4 were obtained for temperature analysis. Considering the vast amount of data involved it was decided to prepare the available data for the SAS system. The SAS system is a general integrated system of software providing complete control over data management, analysis, and graphical and tabular presentation [31]. SAS system has significantly more capability to manipulate multiple data sets compared to other statistical packages such as SPSS-X [32] and BMDP [33]. The steps involved in the preparation of the reactor data for the SAS system are summarized below:

1. The original reel magnetic tapes (13 tapes) containing the data for OC-3 and OC-4 were sent to the C&T Division of ORNL to be copied on IBM cartridge tapes (3 tapes) [40].
2. The cartridge tapes were brought to UTCC at Knoxville to be read and converted to EBCDIC format.
3. The data reading/translating program, included in Appendix B, was invoked to perform the required task of reading, translating

and copying of the data. The translated data were written onto five IBM cartridge tapes in a format suitable for the SAS system. Two target tapes were required for the OC-3 data and three for the OC-4 data [21, June 1990].

5.6 Temperature Data for OC-3

The OC-3 experiment was the second creep experiment conducted to achieve the nominal specimen temperature of 900°C (The OC-1 experiment was the first experiment at this temperature). The capsule was in ORR for two reactor cycles (about 110 days).

The signals reported by the sensors involved were recorded at five minute intervals. The contents of a typical record of the 128-point data base for OC-3, suitable for statistical analysis by SAS, is depicted in Figure 5-2. The point names of interest in this database are shown in Table 5-2. The two-digit numbers involved in the point names indicate the numbers of the zones of the specimen columns. Letters A and B in the point names indicate the association of the FTC's/setpoints with the West and East stressed columns respectively. The setpoint values and the information regarding the temperatures reported by the FTC's are of particular interest for temperature analysis. Knowing the variation of reactor power with time would also be informative in explaining the fluctuations in temperature that required major adjustments to the setpoint values at the z-trace times. Graphical

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
1	14APR1979	0:04:00	$$$$$	-12288	97	1	V0	.	0
2	14APR1979	0:04:00	T01A	-16381	511	104	T2	852.425	5646
3	14APR1979	0:04:00	T01B	-16380	511	103	T2	858.424	5686
4	14APR1979	0:04:00	T02A	-16379	511	114	T2	847.932	5616
5	14APR1979	0:04:00	T02B	-16378	511	76	T2	844.940	5596
6	14APR1979	0:04:00	T03A	-16377	511	115	T2	833.885	5522
7	14APR1979	0:04:00	T03B	-16376	511	39	T2	833.885	5522
8	14APR1979	0:04:00	T04A	-16375	511	74	T2	853.624	5654
9	14APR1979	0:04:00	T04B	-16374	511	40	T2	831.201	5504
10	14APR1979	0:04:00	T05A	-16373	511	41	T2	840.753	5568
11	14APR1979	0:04:00	T05B	-16372	511	42	T2	828.518	5486
12	14APR1979	0:04:00	T06A	-16368	511	43	T2	838.961	5556
13	14APR1979	0:04:00	T06B	-16367	511	44	T2	827.028	5476
14	14APR1979	0:04:00	T07A	-16366	511	45	T2	845.837	5602
15	14APR1979	0:04:00	T07B	-16365	511	46	T2	830.604	5500
16	14APR1979	0:04:00	T08A	-16364	511	47	T2	852.126	5644
17	14APR1979	0:04:00	T08B	-16363	511	48	T2	831.499	5506
18	14APR1979	0:04:00	T09A	-16362	511	49	T2	857.823	5682
19	14APR1979	0:04:00	T09B	-16361	511	50	T2	846.435	5606
20	14APR1979	0:04:00	T10A	-16360	507	51	T2	786.984	5206
21	14APR1979	0:04:00	T10B	-16359	507	52	T2	762.817	5042
22	14APR1979	0:04:00	T00N	-16383	353	53	T2	871.653	5774
23	14APR1979	0:04:00	T00S	-16382	353	54	T2	872.857	5782
24	14APR1979	0:04:00	Z1807N	4140	353	55	Z1	15.991	2620
25	14APR1979	0:04:00	Z1808S	4141	353	56	Z1	16.223	2658
26	14APR1979	0:04:00	.TREF1	-12259	383	57	T1	23.644	510
27	14APR1979	0:04:00	P1703D	1280	427	58	P1	-1.000	-1
28	14APR1979	0:04:00	P1703H	1024	427	59	P1	-1.000	-1
29	14APR1979	0:04:00	P1704D	1792	427	120	P2	1.000	-1
30	14APR1979	0:04:00	P1704H	1536	427	78	P2	-1.000	-1
31	14APR1979	0:04:00	P1705D	2304	427	116	P3	1.000	-1
32	14APR1979	0:04:00	P1705H	2048	427	117	P3	1.000	-1
33	14APR1979	0:04:00	P1706D	2816	427	60	P4	1.000	-1
34	14APR1979	0:04:00	P1706H	2560	427	73	P4	1.000	-1
35	14APR1979	0:04:00	P1805D	0	427	66	P1	-1.000	-1
36	14APR1979	0:04:00	P1805H	256	427	106	P1	-1.000	-1
37	14APR1979	0:04:00	P1806D	512	427	107	P1	1.000	-1
38	14APR1979	0:04:00	P1806H	768	427	65	P1	-1.000	-1
39	14APR1979	0:04:00	F1812	3072	299	108	F1	-1.000	-1
40	14APR1979	0:04:00	I01	0	321	109	J1	0.593	607
41	14APR1979	0:04:00	I02	770	321	94	J2	0.319	326
42	14APR1979	0:04:00	I03	512	321	110	J3	0.679	694
43	14APR1979	0:04:00	I04	768	321	111	J4	0.779	797
44	14APR1979	0:04:00	I05	1	321	105	J5	0.846	866

Figure 5-2. A typical record of the 128-point database for OC-3.

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
45	14APR1979	0:04:00	I06	257	321	112	J6	1	867
46	14APR1979	0:04:00	I07	513	321	113	J7	1	665
47	14APR1979	0:04:00	I08	769	321	61	J8	1	770
48	14APR1979	0:04:00	I09	2	321	27	J9	1	781
49	14APR1979	0:04:00	I10	258	321	28	JA	1	1022
50	14APR1979	0:04:00	J01	-28640	353	62	J1	1318	3148
51	14APR1979	0:04:00	J02	-28639	353	29	J2	83	198
52	14APR1979	0:04:00	J03	-28638	353	30	J3	1011	2416
53	14APR1979	0:04:00	J04	-28637	353	63	J4	2583	6156
54	14APR1979	0:04:00	J05	-28636	353	31	J5	2732	6500
55	14APR1979	0:04:00	J06	-28635	353	32	J6	2483	5932
56	14APR1979	0:04:00	J07	-28634	353	64	J7	2456	5796
57	14APR1979	0:04:00	J08	-28633	353	33	J8	1667	3942
58	14APR1979	0:04:00	J09	-28632	353	34	J9	1355	3214
59	14APR1979	0:04:00	J10	-28631	353	35	JA	1333	3126
60	14APR1979	0:04:00	OC1BKU	768	395	36	BK	1	-1
61	14APR1979	0:04:00	P1703	-12237	511	37	P1	761	6238
62	14APR1979	0:04:00	P1704	-12240	511	38	P2	770	6306
63	14APR1979	0:04:00	P1705	-12236	505	68	P3	61	502
64	14APR1979	0:04:00	P1706	-12239	505	67	P4	66	544
65	14APR1979	0:04:00	P1504	-12233	511	121	P2	748	6130
66	14APR1979	0:04:00	P1503	-12230	511	79	P1	746	6110
67	14APR1979	0:04:00	REAPWR	53	483	69	JB	29944510	4938
68	14APR1979	0:04:00	P1814	-12238	511	70	P5	60	4902
69	14APR1979	0:04:00	ST00N	514	320	22	I1	.	0
70	14APR1979	0:04:00	ST00S	514	320	23	I1	.	0
71	14APR1979	0:04:00	T09BSP	514	320	2	J9	845	0
72	14APR1979	0:04:00	T10ASP	514	320	93	JA	821	0
73	14APR1979	0:04:00	PWRWDG	3840	427	3	MO	-1	0
74	14APR1979	0:04:00	F1813	47	353	92	F1	153	1254
75	14APR1979	0:04:00	T27A	-16357	353	4	T2	91	448
76	14APR1979	0:04:00	F1803	42	353	91	F2	131	536
77	14APR1979	0:04:00	T28A	-16356	353	5	T2	48	166
78	14APR1979	0:04:00	NUMHRS	514	320	90	I1	204	0
79	14APR1979	0:04:00	STDATE	514	320	6	I1	7613412	0
80	14APR1979	0:04:00	T11A	-16358	353	89	T2	491	3170
81	14APR1979	0:04:00	T06C	-16369	353	7	T2	826	5470
82	14APR1979	0:04:00	T05D	-16370	353	88	T2	830	5496
83	14APR1979	0:04:00	T05C	-16371	353	8	T2	845	5596
84	14APR1979	0:04:00	T05ASP	514	320	87	J5	840	0
85	14APR1979	0:04:00	T05BSP	514	320	9	J5	828	0
86	14APR1979	0:04:00	T04BSP	514	320	86	J4	830	0
87	14APR1979	0:04:00	T04ASP	514	320	10	J4	852	0
88	14APR1979	0:04:00	T03BSP	514	320	84	J3	834	0

Figure 5-2 (continued)

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
89	14APR1979	0:04:00	T03ASP	514	320	11	J3	834.000	0
90	14APR1979	0:04:00	T02BSP	514	320	85	J2	843.460	0
91	14APR1979	0:04:00	T02ASP	514	320	83	J2	854.540	0
92	14APR1979	0:04:00	T01BSP	514	320	82	J1	857.199	0
93	14APR1979	0:04:00	T01ASP	514	320	12	J1	851.801	0
94	14APR1979	0:04:00	P1505	-12232	511	102	P3	812.011	6652
95	14APR1979	0:04:00	T08BSP	514	320	13	J8	830.755	0
96	14APR1979	0:04:00	T10BSP	514	320	101	JA	797.722	0
97	14APR1979	0:04:00	T09ASP	514	320	81	J9	856.686	0
98	14APR1979	0:04:00	T08ASP	514	320	14	J8	851.350	0
99	14APR1979	0:04:00	T07BSP	514	320	100	J7	830.744	0
100	14APR1979	0:04:00	T07ASP	514	320	15	J7	846.256	0
101	14APR1979	0:04:00	T06BSP	514	320	99	J6	827.108	0
102	14APR1979	0:04:00	T06ASP	514	320	16	J6	845.892	0
103	14APR1979	0:04:00	CAULIM	514	320	98	I1	10.000	0
104	14APR1979	0:04:00	ALMLIM	514	320	17	I1	20.000	0
105	14APR1979	0:04:00	P1506	-12231	511	95	P4	808.838	6626
106	14APR1979	0:04:00	P1503D	3328	427	18	P1	-1.000	-1
107	14APR1979	0:04:00	P1503H	513	427	97	P1	-1.000	-1
108	14APR1979	0:04:00	P1504D	3584	427	19	P2	1.000	-1
109	14APR1979	0:04:00	P1504H	769	427	71	P2	-1.000	-1
110	14APR1979	0:04:00	P1505D	1	427	20	P3	1.000	-1
111	14APR1979	0:04:00	P1505H	1025	427	72	P3	-1.000	-1
112	14APR1979	0:04:00	P1506D	257	427	21	P4	-1.000	-1
113	14APR1979	0:04:00	P1506H	1281	427	96	P4	-1.000	-1
114	14APR1979	0:04:00	F1802	43	353	80	F1	9.521	78
115	14APR1979	0:04:00	F1804	46	353	75	F1	163.574	1340
116	14APR1979	0:04:00	OCSBDO	512	267	77	DO	1.000	-1
117	14APR1979	0:04:00	OCSBMU	256	267	119	MU	1.000	0
118	14APR1979	0:04:00		0	96	24		.	0
119	14APR1979	0:04:00	ZCONSW	3841	299	25	S4	-1.000	-1
120	14APR1979	0:04:00	MTALRM	3840	267	26	MT	1.000	-1
121	14APR1979	0:04:00	SETLIM	514	320	122	I1	10.000	0
122	14APR1979	0:04:00	PT1503	0	96	118		.	0
123	14APR1979	0:04:00		0	0	123		.	0
124	14APR1979	0:04:00		0	0	124		.	0
125	14APR1979	0:04:00		0	0	125		.	0
126	14APR1979	0:04:00		0	0	126		.	0
127	14APR1979	0:04:00		0	0	127		.	0
128	14APR1979	0:04:00		0	0	128		.	0

Figure 5-2 (continued)

Table 5-2. The Point Names of Interest in the Analysis of Reactor Data

Point Name	Definition
T01A	Temperature reported by West FTC in Zone 1 (°C)
T01B	Temperature reported by East FTC in Zone 1 (°C)
T02A	Temperature reported by West FTC in Zone 2 (°C)
T02B	Temperature reported by East FTC in Zone 2 (°C)
⋮	
T10A	Temperature reported by West FTC in Zone 10 (°C)
T10B	Temperature reported by East FTC in Zone 10 (°C)
T01ASP	Setpoint value for T01A
T01BSP	Setpoint value for T01B
T02ASP	Setpoint value for T02A
T02BSP	Setpoint value for T02B
⋮	
T10ASP	Setpoint value for T10A
T10BSP	Setpoint value for T10B
T00N	Temperature reported by the MTC in the North control column (°C)
T00N	Temperature reported by the MTC in the South control column (°C)
Z1807N	Elevation of the MTC in the North control column (in)
Z1808S	Elevation of the MTC in the South control column (in)
REAPWR	Reactor power (MW)

representations of variation of setpoint values and reactor power with z-trace times are included in subsection 5.6.1 and section 5.7, respectively.

5.6.1 Analysis of Temperature Data for OC-3

Examination of the ORR log books for OC-3 revealed that the following steps have been followed each time that the setpoints were readjusted by the experiment:

1. The arithmetic mean of the temperatures reported by the MTC in the north control column (point name T00N) and the MTC in the south control column (point name T00S) was computed for the corresponding zone of the specimen column. The point names Z1807N and Z1808S (Figure 5-2) indicate the elevation of the MTC's by which it is determined which zone is being traced. This averaging process involved taking five pairs of temperature for each zone. Table 5-3 shows the z-trace No. 36 for OC-3 at 09:22-27 on April 11, 1979 [34].

2. The difference between the experiment nominal temperature (900°C) and the average temperature for each zone (MTC) was obtained (ΔT). In other words:

Table 5-3. Typical Complete Z-Trace for OC-3.

Time	Zone	Z1807N	Z1808S	TOON TEMP	TOOS TEMP	AVG TMP	ΔT
09:24:05	1	15.04	14.99	893.27	898.12	895.69	
09:25:07	1	15.04	14.99	891.76	896.91	894.33	
09:26:08	1	15.04	14.99	893.57	898.42	896.00	+4
09:27:10	1	15.04	14.99	892.68	897.23	894.95	
09:28:05	1	15.04	14.99	893.60	898.15	895.88	
09:29:41	2	13.99	13.92	896.64	894.82	895.73	
09:30:42	2	13.99	13.92	897.24	895.73	986.48	
09:31:43	2	13.99	13.92	896.65	894.83	895.74	+4
09:32:44	2	13.99	13.92	897.26	895.14	896.20	
09:33:41	2	13.99	13.92	896.95	894.83	895.89	
09:35:44	3	11.98	11.89	900.92	893.33	897.12	
09:36:45	3	11.99	11.89	900.02	892.44	896.23	
09:37:46	3	11.96	11.90	900.02	892.44	896.23	+4
09:38:47	3	11.96	11.89	901.24	893.65	897.44	
09:39:44	3	11.96	11.89	900.02	892.14	896.08	
09:41:45	4	10.03	9.96	899.45	889.45	894.45	
09:42:46	4	10.03	9.96	899.45	889.14	894.30	
09:43:47	4	10.03	9.96	899.45	889.45	894.45	+6
09:44:49	4	10.03	9.96	899.16	888.86	894.01	
09:45:45	4	10.03	9.96	900.68	890.37	895.52	
09:47:49	5	7.98	7.90	907.07	888.27	897.67	
09:48:50	5	7.97	7.90	903.44	884.66	894.05	
09:49:51	5	7.96	7.90	906.48	887.38	896.93	+3
09:50:52	5	7.96	7.90	903.46	885.58	894.52	
09:51:49	5	7.96	7.90	906.51	888.32	897.42	
09:53:51	6	6.01	5.93	904.08	884.69	894.39	
09:54:53	6	6.01	5.93	904.08	884.08	894.08	
09:55:54	6	6.01	5.93	905.01	885.31	895.16	+6
09:56:55	6	6.01	5.93	903.52	884.13	893.83	
09:57:51	6	6.01	5.94	904.43	884.74	894.59	
09:59:54	7	3.99	3.92	903.54	885.66	894.60	
10:00:55	7	3.99	3.93	902.32	884.15	893.24	
10:01:56	7	3.99	3.92	903.24	885.36	894.30	+6
10:02:57	7	3.99	3.92	903.86	885.68	894.77	
10:03:54	7	3.99	3.93	903.27	885.39	894.33	
10:05:56	8	1.99	1.92	901.46	887.83	894.64	
10:06:57	8	1.99	1.92	901.78	888.14	894.96	
10:07:58	8	1.99	1.92	901.17	887.54	894.36	+5
10:09:00	8	1.99	1.92	901.78	888.45	895.11	
10:09:56	8	1.99	1.92	901.19	887.86	894.52	
10:11:58	9	0.00	-0.05	898.79	891.22	895.01	
10:13:00	9	0.00	-0.05	900.01	892.43	896.22	
10:14:01	9	0.00	-0.06	898.51	890.63	894.57	+5
10:15:01	9	0.00	-0.05	898.81	891.23	895.02	
10:15:58	9	0.00	-0.06	898.83	891.25	895.04	

$$\Delta T_{ij} = \overline{MTC_{ij}} - 900 \tag{5-1}$$

where,

ΔT_{ij} = deviation from the nominal temperature for zone i at z-trace No. j.

MTC_{ij} = average temperature for zone i at z-trace No. j.

Positive or negative values for ΔT_{ij} indicate that the temperature of the specimens in zone i is higher or lower than the required temperature, respectively. For nonzero ΔT_i, the setpoint values for zone i (point names T0iASP and T0iBSP) must be adjusted to inform the two heaters of the zone to provide required power. In other words:

$$(SP)_{i,j} = (SP)_{i,\,j-1} - \Delta T_{ij} \tag{5-2}$$

where,

SP = setpoint value

i = the index indicating the zone number

j = the sequence number of z-trace.

Considering the above discussion, the specimen temperature, at any z-trace time j for zone i can be found by the following calculations:

$$\Delta T_{ij} = (SP)_{ij-1} - (SP)_{i,j} \tag{5-3}$$

$$\overline{MTC_{ij}} = 900 + \Delta T_{ij} \tag{5-4}$$

The above algorithm was incorporated in a SAS program (Appendix E) to find the variation of setpoint values with time and the variation of the zone temperatures with time. Figures 5-3 and 5-4 show variations of set point values and specimens mean temperature for zone 4, as a typical zone. The similar graphs for the remaining zones are included in Appendix C.

It should be noted that during the absence of MTC's, in other words, between two successive z-traces, the zone/specimen temperatures must be determined by invoking the FTC reports. The temperature of the specimen holder (graphite block) at different elevations (corresponding to different zones) are monitored by two FTC's for each zone. The deviation of the temperatures reported by these two FTC's from the setpoint values corresponding to them indicates the deviation of the specimen temperature (MTC) from the nominal temperature of the experiment (900°C).

In other words, at five minute intervals the specimen temperature (say MTC) can be deciphered by the following equations:

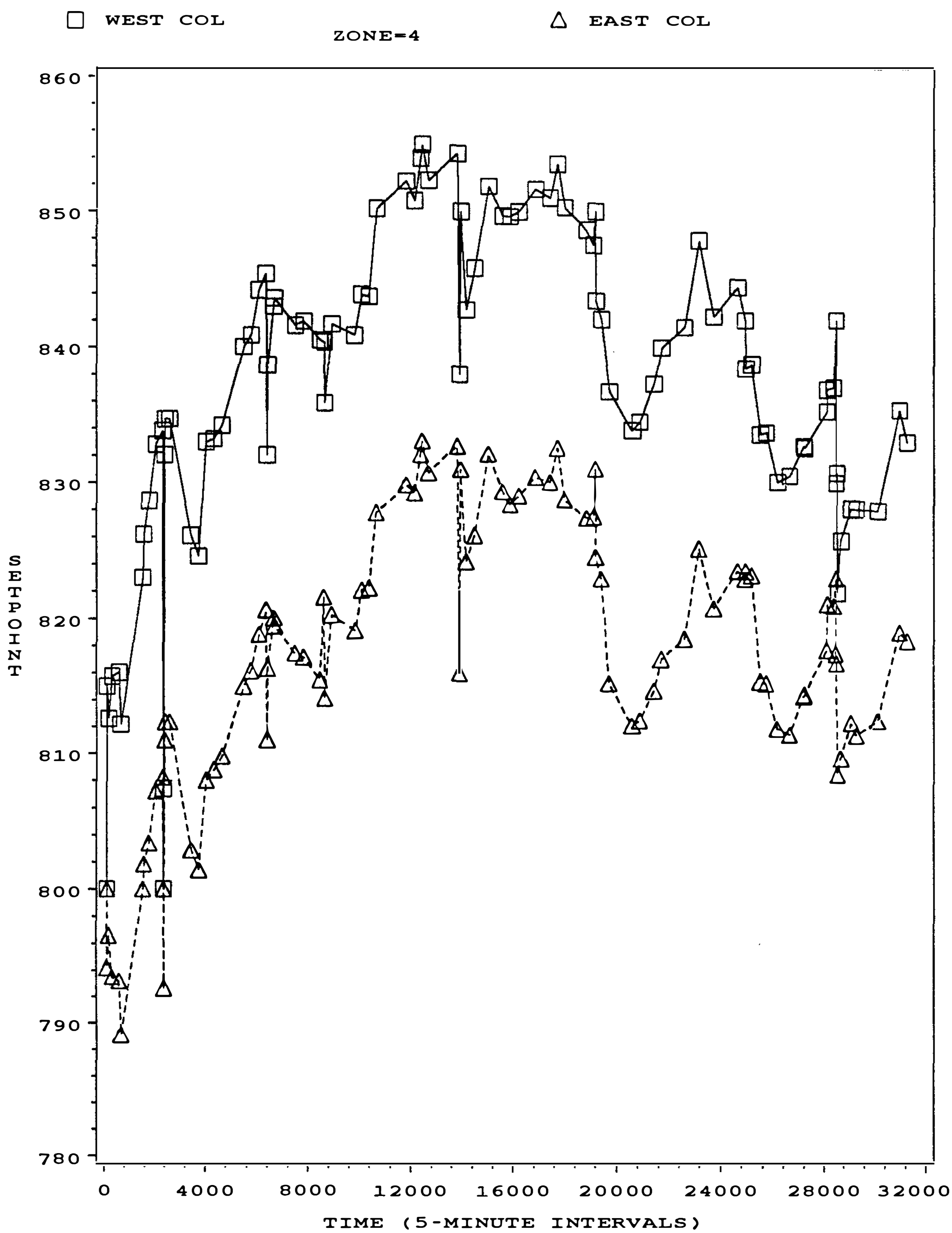


Figure 5-3. Variation of setpoint values with time for zone 4 of the west and east columns of OC-3.

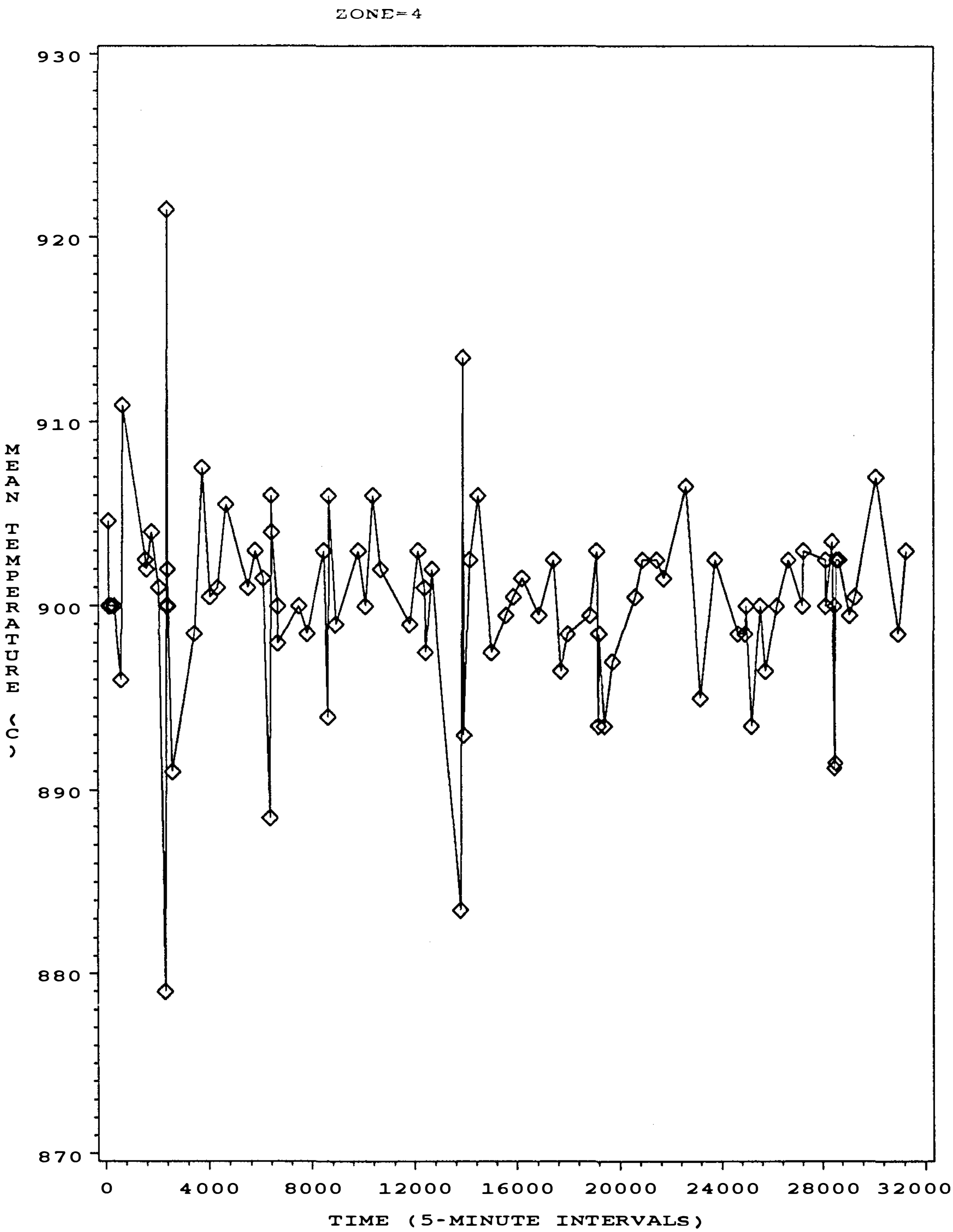


Figure 5-4. Variation of the mean temperature (at z-trace time) for zone 4 of the specimen columns of OC-3.

$$\Delta T_i = FTC_i - SP_i \tag{5-5}$$

$$T_i = 900 + \Delta T_i \tag{5-6}$$

where

ΔT_i = difference between FTC report and its corresponding setpoint value, for zone i

FTC_i = temperature report from a fixed TC in zone i

SP_i = a setpoint value for zone i

T_i = specimen temperature in zone i.

Considering the number of 5-minute intervals involved in the core residence time of the OC-3 irradiation capsule (about 120 days) a SAS program was developed (Appendix F) to set up different tables and charts to indicate the extent and duration of specimens temperature fluctuations. A summary of such an analysis is given in Figure 5-5. Figures 5-6 and 5-7 convey additional information regarding the temperature analysis. Q_1 and Q_3 in the column headings represent the first and the third quartiles, respectively. Quartiles are defined in Section 2 of Chapter 7. Figures 5-8 through 5-17 represent the temperature distributions in a more descriptive manner. Since the graphite specimens are exposed to the temperature fluctuations along specimen columns, the irradiation temperature to accompany the results of irradiation induced creep studies (Chapter 8), is obtained by considering the overall time-averaged zone temperatures.

ZONE	MNRANGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
1	<-40	2577	0.8	2577	0.8
1	-40 -35	6	0.0	2583	0.8
1	-35 -30	2	0.0	2585	0.8
1	-30 -25	3	0.0	2588	0.8
1	-25 -20	3	0.0	2591	0.8
1	-20 -15	5	0.0	2596	0.8
1	-15 -10	22	0.0	2618	0.8
1	-10 -5	272	0.1	2890	0.9
1	-5 -0	10839	3.4	13729	4.3
1	0	2	0.0	13731	4.3
1	0-5	18363	5.7	32094	10.0
1	5-10	5	0.0	32099	10.0
2	<-40	7313	2.3	39412	12.3
2	-35 -30	2	0.0	39414	12.3
2	-20 -15	2	0.0	39416	12.3
2	-15 -10	48	0.0	39464	12.3
2	-10 -5	1318	0.4	40782	12.7
2	-5 -0	3383	1.1	44165	13.8
2	0	1	0.0	44166	13.8
2	0-5	19979	6.2	64145	20.0
2	5-10	45	0.0	64190	20.0
2	10-15	5	0.0	64195	20.0
2	>40	3	0.0	64198	20.0
3	<-40	2320	0.7	66518	20.7
3	-40 -35	3	0.0	66521	20.7
3	-35 -30	1	0.0	66522	20.7
3	-30 -25	1	0.0	66523	20.7
3	-25 -20	4	0.0	66527	20.7
3	-20 -15	1	0.0	66528	20.7
3	-15 -10	4	0.0	66532	20.7
3	-10 -5	2090	0.7	68622	21.4
3	-5 -0	5887	1.8	74509	23.2
3	0	3	0.0	74512	23.2
3	0-5	21532	6.7	96044	29.9
3	5-10	3	0.0	96047	29.9
3	10-15	1	0.0	96048	29.9
3	>40	249	0.1	96297	30.0
4	<-40	2574	0.8	98871	30.8
4	-40 -35	3	0.0	98874	30.8
4	-35 -30	3	0.0	98877	30.8
4	-30 -25	2	0.0	98879	30.8
4	-25 -20	1	0.0	98880	30.8
4	-20 -15	3	0.0	98883	30.8
4	-15 -10	12	0.0	98895	30.8
4	-10 -5	236	0.1	99131	30.9
4	-5 -0	12693	4.0	111824	34.8
4	0-5	16556	5.2	128380	40.0
4	5-10	16	0.0	128396	40.0
5	<-40	2576	0.8	130972	40.8
5	-40 -35	1	0.0	130973	40.8
5	-35 -30	2	0.0	130975	40.8

Figure 5-5. Frequency distributions for ranges of temperature variation above and below 0°C for the OC-3 experiment.

ZONE	MNRANGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
5	-30 -25	2	0.0	130977	40.8
5	-25 -20	6	0.0	130983	40.8
5	-20 -15	4	0.0	130987	40.8
5	-15 -10	36	0.0	131023	40.8
5	-10 -5	345	0.1	131368	40.9
5	-5 -0	11532	3.6	142900	44.5
5	0	1	0.0	142901	44.5
5	0-5	17469	5.4	160370	50.0
5	5-10	124	0.0	160494	50.0
5	10-15	1	0.0	160495	50.0
6	<-40	2571	0.8	163066	50.8
6	-40 -35	2	0.0	163068	50.8
6	-35 -30	2	0.0	163070	50.8
6	-30 -25	3	0.0	163073	50.8
6	-20 -15	1	0.0	163074	50.8
6	-15 -10	7	0.0	163081	50.8
6	-10 -5	138	0.0	163219	50.8
6	-5 -0	11541	3.6	174760	54.4
6	0-5	17829	5.6	192589	60.0
6	5-10	3	0.0	192592	60.0
6	10-15	2	0.0	192594	60.0
7	<-40	2573	0.8	195167	60.8
7	-40 -35	1	0.0	195168	60.8
7	-35 -30	1	0.0	195169	60.8
7	-30 -25	4	0.0	195173	60.8
7	-25 -20	5	0.0	195178	60.8
7	-20 -15	2	0.0	195180	60.8
7	-15 -10	13	0.0	195193	60.8
7	-10 -5	330	0.1	195523	60.9
7	-5 -0	12128	3.8	207651	64.7
7	0	1	0.0	207652	64.7
7	0-5	17029	5.3	224681	70.0
7	5-10	11	0.0	224692	70.0
7	10-15	1	0.0	224693	70.0
8	<-40	2567	0.8	227260	70.8
8	-40 -35	2	0.0	227262	70.8
8	-35 -30	5	0.0	227267	70.8
8	-30 -25	2	0.0	227269	70.8
8	-25 -20	2	0.0	227271	70.8
8	-20 -15	5	0.0	227276	70.8
8	-15 -10	32	0.0	227308	70.8
8	-10 -5	308	0.1	227616	70.9
8	-5 -0	9439	2.9	237055	73.9
8	0	6	0.0	237061	73.9
8	0-5	19718	6.1	256779	80.0
8	5-10	12	0.0	256791	80.0
8	10-15	1	0.0	256792	80.0
9	<-40	2569	0.8	259361	80.8
9	-40 -35	1	0.0	259362	80.8
9	-35 -30	5	0.0	259367	80.8
9	-30 -25	2	0.0	259369	80.8

Figure 5-5 (continued)

ZONE	MNRANGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
9	-25 -20	1	0.0	259370	80.8
9	-20 -15	4	0.0	259374	80.8
9	-15 -10	42	0.0	259416	80.8
9	-10 -5	591	0.2	260007	81.0
9	-5 -0	9141	2.8	269148	83.8
9	0	4	0.0	269152	83.9
9	0-5	19711	6.1	288863	90.0
9	5-10	22	0.0	288885	90.0
9	10-15	6	0.0	288891	90.0
10	<-40	8443	2.6	297334	92.6
10	-40 -35	2795	0.9	300129	93.5
10	-35 -30	2053	0.6	302182	94.1
10	-30 -25	1823	0.6	304005	94.7
10	-25 -20	2439	0.8	306444	95.5
10	-20 -15	1346	0.4	307790	95.9
10	-15 -10	333	0.1	308123	96.0
10	-10 -5	1484	0.5	309607	96.5
10	-5 -0	2849	0.9	312456	97.3
10	0	3	0.0	312459	97.3
10	0-5	8472	2.6	320931	100.0
10	5-10	1	0.0	320932	100.0
10	>40	58	0.0	320990	100.0

Figure 5-5 (continued)

OBS	ZONE	MN <OR> 0 C	N OF DELTA_MN	MEAN OF DELTA_MN	STD OF DELTA_MN	MODE OF DELTA_MN
1	1	BELOW 900 C	13731	-140.31	298.876	-817.75
2	1	ABOVE 900 C	18368	0.95	0.712	0.60
3	2	BELOW 900 C	12067	-309.93	287.889	-813.16
4	2	ABOVE 900 C	20032	0.83	1.051	0.85
5	3	BELOW 900 C	10314	-165.25	313.315	-0.12
6	3	ABOVE 900 C	21785	5.58	45.441	0.22
7	4	BELOW 900 C	15527	-119.23	273.498	-808.91
8	4	ABOVE 900 C	16572	1.18	0.926	0.05
9	5	BELOW 900 C	14505	-120.93	274.162	-803.93
10	5	ABOVE 900 C	17594	1.04	1.017	0.77
11	6	BELOW 900 C	14265	-122.18	275.392	-803.80
12	6	ABOVE 900 C	17834	0.86	0.680	0.24
13	7	BELOW 900 C	15058	-115.96	269.852	-805.43
14	7	ABOVE 900 C	17041	0.83	0.715	0.18
15	8	BELOW 900 C	12368	-141.00	292.121	-806.82
16	8	ABOVE 900 C	19731	0.65	0.508	0.31
17	9	BELOW 900 C	12360	-143.15	295.672	-781.35
18	9	ABOVE 900 C	19739	0.67	0.610	0.05
19	10	BELOW 900 C	23568	-101.61	217.496	-0.02
20	10	ABOVE 900 C	8531	4.14	35.770	0.06

OBS	MIN OF DELTA_MN	Q1 OF DELTA_MN	MEDIAN OF DELTA_MN	Q3 OF DELTA_MN	MAX OF DELTA_MN
1	-824.9	-3.66	-2.33	-0.349	0.000
2	0.0	0.41	0.81	1.339	8.496
3	-826.3	-412.19	-408.70	-3.230	0.000
4	0.0	0.42	0.71	1.050	68.332
5	-802.7	-6.77	-0.68	-0.196	0.000
6	0.0	0.35	0.67	1.018	433.180
7	-810.5	-3.55	-1.18	-0.370	-0.000
8	0.0	0.44	0.99	1.708	6.990
9	-806.2	-3.69	-1.50	-0.450	0.000
10	0.0	0.35	0.72	1.392	11.011
11	-805.8	-3.57	-0.94	-0.296	-0.000
12	0.0	0.34	0.72	1.229	13.507
13	-807.0	-3.56	-0.83	-0.260	0.000
14	0.0	0.30	0.68	1.176	10.024
15	-808.4	-3.90	-2.30	-0.230	0.000
16	0.0	0.29	0.56	0.899	10.094
17	-816.7	-5.84	-2.71	-0.251	0.000
18	0.0	0.29	0.56	0.887	12.568
19	-1324.8	-44.58	-33.98	-19.655	0.000
20	0.0	0.52	1.08	1.715	440.581

Figure 5-6. Descriptive statistics for temperature by zones: grouped by delta T's above and below 0^{o}C for OC-3.

OBS	ZONE	MNMTC <OR> -600 C	N OF DELTA_MN	MEAN OF DELTA_MN	STD OF DELTA_MN	MODE OF DELTA_MN
1	1	< -600 C	2249	-807.01	27.632	-817.75
2	1	>=-600 C	29850	-3.16	31.761	0.60
3	2	< -600 C	2048	-800.74	27.580	-813.16
4	2	>=-600 C	30051	-69.33	152.628	0.85
5	3	< -600 C	2048	-786.14	26.384	-799.41
6	3	>=-600 C	30051	0.90	49.139	0.22
7	4	< -600 C	2099	-788.89	34.157	-808.91
8	4	>=-600 C	30000	-5.86	49.101	-0.10
9	5	< -600 C	2050	-785.67	28.084	-803.93
10	5	>=-600 C	30049	-4.16	34.026	0.77
11	6	< -600 C	2049	-784.05	28.523	-803.80
12	6	>=-600 C	30050	-4.03	33.146	0.24
13	7	< -600 C	2050	-785.59	28.276	-805.43
14	7	>=-600 C	30049	-4.04	32.463	0.18
15	8	< -600 C	2048	-787.08	28.696	-806.82
16	8	>=-600 C	30051	-3.96	31.785	-2.03
17	9	< -600 C	2047	-796.80	27.609	-781.35
18	9	>=-600 C	30052	-4.17	32.661	-7.58
19	10	< -600 C	2246	-762.26	35.506	-786.16
20	10	>=-600 C	29853	-21.69	39.822	0.06

OBS	MIN OF DELTA_MN	Q1 OF DELTA_MN	MEDIAN OF DELTA_MN	Q3 OF DELTA_MN	MAX OF DELTA_MN
1	-824.9	-817.82	-817.37	-813.28	-603.21
2	-578.9	-0.43	0.30	0.98	8.50
3	-826.3	-813.14	-812.64	-804.02	-600.54
4	-594.1	-2.88	0.42	0.87	68.33
5	-802.7	-799.25	-798.72	-790.34	-600.03
6	-595.1	-0.05	0.43	0.88	433.18
7	-810.5	-808.75	-798.23	-789.07	-600.60
8	-600.0	-0.66	0.14	1.11	6.99
9	-806.2	-804.37	-797.49	-777.17	-607.22
10	-597.9	-0.75	0.21	0.85	11.01
11	-805.8	-804.15	-798.69	-769.00	-601.91
12	-597.9	-0.43	0.21	0.86	13.51
13	-807.0	-805.30	-798.35	-769.21	-600.56
14	-600.0	-0.43	0.13	0.77	10.02
15	-808.4	-806.78	-802.95	-768.66	-603.67
16	-591.3	-0.20	0.28	0.71	10.09
17	-816.7	-815.19	-813.41	-781.29	-601.05
18	-599.3	-0.22	0.28	0.70	12.57
19	-1324.8	-786.25	-783.14	-725.94	-600.30
20	-587.9	-38.12	-20.94	0.23	440.58

Figure 5-7. Descriptive statistics for temperature by zones: grouped by delta T's above and below -600°C for OC-3.

```
                                      FREQUENCY BAR CHART

MNRANGE    MEAN < OR > 0 C                                                                                FREQ     CUM.   PERCENT     CUM.
                                                                                                                   FREQ             PERCENT
<-40      |**********                                                                                     2577     2577      8.03      8.03
-40 -35   |                                                                                                  6     2583      0.02      8.05
-35 -30   |                                                                                                  2     2585      0.01      8.05
-30 -25   |                                                                                                  3     2588      0.01      8.06
-25 -20   |                                                                                                  3     2591      0.01      8.07
-20 -15   |                                                                                                  5     2596      0.02      8.09
-15 -10   |                                                                                                 22     2618      0.07      8.16
-10 -5    |*                                                                                               272     2890      0.85      9.00
-5 -0     |*******************************************                                                   10839    13729     33.77     42.77
      0   |                                                                                                  2    13731      0.01     42.78
0-5       |*************************************************************************                     18363    32094     57.21     99.98
5-10      |                                                                                                  5    32099      0.02    100.00
          |
         --------+--------+--------+--------+--------+--------+--------+--------+--------+-
              2000     4000     6000     8000    10000    12000    14000    16000    18000

                                      FREQUENCY
```

Figure 5-8. Results of descriptive statistics for mean temperature of zone 1 shown in graphical and numerical forms for OC-3.

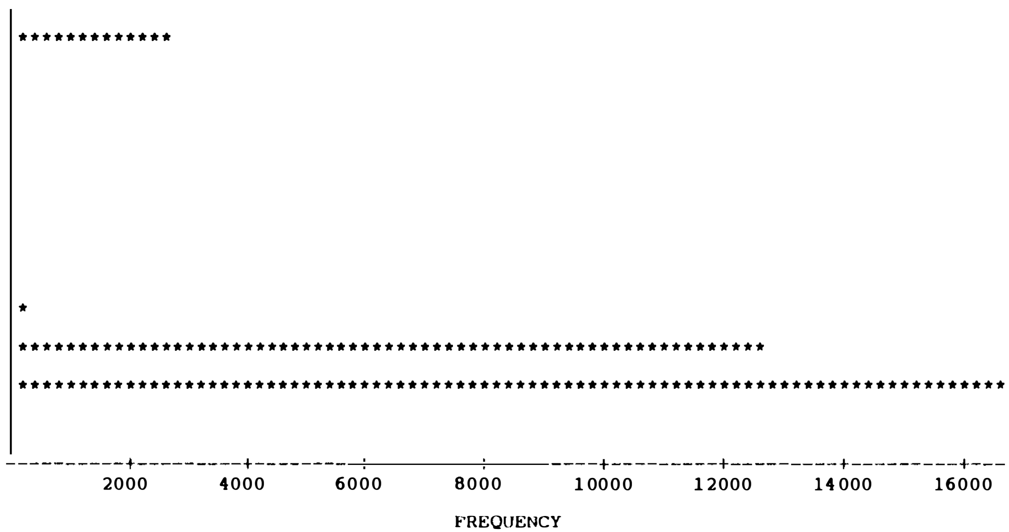
```
                                   OC3  (900 C)

                                     ZONE=2

                               FREQUENCY BAR CHART

MNRANGE   MEAN < OR > 0 C                                                                        FREQ    CUM.   PERCENT     CUM.
                                                                                                         FREQ              PERCENT
         |
<-40     |*****************************                                                          7313    7313    22.78     22.78
-35 -30  |                                                                                          2    7315     0.01     22.79
-20 -15  |                                                                                          2    7317     0.01     22.80
-15 -10  |                                                                                         48    7365     0.15     22.94
-10 -5   |*****                                                                                  1318    8683     4.11     27.05
-5 -0    |**************                                                                         3383   12066    10.54     37.59
       0 |                                                                                          1   12067     0.00     37.59
0-5      |******************************************************************************** 19979   32046    62.24     99.83
5-10     |                                                                                         45   32091     0.14     99.98
10-15    |                                                                                          5   32096     0.02     99.99
>40      |                                                                                          3   32099     0.01    100.00
         |
        -+-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
            2000    4000    6000    8000   10000   12000   14000   16000   18000   20000

                                      FREQUENCY
```

Figure 5-9. Results of descriptive statistics for mean temperature of zone 2 shown in graphical and numerical forms for OC-3.

```
                                   FREQUENCY BAR CHART

MNRANGE    MEAN < OR > 0 C                                                                                   FREQ   CUM.   PERCENT    CUM.
                                                                                                                    FREQ              PERCENT
          |
<-40      | *********                                                                                        2320   2320     7.23     7.23
          |
-40 -35   |                                                                                                     3   2323     0.01     7.24
          |
-35 -30   |                                                                                                     1   2324     0.00     7.24
          |
-30 -25   |                                                                                                     1   2325     0.00     7.24
          |
-25 -20   |                                                                                                     4   2329     0.01     7.26
          |
-20 -15   |                                                                                                     1   2330     0.00     7.26
          |
-15 -10   |                                                                                                     4   2334     0.01     7.27
          |
-10 -5    | ********                                                                                         2090   4424     6.51    13.78
          |
-5 -0     | ************************                                                                         5887  10311    18.34    32.12
          |
       0  |                                                                                                     3  10314     0.01    32.13
          |
0-5       | ************************************************************************************** 21532  31846    67.08    99.21
          |
5-10      |                                                                                                     3  31849     0.01    99.22
          |
10-15     |                                                                                                     1  31850     0.00    99.22
          |
>40       | *                                                                                                 249  32099     0.78   100.00
          |
          --------+--------+--------+--------+--------+--------+--------+--------+--------+--------+------
                2000     4000     6000     8000    10000    12000    14000    16000    18000    20000

                                        FREQUENCY
```

Figure 5-10. Results of descriptive statistics for mean temperature of zone 3 shown in graphical and numerical forms for OC-3.

FREQUENCY BAR CHART



MNRANGE	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	2574	2574	8.02	8.02
-40 -35	3	2577	0.01	8.03
-35 -30	3	2580	0.01	8.04
-30 -25	2	2582	0.01	8.04
-25 -20	1	2583	0.00	8.05
-20 -15	3	2586	0.01	8.06
-15 -10	12	2598	0.04	8.09
-10 -5	236	2834	0.74	8.83
-5 -0	12693	15527	39.54	48.37
0-5	16556	32083	51.58	99.95
5-10	16	32099	0.05	100.00

Figure 5-11. Results of descriptive statistics for mean temperature of zone 4 shown in graphical and numerical forms for OC-3.

FREQUENCY BAR CHART

MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	*************	2576	2576	8.03	8.03
-40 -35		1	2577	0.00	8.03
-35 -30		2	2579	0.01	8.03
-30 -25		2	2581	0.01	8.04
-25 -20		6	2587	0.02	8.06
-20 -15		4	2591	0.01	8.07
-15 -10		36	2627	0.11	8.18
-10 -5	**	345	2972	1.07	9.26
-5 -0	**	11532	14504	35.93	45.19
0		1	14505	0.00	45.19
0-5	**	17469	31974	54.42	99.61
5-10	*	124	32098	0.39	100.00
10-15		1	32099	0.00	100.00

2000 4000 6000 8000 10000 12000 14000 16000

FREQUENCY

Figure 5-12. Results of descriptive statistics for mean temperature of zone 5 shown in graphical and numerical forms for OC-3.

FREQUENCY BAR CHART

MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	**********	2571	2571	8.01	8.01
-40 -35		2	2573	0.01	8.02
-35 -30		2	2575	0.01	8.02
-30 -25		3	2578	0.01	8.03
-20 -15		1	2579	0.00	8.03
-15 -10		7	2586	0.02	8.06
-10 -5	*	138	2724	0.43	8.49
-5 -0	**	11541	14265	35.95	44.44
0-5	***	17829	32094	55.54	99.98
5-10		3	32097	0.01	99.99
10-15		2	32099	0.01	100.00

--------+--------+--------+--------+--------+--------+--------+--------+-------

2000 4000 6000 8000 10000 12000 14000 16000

FREQUENCY

Figure 5-13. Results of descriptive statistics for mean temperature of zone 6 shown in graphical and numerical forms for OC-3.

FREQUENCY BAR CHART

MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	*************	2573	2573	8.02	8.02
-40 -35		1	2574	0.00	8.02
-35 -30		1	2575	0.00	8.02
-30 -25		4	2579	0.01	8.03
-25 -20		5	2584	0.02	8.05
-20 -15		2	2586	0.01	8.06
-15 -10		13	2599	0.04	8.10
-10 -5	**	330	2929	1.03	9.12
-5 -0	***	12128	15057	37.78	46.91
0		1	15058	0.00	46.91
0-5	**	17029	32087	53.05	99.96
5-10		11	32098	0.03	100.00
10-15		1	32099	0.00	100.00

2000 4000 6000 8000 10000 12000 14000 16000

FREQUENCY

Figure 5-14. Results of descriptive statistics for mean temperature of zone 7 shown in graphical and numerical forms for OC-3.

FREQUENCY BAR CHART

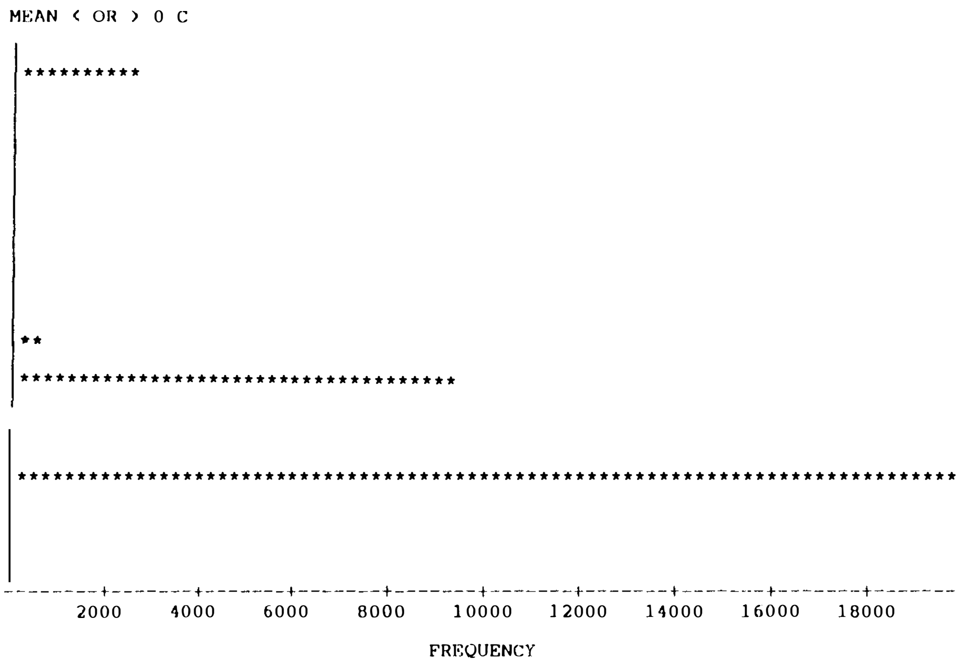
MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	**********	2567	2567	8.00	8.00
-40 -35		2	2569	0.01	8.00
-35 -30		5	2574	0.02	8.02
-30 -25		2	2576	0.01	8.03
-25 -20		2	2578	0.01	8.03
-20 -15		5	2583	0.02	8.05
-15 -10		32	2615	0.10	8.15
-10 -5	*	308	2923	0.96	9.11
-5 -0	**************************************	9439	12362	29.41	38.51
0		6	12368	0.02	38.53
0-5	***	19718	32086	61.43	99.96
5-10		12	32098	0.04	100.00
10-15		1	32099	0.00	100.00

2000 4000 6000 8000 10000 12000 14000 16000 18000

FREQUENCY

Figure 5-15. Results of descriptive statistics for mean temperature of zone 8 shown in graphical and numerical forms for OC-3.

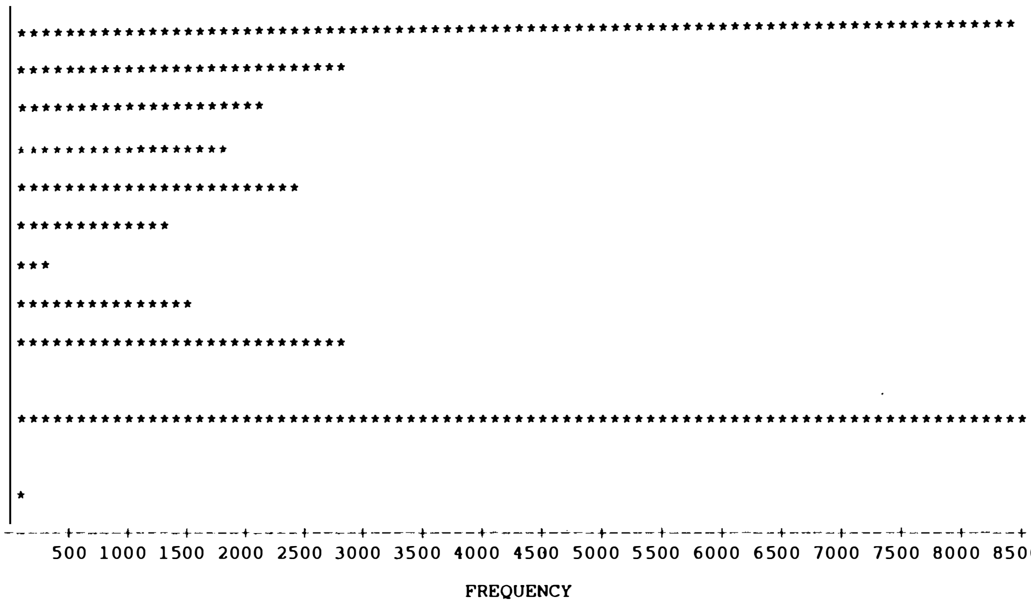
FREQUENCY BAR CHART



MNRANGE	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	2569	2569	8.00	8.00
-40 -35	1	2570	0.00	8.01
-35 -30	5	2575	0.02	8.02
-30 -25	2	2577	0.01	8.03
-25 -20	1	2578	0.00	8.03
-20 -15	4	2582	0.01	8.04
-15 -10	42	2624	0.13	8.17
-10 -5	591	3215	1.84	10.02
-5 -0	9141	12356	28.48	38.49
0	4	12360	0.01	38.51
0-5	19711	32071	61.41	99.91
5-10	22	32093	0.07	99.98
10-15	6	32099	0.02	100.00

Figure 5-16. Results of descriptive statistics for mean temperature of zone 9 shown in graphical and numerical forms for OC-3.

FREQUENCY BAR CHART



MNRANGE	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	8443	8443	26.30	26.30
-40 -35	2795	11238	8.71	35.01
-35 -30	2053	13291	6.40	41.41
-30 -25	1823	15114	5.68	47.09
-25 -20	2439	17553	7.60	54.68
-20 -15	1346	18899	4.19	58.88
-15 -10	333	19232	1.04	59.91
-10 -5	1484	20716	4.62	64.54
-5 -0	2849	23565	8.88	73.41
0	3	23568	0.01	73.42
0-5	8472	32040	26.39	99.82
5-10	1	32041	0.00	99.82
>40	58	32099	0.18	100.00

Figure 5-17. Results of descriptive statistics for mean temperature of zone 10 shown in graphical and numerical forms for OC-3.

Originally, the time-averaged temperatures were obtained considering all temperature values reported. The results showed a typical time-averaged temperature of 845 degrees for each zone as shown in Figure 5-18. It was suspected that the very low temperatures, below 50°C, during the reactor down time had "contaminated" the expected real time-averaged temperature (closer to 900°C than 845°C). The detailed temperature analysis, as shown in Figures 5-5 through 5-17 revealed that more realistic time-averaged temperatures can be obtained if the low temperatures during the reactor down-time/start-up are removed from the averaging process. The time-averaged zone temperatures used in the creep rate analysis have been obtained by considering the temperatures which fell in the 900 ± 100°C temperature band. The new time- averaged temperatures are shown in Figure 5-19. As indicated in Figure 5-19, the mean time-averaged temperatures for all zones except for zone 10 are practically 900°C with standard deviation of less than 4°C. The relatively low mean temperature and large standard deviation for zone 10 are attributed to the fact that less control has been exerted on the temperature for this zone. The overall average temperature and its corresponding standard deviation are given in Figure 5-20(a). Since the specimens of the graphite grade H-451, the grade of interest, have been positioned above zone 10 the average temperature for these specimens was considered to be the mean temperature of the first 9 zones. This mean temperature is T = 899.90°C, as shown in Figure 5-20(b).

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
ZONE=1					
TEMP_A	32099	842.20820307	206.93761328	76.58617000	1307.38300000
TEMP_B	32099	838.83807841	211.72552150	38.23931340	908.20070000
TEMP_MN	32099	840.52314074	207.59376438	75.08617000	908.49585000
ZONE=2					
TEMP_A	32099	849.77936692	202.28760488	62.46326000	1307.19460000
TEMP_B	32099	718.23438696	338.28617216	46.45661000	911.16190000
TEMP_MN	32099	784.00687694	231.97667014	73.74319000	968.33240000
ZONE=3					
TEMP_A	32099	850.69468585	198.21019108	97.27919000	1333.18000000
TEMP_B	32099	850.67785719	198.30713057	97.27919000	1333.18000000
TEMP_MN	32099	850.68627152	198.25840585	97.27919000	1333.18000000
ZONE=4					
TEMP_A	32099	844.70224691	198.99217507	78.75274000	949.69730000
TEMP_B	32099	841.17145115	203.90294282	98.46945000	907.55350000
TEMP_MN	32099	842.93684903	199.50716343	89.51334000	906.99010000
ZONE=5					
TEMP_A	32099	850.46708367	199.56133225	88.00322000	1331.56940000
TEMP_B	32099	841.38586086	203.61210102	95.32352000	910.54930000
TEMP_MN	32099	845.92647226	194.03631153	93.81483000	911.01150000

Figure 5-18. Results of descriptive statistics for temperatures of all zones of OC-3 (Temp_A, Temp_B, Temp_MN, are temperatures of west column, east column, and the mean temperature, respectively).

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
ZONE=6					
TEMP_A	32099	850.70189119	199.82251051	84.90254000	1327.89780000
TEMP_B	32099	841.66291986	202.28073743	99.39212000	910.75020000
TEMP_MN	32099	846.18240553	193.49684829	94.15694000	913.50720000
ZONE=7					
TEMP_A	32099	850.55804373	199.65957542	86.14124000	1328.34460000
TEMP_B	32099	841.52926886	203.11765819	96.47693000	911.28660000
TEMP_MN	32099	846.04365629	193.79683220	93.01318000	910.02390000
ZONE=8					
TEMP_A	32099	850.50798162	200.41677498	82.06052000	1321.80920000
TEMP_B	32099	841.63817463	202.78496049	91.58515000	909.93900000
TEMP_MN	32099	846.07307812	193.98838937	91.61473000	910.09440000
ZONE=9					
TEMP_A	32099	849.82201789	201.70140230	78.38916000	1317.76330000
TEMP_B	32099	840.75304105	206.03025556	88.25224000	909.96950000
TEMP_MN	32099	845.28752947	196.36450975	83.32070000	912.56825000
ZONE=10					
TEMP_A	32099	826.49542023	193.01377720	-424.77350000	1340.58140000
TEMP_B	0	.	.	.	.
TEMP_MN	32099	826.49542023	193.01377720	-424.77350000	1340.58140000

Figure 5-18 (continued)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
ZONE=1					
TEMP_A	29538	900.03738136	2.66718283	804.14160000	908.79100000
TEMP_B	29538	899.78726772	2.86818768	806.10260000	908.20070000
TEMP_MN	29538	899.91232454	2.39677741	805.12210000	908.49585000
ZONE=2					
TEMP_A	29559	899.97828133	3.27146565	800.39990000	918.11990000
TEMP_B	24811	900.05780200	3.36268428	800.08840000	911.16190000
TEMP_MN	24815	900.02519829	3.38449347	800.76905000	968.33240000
ZONE=3					
TEMP_A	29551	899.92333357	2.79610522	800.29760000	940.88530000
TEMP_B	29551	899.93312397	2.79379986	800.00000000	940.88530000
TEMP_MN	29551	899.92822877	2.79292410	800.14880000	940.88530000
ZONE=4					
TEMP_A	29628	899.94466295	3.93838761	800.71280000	949.69730000
TEMP_B	29539	899.95118042	2.76325974	807.75830000	907.55350000
TEMP_MN	29542	899.97606016	2.52851892	801.07850000	906.99010000
ZONE=5					
TEMP_A	29545	899.83465664	2.98144442	800.35060000	911.47370000
TEMP_B	29543	900.03303477	2.83129860	801.23800000	910.54930000
TEMP_MN	29543	899.93716362	2.60425291	805.59970000	911.01150000
ZONE=6					
TEMP_A	29557	900.06105592	2.75937549	800.84840000	918.25760000
TEMP_B	29554	899.80794075	3.05072772	800.17990000	910.75020000
TEMP_MN	29554	899.93752187	2.62264876	807.01440000	913.50720000
ZONE=7					
TEMP_A	29564	899.79674515	3.03014248	800.62430000	941.54790000
TEMP_B	29556	899.85877420	3.14795075	803.74020000	911.28660000
TEMP_MN	29557	899.83498035	2.70928645	803.79345000	910.02390000
ZONE=8					
TEMP_A	29567	899.91134353	3.00940239	801.14400000	914.51320000
TEMP_B	29563	899.75505965	3.23583045	800.82540000	909.93900000
TEMP_MN	29565	899.83220238	2.93195605	800.20540000	910.09440000
ZONE=9					
TEMP_A	29558	899.68699381	3.08052622	802.39160000	919.26440000
TEMP_B	29556	899.83951932	3.31902921	801.57670000	909.96950000
TEMP_MN	29556	899.76653428	2.91705782	803.00795000	912.56825000
ZONE=10					
TEMP_A	29534	879.91944189	19.60234401	804.78640000	905.07030000
TEMP_B	0	.	.	.	.
TEMP_MN	29534	879.91944189	19.60234401	804.78640000	905.07030000

Figure 5-19. Descriptive statistics for temperatures in the 900°C ± 100°C band for different zones of OC-3.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
TEMP_A	295601	897.91115484	9.10346049	800.29760000	949.69730000
TEMP_B	261211	899.88849445	3.04515243	800.00000000	940.88530000
TEMP_MN	290755	897.87349006	9.07508104	800.14880000	968.33240000

(a) Considering 10 zones.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
TEMP_A	266067	899.90827304	3.08227308	800.29760000	949.69730000
TEMP_B	261211	899.88849445	3.04515243	800.00000000	940.88530000
TEMP_MN	261221	899.90339906	2.76767629	800.14880000	968.33240000

(b) Considering 9 zones.

Figure 5-20. Descriptive statistics for all temperatures in the 900°C ± 100°C band for OC-3.

5.7 Reactor Power

To see the fluctuation of the reactor power during the course of OC-3 experiment some SAS programs, included in Appendix G, were written to determine the values of the reactor power at those times that the setpoints were changed. The variation of reactor power with time is depicted in Figure 5-21.

5.8 Temperature Data for OC-4

The OC-4 experiment was the second 600°C experiment conducted at ORNL (the first OC-experiment performed at this temperature was OC-2). The OC-4 capsule resided in the ORR core for two cycles of the reactor.

Like OC-3, during the conduction of the OC-4 experiment, the signals reported by the sensors involved were recorded at five-minute intervals. The database for this experiment was a 600-point data base, as opposed to the OC-3 experiment that had 128 point data base. The number of points (channels) devoted to OC-4 was the same as that of OC-3 but examination of the database revealed that in addition to the points for OC-4 some other points associated with other experiments had also been recorded on the magnetic tapes. As a whole, about 215 channels out of 600 available had been used.

In order to minimize the size of data set and hence decrease the number of target tapes (to contain the translated and formatted data), the blank points (unused channels) were not copied onto the target tapes. However,

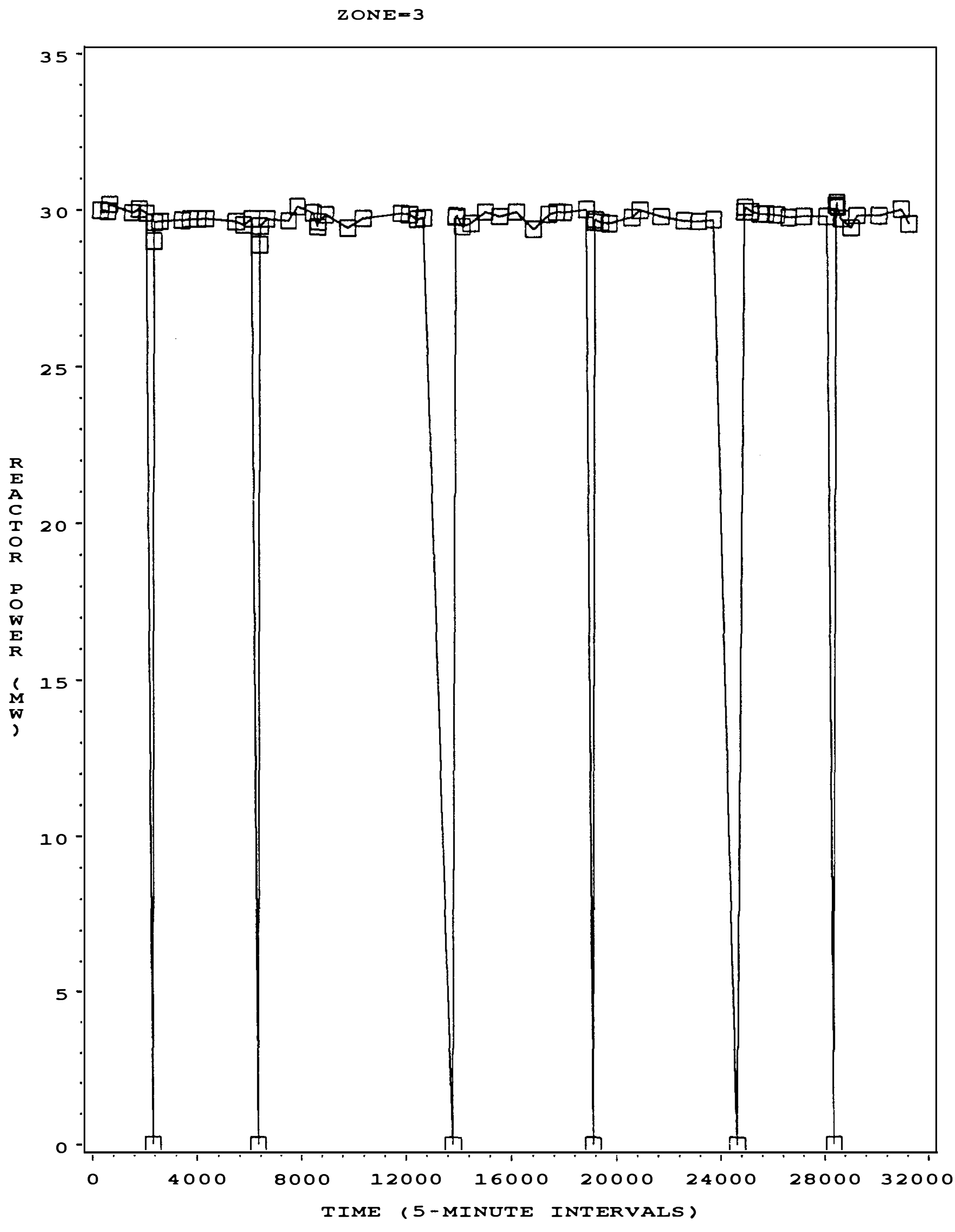


Figure 5-21. Variation of reactor power with time for OC-3 experiment.

three IBM cartridge tapes were required to contain the cut off database. A typical 215-point database for OC-4 is depicted in Figure 5-22. The point names of interest are the same as the ones shown in Table 5-2 (p. 58).

5.8.1 Analysis of Temperature Data for OC-4

Examination of the progress reports and the log books for OC-4 experiment indicated that the procedures used in OC-3 were also used in OC-4 to control the experiment temperature. This was due to the fact that OC-3 and OC-4 mainly, had the same design except that a lower temperature was maintained on the graphite specimens in OC-4 (600°C instead of 900°C).

Considering the similarity of temperature control for OC-4 to that for OC-3, the algorithm used for analyzing the OC-3 temperature data (Section 5-6.1) was adopted for OC-4. Figures 5-23 and 5-24 show the variation of the setpoint values and specimen mean temperatures with time for zone 5. Again, like the similar figures for OC-3 experiment, the points in the graphs have been found at each z-trace time. Appendix D contains the figures for the remaining zones.

The results of some crude temperature analyses for OC-4 are depicted in Figures 5-25 and 5-26. A summary of detailed temperature analyses is given in Figure 5-27. Descriptive statistics for deviation of mean temperature from 600°C are shown in graphical and numerical forms in Figures 5-28 through 5-37. The time-averaged temperatures for each zone, considering all

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
1	21DEC1980	0:03:00	$$$$$	-12288	97	1	V0	.	0
2	21DEC1980	0:03:00	CAULIM	514	64	4	I1	10	0
3	21DEC1980	0:03:00	F1802	43	353	197	F1	-0	-4
4	21DEC1980	0:03:00	ALMLIM	514	64	198	I1	20	0
5	21DEC1980	0:03:00	OC1BKU	768	267	2	BK	1	-1
6	21DEC1980	0:03:00	F1803	42	353	171	F2	120	490
7	21DEC1980	0:03:00	F1804	46	353	172	F1	139	1142
8	21DEC1980	0:03:00	F1812	3072	299	173	F1	1	-1
9	21DEC1980	0:03:00	F1813	47	353	175	F1	122	996
10	21DEC1980	0:03:00	.TREF6	-16266	353	174	T6	65	434
11	21DEC1980	0:03:00	I02	770	321	176	J2	.	0
12	21DEC1980	0:03:00	I03	512	321	3	J3	0	66
13	21DEC1980	0:03:00	I04	768	321	6	J4	.	0
14	21DEC1980	0:03:00	I05	1	321	7	J5	.	0
15	21DEC1980	0:03:00	I06	257	321	8	J6	0	383
16	21DEC1980	0:03:00	I07	513	321	9	J7	1	747
17	21DEC1980	0:03:00	108	769	321	180	J8	1	566
18	21DEC1980	0:03:00	I09	2	321	179	J9	1	752
19	21DEC1980	0:03:00	I10	258	321	95	JA	1	822
20	21DEC1980	0:03:00	J01	-28640	353	162	J1	316	670
21	21DEC1980	0:03:00	J02	-28639	353	161	J2	-2	-4
22	21DEC1980	0:03:00	J03	-28638	353	163	J3	46	98
23	21DEC1980	0:03:00	J04	-28637	353	164	J4	-3	-4
24	21DEC1980	0:03:00	J05	-28636	353	190	J5	-2	-4
25	21DEC1980	0:03:00	J06	-28635	353	189	J6	346	822
26	21DEC1980	0:03:00	J07	-28634	353	188	J7	558	1308
27	21DEC1980	0:03:00	J08	-28613	353	196	J8	814	1920
28	21DEC1980	0:03:00	J09	-28632	353	11	J9	1022	2446
29	21DEC1980	0:03:00	J10	-28631	353	12	JA	773	1864
30	21DEC1980	0:03:00	MTALRM	3840	11	13	MT	1	-1
31	21DEC1980	0:03:00	NUMHRS	514	64	14	I1	204	0
32	21DEC1980	0:03:00	OCSBDO	512	267	15	DO	1	-1
33	21DEC1980	0:03:00	OCSBMU	256	267	16	MU	1	0
34	21DEC1980	0:03:00	PWRWDG	3840	427	17	MO	-1	0
35	21DEC1980	0:03:00	P1503	-12230	511	18	P1	764	6260
36	21DEC1980	0:03:00	P1503D	3328	427	19	P1	1	-1
37	21DEC1980	0:03:00	P1503H	513	427	20	P1	1	-1
38	21DEC1980	0:03:00	REAPWR	53	483	21	JB	27991870	4620
39	21DEC1980	0:03:00	SETLIM	514	320	22	I1	10	0
40	21DEC1980	0:03:00	T01A	-16381	511	23	T2	532	3476
41	21DEC1980	0:03:00	T01ASP	514	64	24	J1	532	0
42	21DEC1980	0:03:00	T01B	-16380	511	25	T2	549	3594
43	21DEC1980	0:03:00	T01BSP	514	64	26	J1	548	0
44	21DEC1980	0:03:00	T02A	-16379	511	27	T2	552	3622
45	21DEC1980	0:03:00	T02ASP	514	64	28	J2	549	0

Figure 5-22. Complete data set for the 215-point data base (obtained from 600-point data base) for OC-4.

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
46	21DEC1980	0:03:00	T02B	-16378	511	29	T2	540	3534
47	21DEC1980	0:03:00	T02BSP	514	64	30	J2	537	0
48	21DEC1980	0:03:00	T03A	-16377	511	211	T2	538	3518
49	21DEC1980	0:03:00	T03ASP	514	64	210	J3	535	0
50	21DEC1980	0:03:00	T03B	-16376	511	31	T2	508	3308
51	21DEC1980	0:03:00	T03BSP	514	64	32	J3	510	0
52	21DEC1980	0:03:00	T04A	-16375	511	33	T2	542	3552
53	21DEC1980	0:03:00	T04ASP	514	64	5	J4	540	0
54	21DEC1980	0:03:00	T04B	-16374	511	34	T2	510	3344
55	21DEC1980	0:03:00	T04BSP	514	64	35	J4	512	0
56	21DEC1980	0:03:00	.TREF1	-12259	117	36	T1	20	48
57	21DEC1980	0:03:00	P1504	-12233	511	37	P2	770	6308
58	21DEC1980	0:03:00	P1504D	3584	427	57	P2	1	-1
59	21DEC1980	0:03:00	P1504H	769	427	58	P2	1	-1
60	21DEC1980	0:03:00	P1505	-12232	511	59	P3	786	6440
61	21DEC1980	0:03:00	P1505D	1	427	60	P3	1	-1
62	21DEC1980	0:03:00	T308	-16258	353	61	T7	309	1628
63	21DEC1980	0:03:00	P1505H	1025	427	63	P3	1	-1
64	21DEC1980	0:03:00	P1506	-12231	511	64	P4	767	6288
65	21DEC1980	0:03:00	P1506D	257	427	65	P4	1	-1
66	21DEC1980	0:03:00	P1506H	1281	427	66	P4	1	-1
67	21DEC1980	0:03:00	P1703	-12237	511	67	P1	756	6194
68	21DEC1980	0:03:00	P1703D	1280	427	68	P1	1	-1
69	21DEC1980	0:03:00	P1703H	1024	427	69	P1	1	-1
70	21DEC1980	0:03:00	P1704	-12240	511	70	P2	752	6164
71	21DEC1980	0:03:00	P1704D	1792	427	71	P2	1	-1
72	21DEC1980	0:03:00	P1704H	1536	427	72	P2	1	-1
73	21DEC1980	0:03:00	P1705	-12236	511	73	P3	798	6538
74	21DEC1980	0:03:00	P1705D	2304	427	74	P3	1	-1
75	21DEC1980	0:03:00	P1705H	2048	427	75	P3	1	-1
76	21DEC1980	0:03:00	P1706	-12239	511	76	P4	800	6552
77	21DEC1980	0:03:00	P1706D	2816	427	77	P4	1	-1
78	21DEC1980	0:03:00	P1706H	2560	427	78	P4	1	-1
79	21DEC1980	0:03:00	P1805D	0	427	79	P1	1	-1
80	21DEC1980	0:03:00	P1805H	256	427	80	P1	1	-1
81	21DEC1980	0:03:00	P1806D	512	427	81	P1	1	-1
82	21DEC1980	0:03:00	P1806H	768	427	82	P1	1	-1
83	21DEC1980	0:03:00	P1814	-12238	511	83	P5	61	5040
84	21DEC1980	0:03:00	STDATE	514	64	38	I1	7613400	0
85	21DEC1980	0:03:00	ST00N	514	320	181	I1	.	0
86	21DEC1980	0:03:00	ST00S	514	320	39	I1	.	0
87	21DEC1980	0:03:00	T00N	-16354	353	213	T2	589	3876
88	21DEC1980	0:03:00	T00S	-16382	353	212	T2	602	3966
89	21DEC1980	0:03:00	T202	-16265	353	84	T7	377	2102
90	21DEC1980	0:03:00	T05ASP	514	64	85	J5	507	0

Figure 5-22 (continued)

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
91	21DEC1980	0:03:00	T201	-16263	353	86	T7	398.945	2250
92	21DEC1980	0:03:00	T05BSP	514	64	214	J5	524.505	0
93	21DEC1980	0:03:00	T05C	-16371	353	114	T2	530.292	3468
94	21DEC1980	0:03:00	T05D	-16370	353	112	T2	506.075	3270
95	21DEC1980	0:03:00	F2245	4197	352	110	V1	35.412	58
96	21DEC1980	0:03:00	T06ASP	514	64	215	J6	514.570	0
97	21DEC1980	0:03:00	T2208	-16284	352	183	V1	804.200	58
98	21DEC1980	0:03:00	T06BSP	514	64	87	J6	522.930	0
99	21DEC1980	0:03:00	T06C	-16369	353	88	T2	505.499	3298
100	21DEC1980	0:03:00	T2207	-16284	352	40	V1	840.600	58
101	21DEC1980	0:03:00	T07ASP	514	64	41	J7	508.144	0
102	21DEC1980	0:03:00	T2206	-16284	352	42	V1	843.000	58
103	21DEC1980	0:03:00	T07BSP	514	64	43	J7	507.856	0
104	21DEC1980	0:03:00	T2205	-16284	352	44	V1	18.500	58
105	21DEC1980	0:03:00	T08ASP	514	64	45	J8	529.286	0
106	21DEC1980	0:03:00	T2204	-16284	352	46	V1	846.000	58
107	21DEC1980	0:03:00	T08BSP	514	64	47	J8	526.691	0
108	21DEC1980	0:03:00	T2203	-16284	352	48	V1	21.500	58
109	21DEC1980	0:03:00	T09ASP	514	64	49	J9	543.657	0
110	21DEC1980	0:03:00	TST114	-16270	97	50	T7	63.488	-14
111	21DEC1980	0:03:00	T09BSP	514	64	51	J9	524.343	0
112	21DEC1980	0:03:00	TST113	-16271	97	52	T7	64.099	-8
113	21DEC1980	0:03:00	T10ASP	514	64	53	JA	531.811	0
114	21DEC1980	0:03:00	TST112	-16272	97	54	T7	110.914	300
115	21DEC1980	0:03:00	T10BSP	514	64	55	JA	510.189	0
116	21DEC1980	0:03:00	T11A	-16358	353	177	T2	148.516	856
117	21DEC1980	0:03:00	T27A	-16357	353	90	T2	92.639	486
118	21DEC1980	0:03:00	T28A	-16356	353	178	T2	37.674	124
119	21DEC1980	0:03:00	ZCONSW	3841	43	92	S4	-1.000	-1
120	21DEC1980	0:03:00	Z1807N	4140	353	93	Z1	15.674	2570
121	21DEC1980	0:03:00	Z1808S	4141	353	94	Z1	15.955	2616
122	21DEC1980	0:03:00	T123	-16306	353	187	T6	-1.494	0
123	21DEC1980	0:03:00	T107	-16319	353	96	T4	17.402	-34
124	21DEC1980	0:03:00	T108	-16318	353	186	T4	21.101	-8
125	21DEC1980	0:03:00	T109	-16330	353	98	T4	63.439	264
126	21DEC1980	0:03:00	T111	-16316	353	99	T4	21.409	-8
127	21DEC1980	0:03:00	T112	-16315	353	185	T4	19.560	-22
128	21DEC1980	0:03:00	T2202	-16284	352	101	V1	786.300	58
129	21DEC1980	0:03:00	ZLITE	2048	1	184	ZL	1.000	0
130	21DEC1980	0:03:00	T114	-16283	353	103	T8	19.668	-16
131	21DEC1980	0:03:00	T115	-16313	353	191	T4	20.793	-12
132	21DEC1980	0:03:00	T117	-16311	353	105	T4	16.168	-40
133	21DEC1980	0:03:00	T118	-16310	353	192	T4	20.177	-14
134	21DEC1980	0:03:00	T119	-16309	353	107	T4	21.101	-10
135	21DEC1980	0:03:00	T120	-16308	353	193	T4	19.869	-14

Figure 5-22 (continued)

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
136	21DEC1980	0:03:00	T121	-16307	353	109	T4	16.477	-36
137	21DEC1980	0:03:00	.TREFW	-16299	353	194	T4	6.287	-106
138	21DEC1980	0:03:00	T127	-16304	353	111	T4	18.019	-32
139	21DEC1980	0:03:00	T128	-16303	353	182	T4	19.869	-20
140	21DEC1980	0:03:00	T129	-16302	353	113	T4	16.168	-42
141	21DEC1980	0:03:00	T130	-16301	353	195	T4	19.869	-18
142	21DEC1980	0:03:00	T131	-16300	353	115	T4	-0.828	-152
143	21DEC1980	0:03:00	T124	-16305	353	150	T4	18.636	-24
144	21DEC1980	0:03:00	T307	-16260	353	123	T7	357.109	1966
145	21DEC1980	0:03:00	T304	-16261	353	124	T7	457.682	2662
146	21DEC1980	0:03:00	T133A	-16296	353	125	T4	15.551	-48
147	21DEC1980	0:03:00	T133B	-16295	353	116	T4	20.485	-18
148	21DEC1980	0:03:00	T309	-16257	353	151	T7	49.416	-104
149	21DEC1980	0:03:00	T306	-16259	353	126	T7	402.714	2278
150	21DEC1980	0:03:00	T106	-16285	353	127	T8	22.858	-14
151	21DEC1980	0:03:00	T110	-16284	353	152	T8	22.858	-10
152	21DEC1980	0:03:00	T113	-16314	353	130	T4	33.104	68
153	21DEC1980	0:03:00	T122	-16282	353	131	T8	79.434	100
154	21DEC1980	0:03:00	T125	-16281	353	165	T8	29.188	0
155	21DEC1980	0:03:00	T126	-16280	353	132	T8	42.672	18
156	21DEC1980	0:03:00	T132	-16279	353	133	T8	32.327	0
157	21DEC1980	0:03:00	T134	-16278	353	134	T8	34.410	2
158	21DEC1980	0:03:00	T303	-16262	353	135	T7	455.372	2646
159	21DEC1980	0:03:00	T133	-16293	353	136	T5	16.930	-8
160	21DEC1980	0:03:00	.TREF3	-12196	353	153	T3	23.858	896
161	21DEC1980	0:03:00	F804	108	353	122	F4	-0.070	-4
162	21DEC1980	0:03:00	F803	-12181	353	143	F3	-0.935	-76
163	21DEC1980	0:03:00	F805	-12179	353	154	F3	1.097	-28
164	21DEC1980	0:03:00	F806	-12178	353	155	F5	-0.676	-78
165	21DEC1980	0:03:00	T116	-16312	353	138	T4	115.101	608
166	21DEC1980	0:03:00	T2201	-16284	352	139	V1	746.800	58
167	21DEC1980	0:03:00	T203	-16291	353	140	T7	371.654	2062
168	21DEC1980	0:03:00	T204	-16269	353	141	T7	327.655	1760
169	21DEC1980	0:03:00	T205	-16268	353	142	T7	283.126	1456
170	21DEC1980	0:03:00	T206	-16267	353	156	T7	266.652	1344
171	21DEC1980	0:03:00	FCV740	3	321	159	J1	.	0
172	21DEC1980	0:03:00	FCV742	259	321	146	J1	.	0
173	21DEC1980	0:03:00	F1202	60	353	147	F4	1.955	112
174	21DEC1980	0:03:00	F1205	61	353	157	F4	11.870	680
175	21DEC1980	0:03:00	F1203	62	353	91	F4	31.491	1804
176	21DEC1980	0:03:00	F1206	63	353	89	F4	12.114	694
177	21DEC1980	0:03:00	T05A	-16373	511	167	T2	509.824	3324
178	21DEC1980	0:03:00	T05B	-16372	511	168	T2	528.563	3456
179	21DEC1980	0:03:00	F2244	4197	352	169	V1	5.611	58
180	21DEC1980	0:03:00	F2215	-12187	352	170	V1	44.028	58

Figure 5-22 (continued)

SENSOR	DATE	TIME	POINT	GAINCHAN	FLAGWORD	SEQUENCE	SENSTYPE	REALDATA	RAWDATA
181	21DEC1980	0:03:00	RR101A	4197	352	166	V1	4.506	57
182	21DEC1980	0:03:00	T10A	-16345	511	128	T2	531.734	3476
183	21DEC1980	0:03:00	TST31	-16353	97	108	T2	18.596	0
184	21DEC1980	0:03:00	T07B	-16365	511	106	T2	504.057	3282
185	21DEC1980	0:03:00	T07A	-16366	511	104	T2	504.057	3282
186	21DEC1980	0:03:00	T06B	-16367	511	102	T2	524.527	3430
187	21DEC1980	0:03:00	T06A	-16368	511	100	T2	512.707	3346
188	21DEC1980	0:03:00	HFRVLT	20581	96	97	V1	0.919	58
189	21DEC1980	0:03:00	HFRPWR	20580	352	117	V1	96.693	58
190	21DEC1980	0:03:00	HFRDAT	3584	267	118	HF	1.000	-1
191	21DEC1980	0:03:00	T08A	-16364	511	209	T2	527.986	3450
192	21DEC1980	0:03:00	T08B	-16363	511	158	T2	527.986	3452
193	21DEC1980	0:03:00	T09A	-16362	511	145	T2	542.976	3558
194	21DEC1980	0:03:00	T09B	-16361	511	149	T2	524.815	3432
195	21DEC1980	0:03:00	T10B	-16359	511	144	T2	510.400	3330
196	21DEC1980	0:03:00	I01	514	321	62	J2	0.365	352
197	21DEC1980	0:03:00	BNCH1	515	65	148	J1	.	0
198	21DEC1980	0:03:00	BNCH2	771	65	199	J1	.	0
199	21DEC1980	0:03:00	V01	128	353	200	V2	69.336	5696
200	21DEC1980	0:03:00	V02	129	353	201	V2	81.592	6686
201	21DEC1980	0:03:00	V03	130	353	202	V2	73.901	6060
202	21DEC1980	0:03:00	V04	131	353	203	V2	64.746	5306
203	21DEC1980	0:03:00	V05	132	353	204	V2	47.363	3884
204	21DEC1980	0:03:00	V06	133	353	205	V2	78.076	6400
205	21DEC1980	0:03:00	V07	134	353	206	V2	63.281	5190
206	21DEC1980	0:03:00	V08	135	353	207	V2	99.976	8190
207	21DEC1980	0:03:00	V09	136	353	208	V2	80.005	6552
208	21DEC1980	0:03:00	V10	137	353	119	V2	74.097	6066
209	21DEC1980	0:03:00	T301	-16264	353	129	T7	387.340	2180
210	21DEC1980	0:03:00	NORUP	1024	1	120	NU	1.000	0
211	21DEC1980	0:03:00	NORDN	1280	1	121	NK	1.000	0
212	21DEC1980	0:03:00	SOUUP	1536	1	137	SU	1.000	0
213	21DEC1980	0:03:00	SOUDN	1792	1	56	SU	1.000	0
214	21DEC1980	0:03:00	TST01	-16383	97	160	T2	540.670	3552
215	21DEC1980	0:03:00	TST24	-16360	97	10	T2	-20.721	-244

Figure 5-22 (continued)

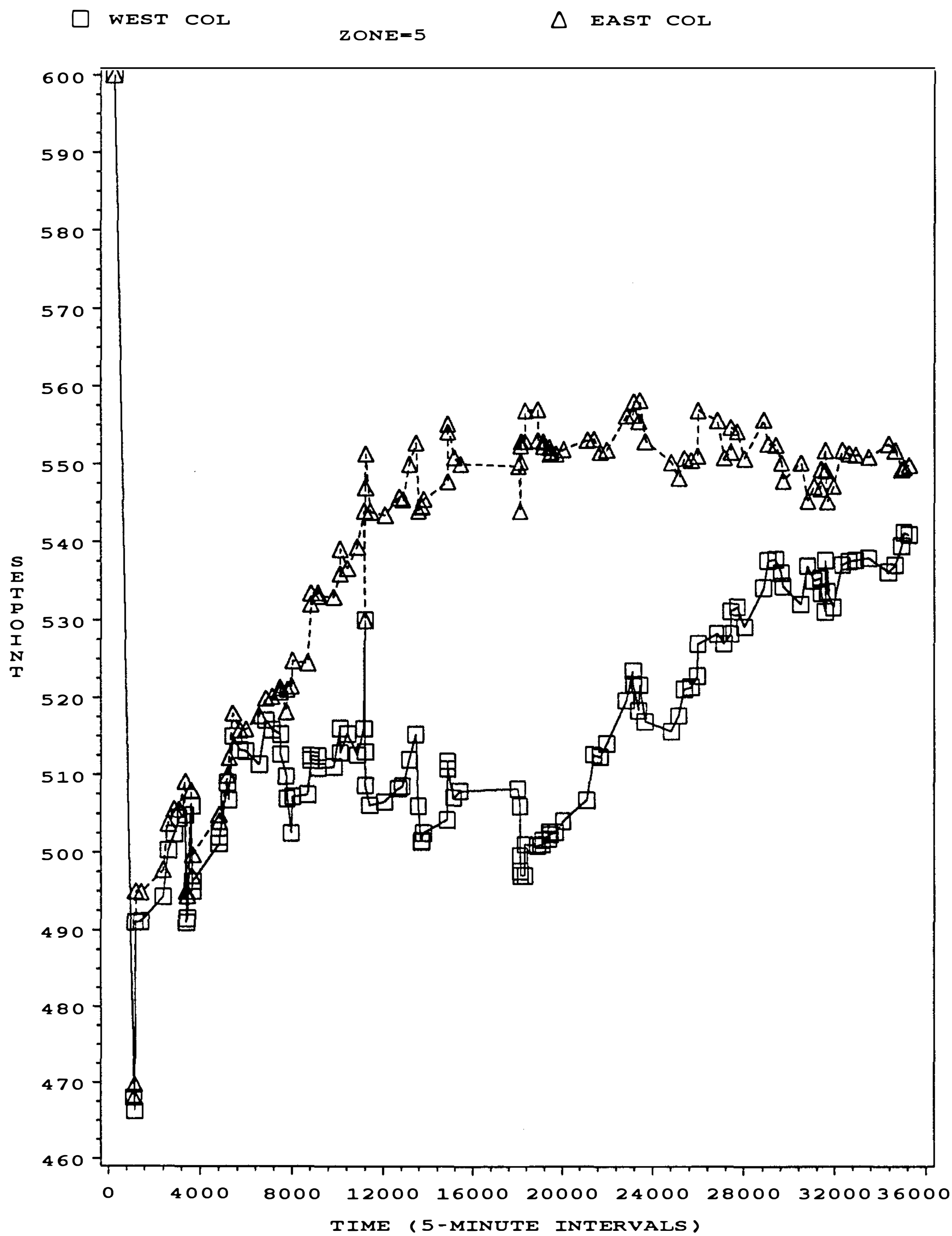


Figure 5-23. Variation of setpoint values with z-trace time for zone 5 of the west and east columns of OC-4.

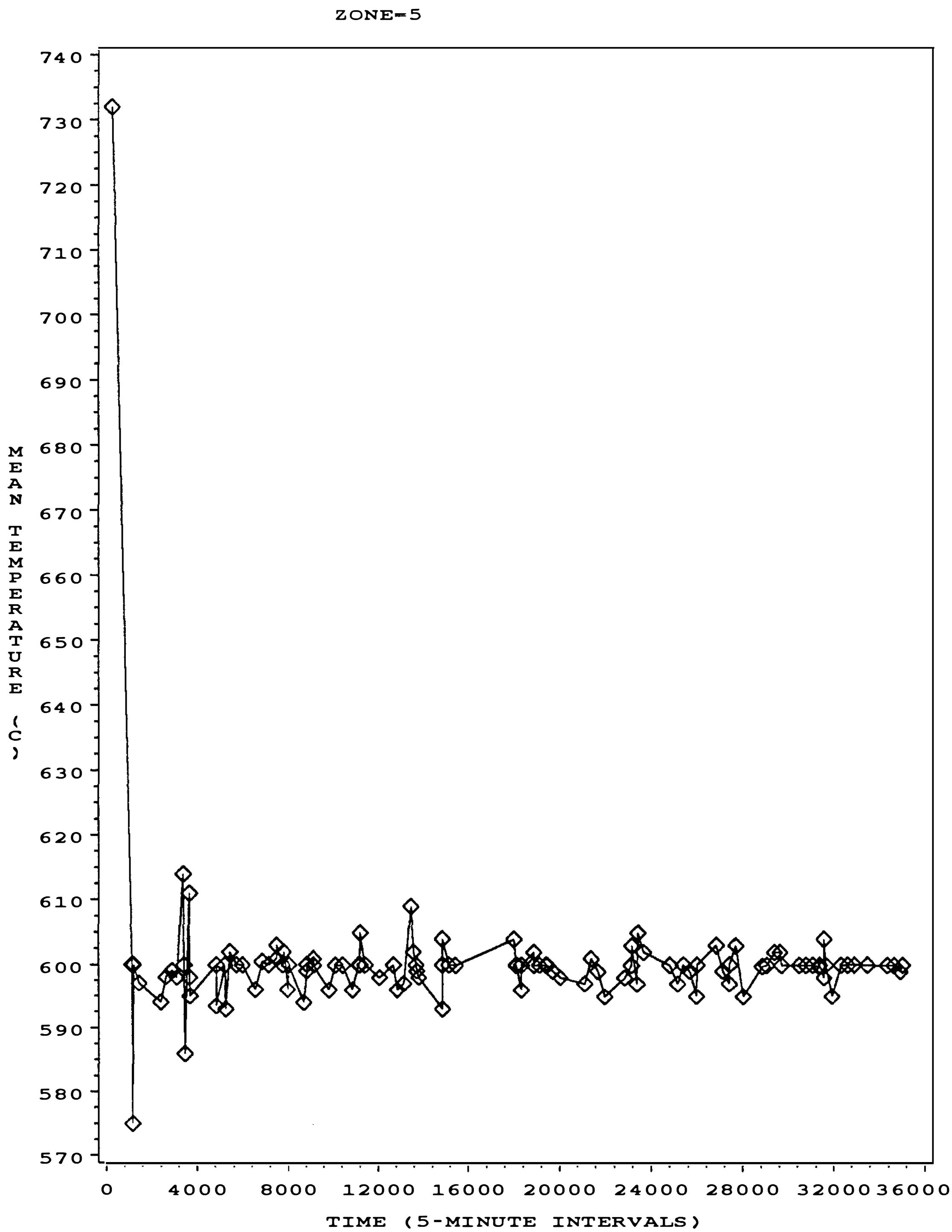


Figure 5-24. Variation of the mean temperature (at z-trace time) for zone 5 of the specimen columns of OC-4.

OBS	ZONE	MN <OR> 0 C	N OF DELTA_MN	MEAN OF DELTA_MN	STD OF DELTA_MN	MODE OF DELTA_MN
1	1	BELOW 600 C	9478	-106.17	200.212	-0.09
2	1	ABOVE 600 C	25783	10.32	29.028	0.19
3	2	BELOW 600 C	5219	-190.62	237.055	-477.54
4	2	ABOVE 600 C	30042	11.60	21.058	0.84
5	3	BELOW 600 C	8218	-106.70	199.767	-495.00
6	3	ABOVE 600 C	26816	11.27	33.689	106.76
7	4	BELOW 600 C	7650	-93.33	187.544	-479.00
8	4	ABOVE 600 C	27072	10.52	31.568	0.30
9	5	BELOW 600 C	6388	-139.84	211.305	-0.05
10	5	ABOVE 600 C	19457	13.80	34.336	0.30
11	6	BELOW 600 C	6753	-113.82	196.613	-0.01
12	6	ABOVE 600 C	12584	0.40	0.522	0.20
13	7	BELOW 600 C	5975	-127.70	202.676	-419.37
14	7	ABOVE 600 C	13362	0.74	6.968	0.03
15	8	BELOW 600 C	6658	-117.32	199.431	-421.53
16	8	ABOVE 600 C	12679	0.47	0.369	0.21
17	9	BELOW 600 C	11829	-210.30	160.872	-269.72
18	9	ABOVE 600 C	7508	0.44	0.407	0.00
19	10	BELOW 600 C	8436	-96.17	188.530	-0.03

OBS	MIN OF DELTA_MN	Q1 OF DELTA_MN	MEDIAN OF DELTA_MN	Q3 OF DELTA_MN	MAX OF DELTA_MN
1	-564.99	-3.65	-1.74	-0.2019	0.000
2	0.00	0.28	0.53	1.9620	108.620
3	-565.15	-477.62	-2.00	-0.7241	-0.000
4	0.00	0.57	2.67	16.0780	89.996
5	-600.07	-4.53	-1.26	-0.1229	0.000
6	0.00	0.22	0.46	2.0310	145.087
7	-600.00	-2.70	-1.70	-0.4089	0.000
8	0.00	0.32	0.56	1.5777	128.212
9	-565.15	-428.78	-1.80	-0.2315	0.000
10	0.00	0.30	0.60	2.8238	114.017
11	-565.30	-94.14	-1.80	-0.1680	0.000
12	0.00	0.18	0.33	0.4885	13.526
13	-565.15	-417.55	-1.68	-0.1223	0.000
14	0.00	0.20	0.40	0.6099	335.762
15	-565.30	-166.66	-1.96	-0.2488	-0.000
16	0.00	0.24	0.43	0.6363	9.515
17	-565.45	-270.10	-268.76	-1.9914	0.000
18	0.00	0.18	0.38	0.6216	14.728
19	-565.30	-3.00	-1.07	-0.1862	-0.000

OBS	ZONE	MN <OR> 0 C	N OF DELTA_MN	MEAN OF DELTA_MN	STD OF DELTA_MN	MODE OF DELTA_MN
20	10	ABOVE 600 C	10901	0.548917	0.633158	0.0238

OBS	MIN OF DELTA_MN	Q1 OF DELTA_MN	MEDIAN OF DELTA_MN	Q3 OF DELTA_MN	MAX OF DELTA_MN
20	0.0001	0.2071	0.4409	0.7502	26.1433

Figure 5-25. Descriptive statistics for temperature by zones: grouped by delta T's above and below $0^{\circ}C$ for OC-4.

OBS	ZONE	MNMTC <OR> -300 C	N OF DELTA_MN	MEAN OF DELTA_MN	STD OF DELTA_MN	MODE OF DELTA_MN
1	1	< -300 C	1963	-494.90	32.395	-489.54
2	1	>=-300 C	33298	6.95	28.341	0.19
3	2	< -300 C	1963	-493.26	33.017	-477.54
4	2	>=-300 C	33298	9.67	22.837	0.84
5	3	< -300 C	1738	-488.59	46.038	-495.00
6	3	>=-300 C	33296	8.24	32.178	106.76
7	4	< -300 C	1426	-481.00	46.141	-479.00
8	4	>=-300 C	33296	7.71	30.372	0.30
9	5	< -300 C	1884	-462.95	47.008	-429.86
10	5	>=-300 C	23961	10.32	33.090	-0.05
11	6	< -300 C	1633	-457.64	52.703	-420.73
12	6	>=-300 C	17704	-0.92	10.494	0.20
13	7	< -300 C	1633	-453.52	51.964	-419.37
14	7	>=-300 C	17704	-0.71	13.430	0.03
15	8	< -300 C	1634	-462.06	52.816	-421.53
16	8	>=-300 C	17703	-1.14	12.946	0.21
17	9	< -300 C	1681	-468.82	52.273	-433.68
18	9	>=-300 C	17656	-96.07	128.659	-269.72
19	10	< -300 C	1635	-476.16	39.990	-455.96

OBS	MIN OF DELTA_MN	Q1 OF DELTA_MN	MEDIAN OF DELTA_MN	Q3 OF DELTA_MN	MAX OF DELTA_MN
1	-564.99	-500.71	-489.66	-487.47	-304.35
2	-291.75	0.04	0.38	0.89	108.62
3	-565.15	-503.40	-479.04	-477.17	-328.36
4	-282.06	0.38	2.04	14.66	90.00
5	-600.07	-495.00	-481.75	-458.49	-319.39
6	-287.50	0.07	0.32	1.44	145.09
7	-600.00	-495.61	-479.00	-449.94	-324.42
8	-289.91	0.14	0.44	1.13	128.21
9	-565.15	-483.00	-446.51	-429.60	-312.13
10	-298.53	0.11	0.43	1.91	114.02
11	-565.30	-484.89	-421.94	-420.58	-305.34
12	-289.21	-0.06	0.21	0.42	13.53
13	-565.15	-469.70	-420.70	-419.56	-300.54
14	-288.07	0.01	0.27	0.53	335.76
15	-565.30	-490.35	-423.15	-421.71	-315.03
16	-293.15	-0.06	0.28	0.55	9.52
17	-565.45	-495.57	-434.65	-433.63	-303.65
18	-298.41	-268.69	-0.15	0.30	14.73
19	-565.30	-480.85	-458.02	-455.83	-304.65

OBS	ZONE	MNMTC <OR> -300 C	N OF DELTA_MN	MEAN OF DELTA_MN	STD OF DELTA_MN	MODE OF DELTA_MN
20	10	>=-300 C	17702	-1.512	15.9041	0.0238

OBS	MIN OF DELTA_MN	Q1 OF DELTA_MN	MEDIAN OF DELTA_MN	Q3 OF DELTA_MN	MAX OF DELTA_MN
20	-296.52	-0.21839	0.1529	0.539337	26.1433

Figure 5-26. Descriptive statistics for temperature by zones: grouped by delta T's above and below -300°C for OC-4.

ZONE	MNRANGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
1	<-40	2171	0.6	2171	0.6
1	-40 -35	3	0.0	2174	0.6
1	-35 -30	3	0.0	2177	0.6
1	-30 -25	4	0.0	2181	0.6
1	-25 -20	4	0.0	2185	0.6
1	-20 -15	6	0.0	2191	0.6
1	-15 -10	20	0.0	2211	0.6
1	-10 -5	37	0.0	2248	0.6
1	-5 -0	7229	2.1	9477	2.7
1	0	1	0.0	9478	2.7
1	0-5	21578	6.1	31056	8.8
1	5-10	1866	0.5	32922	9.3
1	10-15	45	0.0	32967	9.3
1	>40	2294	0.7	35261	10.0
2	<-40	2165	0.6	37426	10.6
2	-35 -30	5	0.0	37431	10.6
2	-30 -25	3	0.0	37434	10.6
2	-25 -20	10	0.0	37444	10.6
2	-20 -15	20	0.0	37464	10.6
2	-15 -10	5	0.0	37469	10.6
2	-10 -5	29	0.0	37498	10.6
2	-5 -0	2982	0.8	40480	11.5
2	0-5	19071	5.4	59551	16.9
2	5-10	2314	0.7	61865	17.5
2	10-15	468	0.1	62333	17.7
2	15-20	3685	1.0	66018	18.7
2	20-25	2044	0.6	68062	19.3
2	25-30	114	0.0	68176	19.3
2	30-35	42	0.0	68218	19.3
2	35-40	10	0.0	68228	19.3
2	>40	2294	0.7	70522	20.0
3	<-40	2167	0.6	72689	20.6
3	-40 -35	3	0.0	72692	20.6
3	-35 -30	3	0.0	72695	20.6
3	-30 -25	7	0.0	72702	20.6
3	-25 -20	5	0.0	72707	20.6
3	-20 -15	11	0.0	72718	20.6
3	-15 -10	35	0.0	72753	20.6
3	-10 -5	40	0.0	72793	20.6
3	-5 -0	6171	1.8	78964	22.4
3	0	3	0.0	78967	22.4
3	0-5	23794	6.7	102761	29.1

Figure 5-27. Frequency distributions for ranges of temperature variation above and below 0°C for the OC-4 experiment.

ZONE	MNRANGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
3	5-10	670	0.2	103431	29.3
3	10-15	63	0.0	103494	29.4
3	>40	2289	0.6	105783	30.0
4	<-40	2151	0.6	107934	30.6
4	-40 -35	9	0.0	107943	30.6
4	-35 -30	5	0.0	107948	30.6
4	-30 -25	10	0.0	107958	30.6
4	-25 -20	7	0.0	107965	30.6
4	-20 -15	4	0.0	107969	30.6
4	-15 -10	10	0.0	107979	30.6
4	-10 -5	48	0.0	108027	30.6
4	-5 -0	5944	1.7	113971	32.3
4	0	1	0.0	113972	32.3
4	0-5	24314	6.9	138286	39.2
4	5-10	446	0.1	138732	39.3
4	10-15	23	0.0	138755	39.4
4	35-40	1	0.0	138756	39.4
4	>40	2288	0.6	141044	40.0
5	<-40	11463	3.3	152507	43.3
5	-40 -35	4	0.0	152511	43.3
5	-35 -30	7	0.0	152518	43.3
5	-30 -25	9	0.0	152527	43.3
5	-25 -20	1	0.0	152528	43.3
5	-20 -15	4	0.0	152532	43.3
5	-15 -10	13	0.0	152545	43.3
5	-10 -5	19	0.0	152564	43.3
5	-5 -0	4283	1.2	156847	44.5
5	0	1	0.0	156848	44.5
5	0-5	16259	4.6	173107	49.1
5	5-10	842	0.2	173949	49.3
5	10-15	53	0.0	174002	49.3
5	15-20	10	0.0	174012	49.3
5	>40	2293	0.7	176305	50.0
6	<-40	17713	5.0	194018	55.0
6	-40 -35	19	0.0	194037	55.0
6	-35 -30	4	0.0	194041	55.0
6	-30 -25	6	0.0	194047	55.0
6	-25 -20	10	0.0	194057	55.0
6	-20 -15	20	0.0	194077	55.0
6	-15 -10	17	0.0	194094	55.0
6	-10 -5	20	0.0	194114	55.1
6	-5 -0	4866	1.4	198980	56.4

Figure 5-27 (continued)

ZONE	MNRANGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
6	0	2	0.0	198982	56.4
6	0-5	12557	3.6	211539	60.0
6	5-10	23	0.0	211562	60.0
6	10-15	4	0.0	211566	60.0
7	<-40	17711	5.0	229277	65.0
7	-40 -35	2	0.0	229279	65.0
7	-35 -30	2	0.0	229281	65.0
7	-30 -25	2	0.0	229283	65.0
7	-25 -20	2	0.0	229285	65.0
7	-20 -15	8	0.0	229293	65.0
7	-15 -10	4	0.0	229297	65.0
7	-10 -5	11	0.0	229308	65.0
7	-5 -0	4152	1.2	233460	66.2
7	0	5	0.0	233465	66.2
7	0-5	13294	3.8	246759	70.0
7	5-10	33	0.0	246792	70.0
7	10-15	2	0.0	246794	70.0
7	15-20	1	0.0	246795	70.0
7	25-30	1	0.0	246796	70.0
7	30-35	1	0.0	246797	70.0
7	>40	30	0.0	246827	70.0
8	<-40	17711	5.0	264538	75.0
8	-40 -35	2	0.0	264540	75.0
8	-35 -30	1	0.0	264541	75.0
8	-30 -25	2	0.0	264543	75.0
8	-25 -20	2	0.0	264545	75.0
8	-20 -15	3	0.0	264548	75.0
8	-15 -10	22	0.0	264570	75.0
8	-10 -5	5	0.0	264575	75.0
8	-5 -0	4834	1.4	269409	76.4
8	0-5	12668	3.6	282077	80.0
8	5-10	11	0.0	282088	80.0
9	<-40	23951	6.8	306039	86.8
9	-40 -35	2	0.0	306041	86.8
9	-35 -30	3	0.0	306044	86.8
9	-30 -25	2	0.0	306046	86.8
9	-25 -20	1	0.0	306047	86.8
9	-20 -15	4	0.0	306051	86.8
9	-15 -10	3	0.0	306054	86.8
9	-10 -5	3	0.0	306057	86.8
9	-5 -0	3782	1.1	309839	87.9
9	0	2	0.0	309841	87.9

Figure 5-27 (continued)

ZONE	MNRANGE	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
9	0-5	7503	2.1	317344	90.0
9	5-10	3	0.0	317347	90.0
9	10-15	2	0.0	317349	90.0
10	<-40	17719	5.0	335068	95.0
10	-35 -30	2	0.0	335070	95.0
10	-30 -25	1	0.0	335071	95.0
10	-25 -20	6	0.0	335077	95.0
10	-20 -15	5	0.0	335082	95.0
10	-15 -10	20	0.0	335102	95.0
10	-10 -5	41	0.0	335143	95.0
10	-5 -0	6566	1.9	341709	96.9
10	0-5	10873	3.1	352582	100.0
10	5-10	22	0.0	352604	100.0
10	10-15	4	0.0	352608	100.0
10	20-25	1	0.0	352609	100.0
10	25-30	1	0.0	352610	100.0

Figure 5-27 (continued)

```
                                                  FREQUENCY BAR CHART

MNRANGE    MEAN < OR > 0 C                                                                                                                      FREQ    CUM.   PERCENT   CUM.
                                                                                                                                                        FREQ             PERCENT
          |
<-40      |*********                                                                                   2171    2171     6.16     6.16
-40 -35   |                                                                                               3    2174     0.01     6.17
-35 -30   |                                                                                               3    2177     0.01     6.17
-30 -25   |                                                                                               4    2181     0.01     6.19
-25 -20   |                                                                                               4    2185     0.01     6.20
-20 -15   |                                                                                               6    2191     0.02     6.21
-15 -10   |                                                                                              20    2211     0.06     6.27
-10 -5    |                                                                                              37    2248     0.10     6.38
-5 -0     |*****************************                                                               7229    9477    20.50    26.88
       0  |                                                                                               1    9478     0.00    26.88
0-5       |**************************************************************************************     21578   31056    61.20    88.07
5-10      |*******                                                                                     1866   32922     5.29    93.37
10-15     |                                                                                              45   32967     0.13    93.49
>40       |*********                                                                                   2294   35261     6.51   100.00
          |
         --------+-------+-------+-------+-------+-------+-------+-------+-------+-------+------
              2000    4000    6000    8000   10000   12000   14000   16000   18000   20000

                                              FREQUENCY
```

Figure 5-28. Results of descriptive statistics for mean temperature of zone 1 shown in graphical and numerical forms for OC-4.

FREQUENCY BAR CHART

MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	*********	2165	2165	6.14	6.14
-35 -30		5	2170	0.01	6.15
-30 -25		3	2173	0.01	6.16
-25 -20		10	2183	0.03	6.19
-20 -15		20	2203	0.06	6.25
-15 -10		5	2208	0.01	6.26
-10 -5		29	2237	0.08	6.34
-5 -0	************	2982	5219	8.46	14.80
0-5	**	19071	24290	54.09	68.89
5-10	*********	2314	26604	6.56	75.45
10-15	**	468	27072	1.33	76.78
15-20	***************	3685	30757	10.45	87.23
20-25	********	2044	32801	5.80	93.02
25-30		114	32915	0.32	93.35
30-35		42	32957	0.12	93.47
35-40		10	32967	0.03	93.49
>40	*********	2294	35261	6.51	100.00

--------+-------+-------+-------+-------+-------+-------+-------+-------+----

2000 4000 6000 8000 10000 12000 14000 16000 18000

FREQUENCY

Figure 5-29. Results of descriptive statistics for mean temperature of zone 2 shown in graphical and numerical forms for OC-4.

FREQUENCY BAR CHART

MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	****	2167	2167	6.15	6.15
-40 -35		3	2170	0.01	6.15
-35 -30		3	2173	0.01	6.16
-30 -25		7	2180	0.02	6.18
-25 -20		5	2185	0.01	6.20
-20 -15		11	2196	0.03	6.23
-15 -10		35	2231	0.10	6.33
-10 -5		40	2271	0.11	6.44
-5 -0	************	6171	8442	17.50	23.94
0		3	8445	0.01	23.95
0-5	**	23794	32239	67.48	91.43
5-10	*	670	32909	1.90	93.33
10-15		63	32972	0.18	93.51
>40	*****	2289	35261	6.49	100.00

```
--------+-------+-------+-------+-------+-------+
      4000    8000   12000   16000   20000   24000
```

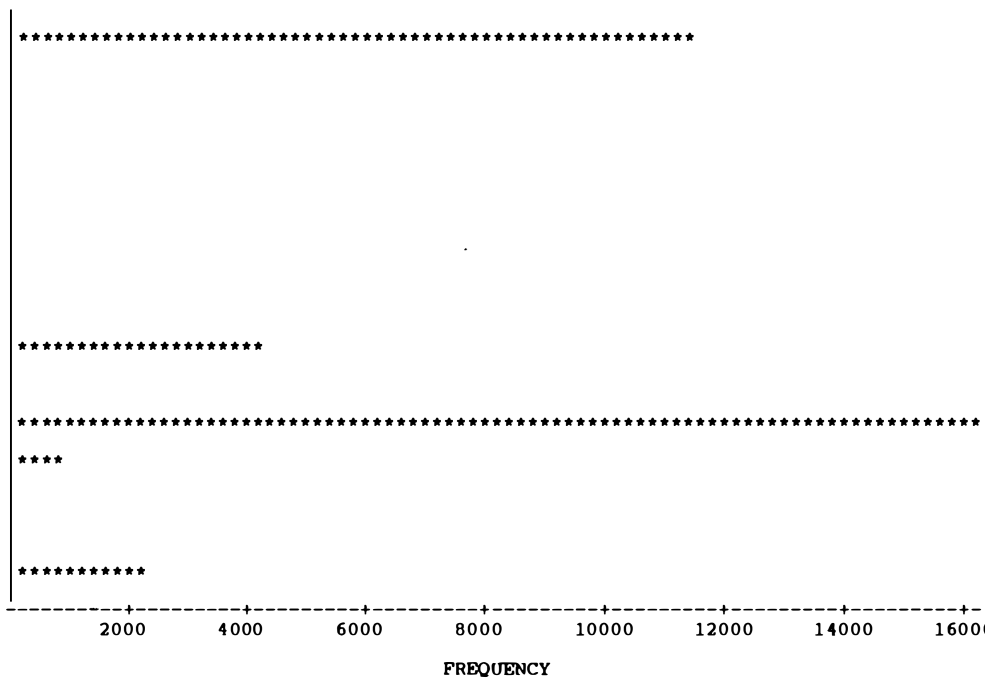
FREQUENCY

Figure 5-30. Results of descriptive statistics for mean temperature of zone 3 shown in graphical and numerical forms for OC-4.

```
                                   FREQUENCY BAR CHART

MNRANGE    MEAN < OR > 0 C                                          FREQ    CUM.   PERCENT    CUM.
                                                                            FREQ            PERCENT

<-40      |****                                                     2151    2151     6.10      6.10
-40 -35   |                                                            9    2160     0.03      6.13
-35 -30   |                                                            5    2165     0.01      6.14
-30 -25   |                                                           10    2175     0.03      6.17
-25 -20   |                                                            7    2182     0.02      6.19
-20 -15   |                                                            4    2186     0.01      6.20
-15 -10   |                                                           10    2196     0.03      6.23
-10 -5    |                                                           48    2244     0.14      6.36
-5 -0     |************                                             5944    8188    16.86     23.22
       0  |                                                            1    8189     0.00     23.22
0-5       |*************************************************       24314   32503    68.95     92.18
5-10      |*                                                         446   32949     1.26     93.44
10-15     |                                                           23   32972     0.07     93.51
35-40     |                                                            1   32973     0.00     93.51
>40       |*****                                                    2288   35261     6.49    100.00
          |
          --------+--------+--------+--------+--------+--------+-
                4000     8000    12000    16000    20000    24000

                                  FREQUENCY
```

Figure 5-31. Results of descriptive statistics for mean temperature of zone 4 shown in graphical and numerical forms for OC-4.

FREQUENCY BAR CHART



MNRANGE	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	11463	11463	32.51	32.51
-40 -35	4	11467	0.01	32.52
-35 -30	7	11474	0.02	32.54
-30 -25	9	11483	0.03	32.57
-25 -20	1	11484	0.00	32.57
-20 -15	4	11488	0.01	32.58
-15 -10	13	11501	0.04	32.62
-10 -5	19	11520	0.05	32.67
-5 -0	4283	15803	12.15	44.82
0	1	15804	0.00	44.82
0-5	16259	32063	46.11	90.93
5-10	842	32905	2.39	93.32
10-15	53	32958	0.15	93.47
15-20	10	32968	0.03	93.50
>40	2293	35261	6.50	100.00

Figure 5-32. Results of descriptive statistics for mean temperature of zone 5 shown in graphical and numerical forms for OC-4.

```
                                          FREQUENCY BAR CHART

MNRANGE    MEAN < OR > 0 C                                                                    FREQ    CUM.    PERCENT    CUM.
                                                                                                      FREQ              PERCENT
<-40        |***********************************************************************  17713   17713    50.23     50.23
-40 -35     |                                                                            19   17732     0.05     50.29
-35 -30     |                                                                             4   17736     0.01     50.30
-30 -25     |                                                                             6   17742     0.02     50.32
-25 -20     |                                                                            10   17752     0.03     50.34
-20 -15     |                                                                            20   17772     0.06     50.40
-15 -10     |                                                                            17   17789     0.05     50.45
-10 -5      |                                                                            20   17809     0.06     50.51
-5 -0       |*******************                                                       4866   22675    13.80     64.31
      0     |                                                                             2   22677     0.01     64.31
0-5         |**************************************************                       12557   35234    35.61     99.92
5-10        |                                                                            23   35257     0.07     99.99
10-15       |                                                                             4   35261     0.01    100.00
            --------+-------+-------+-------+-------+-------+-------+-------+-------
                  2000    4000    6000    8000   10000   12000   14000   16000

                                          FREQUENCY
```

Figure 5-33. Results of descriptive statistics for mean temperature of zone 6 shown in graphical and numerical forms for OC-4.

FREQUENCY BAR CHART

MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	***	17711	17711	50.23	50.23
-40 -35		2	17713	0.01	50.23
-35 -30		2	17715	0.01	50.24
-30 -25		2	17717	0.01	50.25
-25 -20		2	17719	0.01	50.25
-20 -15		8	17727	0.02	50.27
-15 -10		4	17731	0.01	50.29
-10 -5		11	17742	0.03	50.32
-5 -0	*****************	4152	21894	11.78	62.09
0		5	21899	0.01	62.11
0-5	***	13294	35193	37.70	99.81
5-10		33	35226	0.09	99.90
10-15		2	35228	0.01	99.91
15-20		1	35229	0.00	99.91
25-30		1	35230	0.00	99.91
30-35		1	35231	0.00	99.91
>40		30	35261	0.09	100.00

2000 4000 6000 8000 10000 12000 14000 16000

FREQUENCY

Figure 5-34. Results of descriptive statistics for mean temperature of zone 7 shown in graphical and numerical forms for OC-4.

```
                                   FREQUENCY BAR CHART

MNRANGE   MEAN < OR > 0 C                                                          FREQ    CUM.  PERCENT    CUM.
                                                                                           FREQ           PERCENT

<-40      |******************************************************************************  17711   17711    50.23    50.23
-40 -35   |                                                                                    2   17713     0.01    50.23
-35 -30   |                                                                                    1   17714     0.00    50.24
-30 -25   |                                                                                    2   17716     0.01    50.24
-25 -20   |                                                                                    2   17718     0.01    50.25
-20 -15   |                                                                                    3   17721     0.01    50.26
-15 -10   |                                                                                   22   17743     0.06    50.32
-10 -5    |                                                                                    5   17748     0.01    50.33
-5 -0     |*********************                                                            4834   22582    13.71    64.04
0-5       |********************************************************                        12668   35250    35.93    99.97
5-10      |                                                                                   11   35261     0.03   100.00
          --------+--------+--------+--------+--------+--------+--------+--------+--------
                2000     4000     6000     8000    10000    12000    14000    16000

                                        FREQUENCY
```

Figure 5-35. Results of descriptive statistics for mean temperature of zone 8 shown in graphical and numerical forms for OC-4.

```
                              FREQUENCY BAR CHART

MNRANGE   MEAN < OR > 0 C                                         FREQ   CUM.    PERCENT   CUM.
                                                                         FREQ              PERCENT

<-40     |************************************************       23951   23951    67.92     67.92
-40 -35  |                                                           2   23953     0.01     67.93
-35 -30  |                                                           3   23956     0.01     67.94
-30 -25  |                                                           2   23958     0.01     67.94
-25 -20  |                                                           1   23959     0.00     67.95
-20 -15  |                                                           4   23963     0.01     67.96
-15 -10  |                                                           3   23966     0.01     67.97
-10 -5   |                                                           3   23969     0.01     67.98
-5 -0    |********                                                3782   27751    10.73     78.70
      0  |                                                           2   27753     0.01     78.71
0-5      |***************                                         7503   35256    21.28     99.99
5-10     |                                                           3   35259     0.01     99.99
10-15    |                                                           2   35261     0.01    100.00
         --------+-------+-------+-------+-------+-------+
              4000    8000   12000   16000   20000   24000

                              FREQUENCY
```

Figure 5-36. Results of descriptive statistics for mean temperature of zone 9 shown in graphical and numerical forms for OC-4.

FREQUENCY BAR CHART

MNRANGE	MEAN < OR > 0 C	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
<-40	***	17719	17719	50.25	50.25
-35 -30		2	17721	0.01	50.26
-30 -25		1	17722	0.00	50.26
-25 -20		6	17728	0.02	50.28
-20 -15		5	17733	0.01	50.29
-15 -10		20	17753	0.06	50.35
-10 -5		41	17794	0.12	50.46
-5 -0	**************************	6566	24360	18.62	69.08
0-5	***	10873	35233	30.84	99.92
5-10		22	35255	0.06	99.98
10-15		4	35259	0.01	99.99
20-25		1	35260	0.00	100.00
25-30		1	35261	0.00	100.00

```
--------+-------+-------+-------+-------+-------+-------+-------+-------
       2000    4000    6000    8000   10000   12000   14000   16000
                              FREQUENCY
```

Figure 5-37. Results of descriptive statistics for mean temperature of zone 10 shown in graphical and numerical forms for OC-4.

recorded temperatures, are shown in Figure 5-38. The overall average temperatures are shown in Figure 5-39. Again like the similar case for OC-3 experiment, the low values of mean time-averaged temperatures (not close to 600°C) are the results of reactor downtime and/or powerup time.

To ignore the reactor downtime and/or powerup time to obtain "uncontaminated" time-averaged temperatures for OC-4, the time-averaged values of the temperatures in the 600 ± 100°C band were determined for each zone and then for all zones. Figure 5-40 shows descriptive statistics for the time-averaged temperatures for each zone. Figure 5-41(a) depicts the overall time-averaged temperature over all zones. Figure 5-41(b) shows the overall time-averaged temperature over 9 zones. As this figure indicates, the time-averaged temperature for the specimen columns over 9 zones is 601.8°C with a standard deviation of about 10°C.

5.9 Reactor Power During the Life of OC-4

Figure 5-42 shows the variation of ORR power with time. The points in this figure show the reactor power at the times that coincide with the change of the setpoints.

5.10 Summary of Temperature Analyses for OC-3 and OC-4 Experiments

The results of temperature analyses performed on the data provided for OC-3 and OC-4 experiments can be summarized as follows: The best estimate for the irradiation temperature in the OC-3 experiment, obtained as the time-

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
ZONE=1					
TEMP_A	35261	619.98770575	218.97254374	35.00650000	1333.89820000
TEMP_B	35261	538.02961274	167.24233340	35.00650000	612.96870000
TEMP_MN	35261	579.00865924	118.56295093	35.00650000	708.61991500
ZONE=2					
TEMP_A	35261	618.49608734	211.41537342	35.00650000	1297.27170000
TEMP_B	35261	544.84137562	171.19094788	34.69923000	666.80030000
TEMP_MN	35261	581.66913148	117.68999002	34.85286500	689.99574000
ZONE=3					
TEMP_A	34994	622.05142071	208.87845288	-0.06982422	1304.38280000
TEMP_B	34578	552.06387438	141.04076788	0.00000000	618.31690000
TEMP_MN	35034	583.59374125	112.81682578	-0.06982422	745.08726000
ZONE=4					
TEMP_A	34722	625.65459143	202.80550686	0.00000000	1298.74490000
TEMP_B	34448	553.48324190	139.72575027	34.70248000	613.35860000
TEMP_MN	34722	587.64121365	101.87359469	0.00000000	728.21234500
ZONE=5					
TEMP_A	25845	632.95025392	253.30869949	35.00650000	1351.64160000
TEMP_B	24716	515.75653736	188.99223332	34.69923000	619.83670000
TEMP_MN	25845	575.82386543	127.72855550	34.85286500	714.01696500
ZONE=6					
TEMP_A	19337	560.27411158	128.34642273	34.69923000	613.23660000
TEMP_B	19337	560.74448527	128.33103195	34.69923000	613.81520000
TEMP_MN	19337	560.50929842	128.31248019	34.69923000	613.52590000
ZONE=7					
TEMP_A	19337	561.24359357	128.27475583	35.00650000	1349.90370000
TEMP_B	19337	560.86321004	127.21260738	34.69923000	607.93990000
TEMP_MN	19337	561.05340181	127.46368047	34.85286500	935.76225000
ZONE=8					
TEMP_A	19337	559.37765849	130.55900702	34.69923000	608.75800000
TEMP_B	19337	560.44962962	128.89922315	34.69923000	614.21850000
TEMP_MN	19337	559.91364405	129.71283902	34.69923000	609.51520000
ZONE=9					
TEMP_A	19337	384.20256436	258.90171315	34.69923000	616.26100000
TEMP_B	19337	558.84034280	131.87002732	34.39195000	614.00690000
TEMP_MN	19337	471.52145358	162.42058326	34.54559000	614.72840000
ZONE=10					
TEMP_A	19337	558.54878350	133.69824700	35.00650000	629.74730000
TEMP_B	19337	558.16079952	133.26080570	34.39195000	622.53930000
TEMP_MN	19337	558.35479151	133.43997374	34.69922500	626.14330000

Figure 5-38. Results of descriptive statistics for temperatures of all zones of OC-4 (Temp_A, Temp_B, Temp_MN, are temperatures of west column, east column, and the mean temperature, respectively).

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
TEMP_A	262768	587.03611988	209.77231806	-0.06982422	1351.64160000
TEMP_B	260949	548.81069268	150.86855219	0.00000000	666.80030000
TEMP_MN	262808	567.20849104	127.06916154	-0.06982422	935.76225000

Figure 5-39. Descriptive statistics for the overall temperatures in OC-4.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
ZONE=1					
TEMP_A	30850	600.61383977	3.76429051	503.06860000	612.37370000
TEMP_B	30856	600.48931230	4.08301931	502.03640000	612.96870000
TEMP_MN	30971	600.93334657	7.17156020	500.19455000	699.99787000
ZONE=2					
TEMP_A	30908	601.50584620	5.48338947	500.77660000	615.92840000
TEMP_B	30922	608.29353314	15.30924658	500.28000000	666.80030000
TEMP_MN	33209	610.10900308	21.00747635	500.40500000	689.99574000
ZONE=3					
TEMP_A	30941	600.52595524	5.83835698	500.02290000	621.36400000
TEMP_B	30930	600.11716091	5.19052303	500.13790000	618.31690000
TEMP_MN	30941	600.31011938	5.47305387	500.05370000	678.72591000
ZONE=4					
TEMP_A	30948	600.17993977	5.38588835	500.13530000	613.77780000
TEMP_B	30944	600.22827996	5.04181380	501.38400000	613.35860000
TEMP_MN	30972	600.29731801	5.86813145	500.48935000	699.98119000
ZONE=5					
TEMP_A	21613	600.54725111	5.22496183	500.30400000	617.17040000
TEMP_B	20534	600.36718672	5.30700566	500.09080000	619.83670000
TEMP_MN	21615	600.44499665	5.14832927	500.67800000	672.04402500
ZONE=6					
TEMP_A	17646	599.36698978	5.91336056	500.29230000	613.23660000
TEMP_B	17660	599.74513818	5.09799180	501.45660000	613.81520000
TEMP_MN	17663	599.48794181	5.65476333	500.31180000	613.52590000
ZONE=7					
TEMP_A	17615	599.72855172	5.51230929	500.80760000	689.73610000
TEMP_B	17643	599.63496957	5.22550229	500.05860000	607.93990000
TEMP_MN	17631	599.76252313	5.68829847	500.78015000	693.24705000
ZONE=8					
TEMP_A	17609	599.39967252	4.98632892	500.96480000	608.75800000
TEMP_B	17615	599.94007791	5.49670104	500.16460000	614.21850000
TEMP_MN	17611	599.67436603	5.05820776	500.07165000	609.51520000
ZONE=9					
TEMP_A	11330	600.00717038	3.75462549	501.20390000	616.26100000
TEMP_B	17571	599.66022864	3.37601041	503.23830000	614.00690000
TEMP_MN	11329	599.83521201	3.57310153	502.22110000	614.72840000
ZONE=10					
TEMP_A	17554	600.16851372	2.53400868	506.46320000	629.74730000
TEMP_B	17559	599.60182191	2.54416188	500.11250000	622.53930000
TEMP_MN	17554	599.88566769	2.21483276	503.28785000	626.14330000

Figure 5-40. Descriptive statistics for temperatures in the $600^{o}C \pm 100^{o}C$ band for different zones of OC-4.

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
TEMP_A	227014	600.33331094	5.08024192	500.02290000	689.73610000
TEMP_B	232234	601.14031535	7.65027309	500.05860000	666.80030000
TEMP_MN	229496	601.61309587	10.11323454	500.05370000	699.99787000

(a) (Considering 10 zones)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
TEMP_A	209460	600.34712194	5.23748329	500.02290000	689.73610000
TEMP_B	214675	601.26615397	7.91043346	500.05860000	666.80030000
TEMP_MN	211942	601.75616932	10.49165133	500.05370000	699.99787000

(b) (Considering 9 zones)

Figure 5-41. Descriptive statistics for all temperatures in the 600°C ± 100°C band for OC-4.

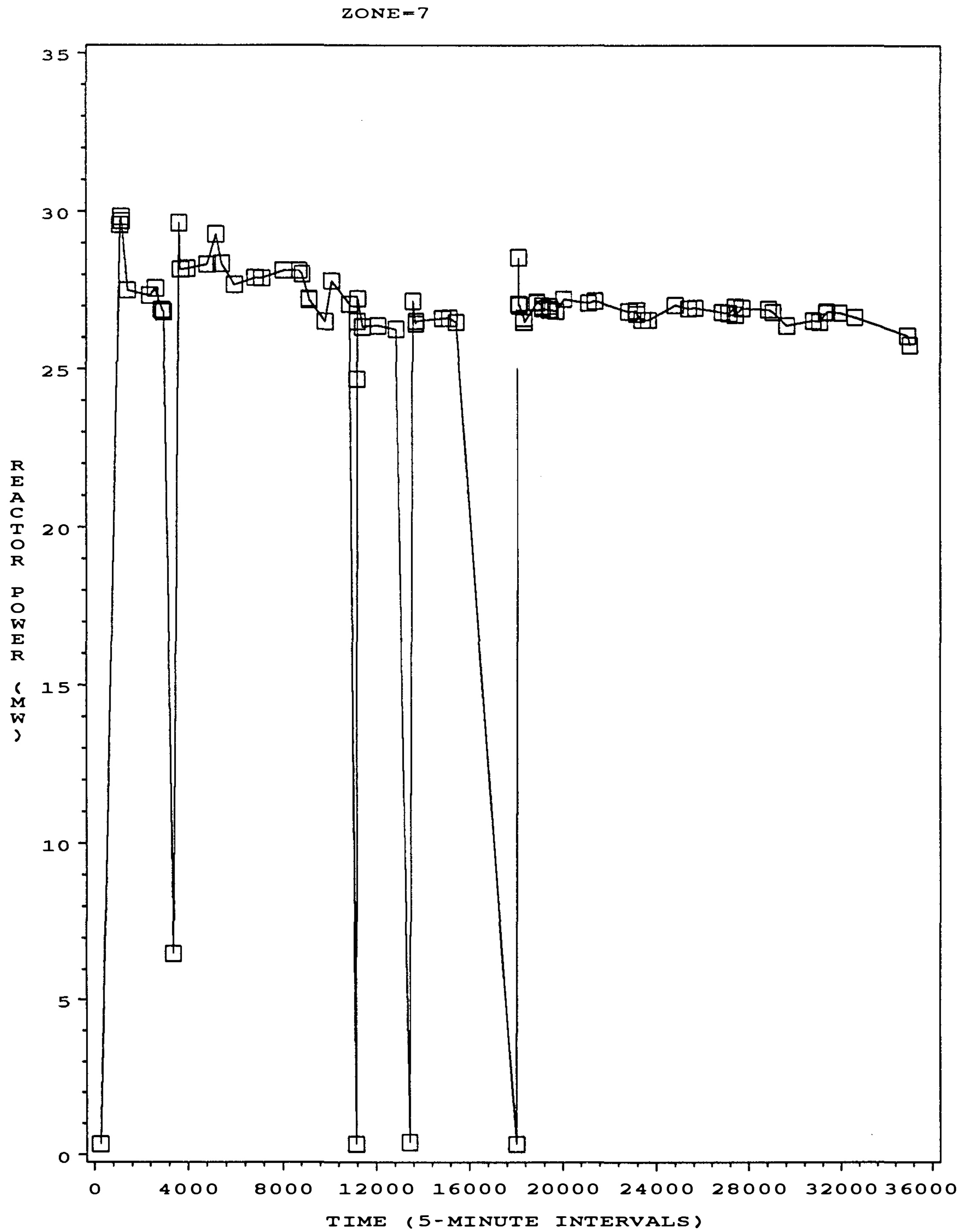


Figure 5-42. Variation of reactor power with time for OC-4 experiment.

averaged temperature over 9 zones, was determined to be 899.9°C with a standard deviation of about 3°C. The similar estimated value, over 9 zones, for OC-4 was determined to be 601.8°C with a standard deviation of about 10°C.

CHAPTER 6

APPROACHES IN CREEP STUDIES [22]

The theories of creep can follow two approaches: the micromechanistic approach and the microanalytical approach. The micromechanistic approach considers the events occurring at the atomic level and involves physical concepts. This approach provides knowledge of the processes that control creep. It sets forth guidelines for clear definition of material properties and for design of better materials for specific applications.

In the microanalytical approach, the behavior of materials under imposed forces is studied from a rheological point of view. This viewpoint is based on microanalytical continuum mechanics. The mathematical theories of elasticity and plasticity are good examples of this approach. These are based on certain macroscopic experimental findings and certain mathematical assumptions. In studying the creep phenomenon, the microanalytical approach is in fact an extension of the theory of plasticity to include the effects of time and temperature (assuming a non-neutron-irradiation environment). The analytical treatment of creep, relaxation, and strain recovery would be made possible by this extension. This approach "can provide basic relations that are broad in scope and can lead to improved procedures for designing structures" [22]. The microanalytical approach and the micromechanistic approach lead to useful results and each can benefit from the other. Both approaches must lead, in the end, to a consistent model.

6.1 Constitutive Equations for Creep [22]

"The connections between externally measurable parameters such as stress, strain rate, temperature, and some internal parameters such as hardness, which govern the inelastic behavior of solids are called constitutive relations" [23]. A constitutive equation is an equation which provides stress-strain-time-temperature relations (assuming a non-neutron-irradiation environment). All important material properties necessary for a mathematical analysis of creep and related phenomena should be defined, in terms of mathematical parameters, by the general form of this equation. One approach in formulating a constitutive equation involves use of analogies with mechanical models or other types of models.

The mechanical models include elastic springs and dashpots. As a very simple example, for a mechanical model composed of an elastic spring and a dashpot in parallel (Kelvin Model), the differential equation is

$$\frac{dx}{dt} + \frac{kx}{\eta} = \frac{1}{\eta} F \tag{6-1}$$

where

x = displacement;

F = applied force;

k = elastic constant;

η = coefficient of viscosity of the liquid in the dashpot.

For a constant F, the solution is the transient creep characterized by x as

$$x = \frac{F}{K}(1 - EXP(-Kt/\eta)) \tag{6-2}$$

A constitutive equation should also predict a (creep) recovery process. For the equation explained above, a recovery process (F=0) beginning at t_1 and x_1 would result

$$x = x_1 EXP(-k(t-t_1)/\eta) \tag{6-3}$$

For a constant extension (creep) rate the above constitutive equation results in a linear force-extension diagram

$$C + \frac{Kx}{\eta} = \frac{1}{\eta} F \Rightarrow F = Kx + \eta C \tag{6-4}$$

More complex constitutive equations are required for realistic simulation of actual materials. The complexity is due to the fact that such simulations involve higher order derivatives and temperature-, stress-, or strain-dependent coefficients. For the case of irradiation-induced creep in graphite, as will be seen later, the secondary creep coefficient is a function of fast-neutron fluence, among other variables.

Establishing a constitutive equation is a difficult task. However, the microanalytical approach to the formulation of theories of creep can be advanced in this direction.

6.2 Creep Function

Creep is defined as the time-dependent plastic deformation of a solid under a constant stress and at a constant temperature; or, in terms of short mathematical notations:

$$\varepsilon = f\,(\sigma, T, t, E) \tag{6-5}$$

where

ϵ = creep strain

σ = stress

T = temperature

t = time

E = Young's modulus

In a neutron irradiation environment, the above function is modified to:

$$\varepsilon = g\,(\sigma, T, \phi, E) \tag{6-6}$$

where, neutron fluence (Φ), which is the time-integrated neutron flux, acts as the pseudotime.

6.3 Viscoelastic Creep Model [13]

The linear viscoelastic creep function given below has been the basis for analyzing the results of virtually all the reported irradiation-induced creep experiments for graphite:

$$\varepsilon = \frac{\sigma}{E_o} + \frac{a\sigma}{E_o}\left[1 - EXP\,(-b\phi)\right] + k\sigma\phi \tag{6-7}$$

where

ϵ = irradiation-induced creep strain

σ = applied uniaxial stress

E_0 = Initial (preirradiated) value of Young's modulus

Φ = fast neutron fluence

a, b, and k, to be explained shortly, are the creep-characterizing parameters of graphite.

The above function can be represented by the rheological model depicted in Figure 6-1(c). As indicated in this figure, the model is composed of a Kelvin element (spring and dashpot in parallel) and a Maxwell element (spring and dashpot in series). The spring of the Maxwell element, the Kelvin element, and the dashpot of the Maxwell element represent the elastic component of the mechanical strain (ϵ_e), the transient component (ϵ_t), and the steady-state component (ϵ_s) of the creep strain, respectively.

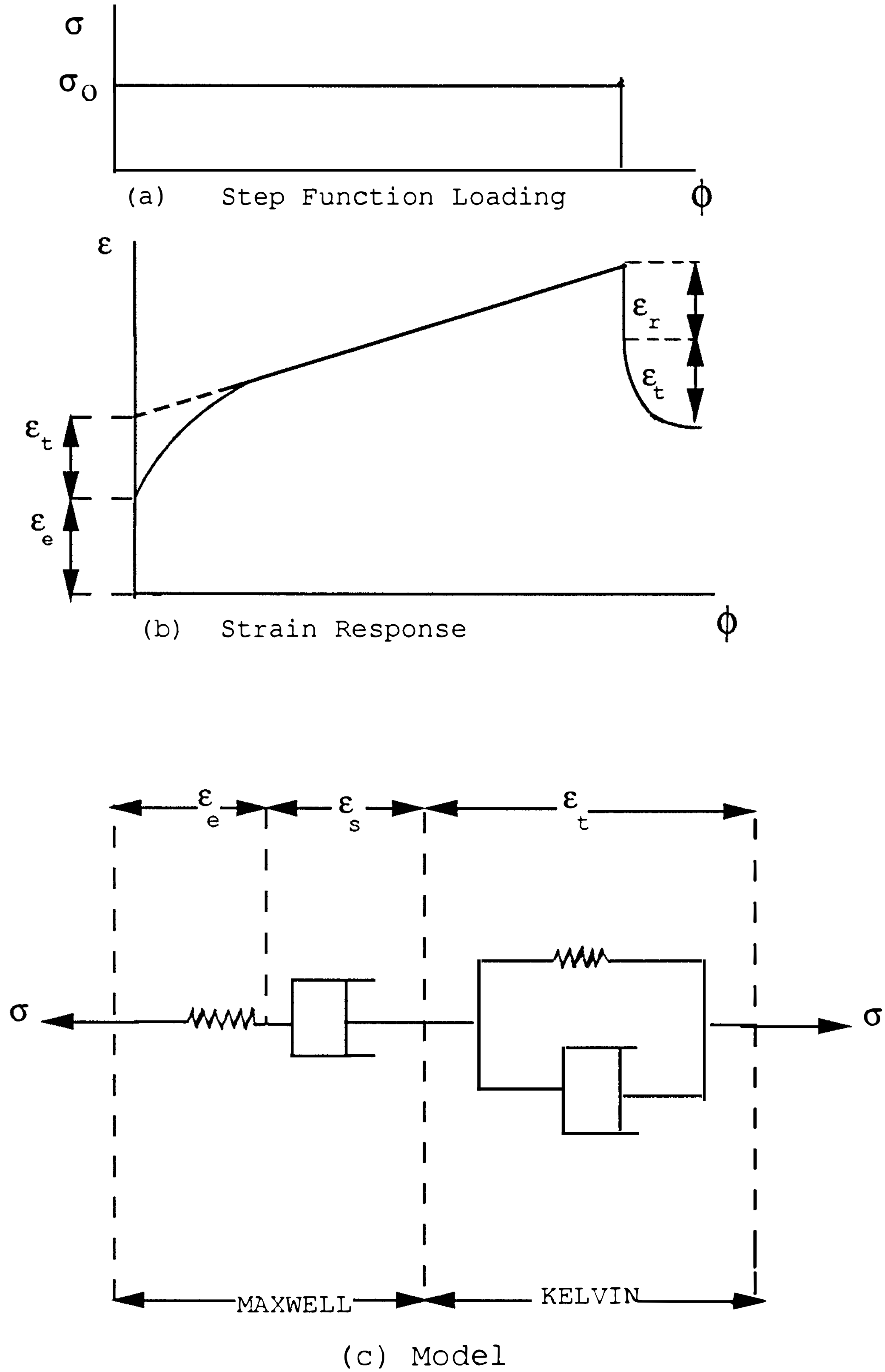


Figure 6-1. Rheological model for irradiation-induced creep strain in graphite.

It should be noted that only the total mechanical strain (elastic and creep strains) is represented by the linear viscoelastic function discussed above; thermal and irradiation strains, which are stress-independent strains, are not involved in the definition of irradiation-induced creep. Figures 6-1(a) and (b) show a step function loading and the corresponding mechanical strain response. The instantaneous elastic strain (ϵ_e), corresponding to the first term in the creep function, is followed by the transient creep (ϵ_t) which is the first stage of creep. The second stage of creep, the steady-state creep, commences after a short interval when the transient creep strain saturates at ϵ_t. The transient and the steady-state creep strains correspond to the second and the third terms of Eq. 6.7, respectively. As Figure 7-1(b) indicates, upon unloading, an elastic strain of ϵ_r is instantaneously recovered. This might be smaller than ϵ_e due to the increase in Young's Modulus because of neutron-irradiation. The transient creep strain, ϵ_t, described by the Kelvin block, is recovered over a short interval but the model assumes the steady-state creep strain, from the Maxwell block, remains as the permanent set [13].

The coefficients in Eq. 6-7, as pointed out before, characterize the creep behavior of graphite:

a = ratio of the maximum transient creep strain to the initial elastic strain. It is nearly equal 1.

b = transient creep exponential coefficient (1/b = time constant); b is temperature dependent.

k = steady-state creep coefficient.

The transient creep strain, compared with the steady-state creep strain, is technologically less important because it saturates very rapidly. For reactor operating conditions, the primary creep can be considered to be saturated. Considering the steady-state creep strain, $k\sigma\Phi$, k is a proportionality factor and technologically the most important factor to know.

6.4 Literature Survey

A literature survey [24-28] indicates that the deformation process responsible for the irradiation-induced creep in graphite is not well defined or understood. This brings about difficulty in explaining structural changes which result in the experimentally observed large changes in resistance to creep. Reference [25] indicates that the creep coefficient K decreases with fluence while irradiation-induced densification and hardening (Young's modulus increase) is in progress. After reaching a minimum, K begins to increase with fluence. This leads to the possible assumption that creep mechanisms are being modified. However, this was not confirmed by the Petten results [30] on grade HTR2E graphite at 300 and 500°C (no consistency between change in E and K). In fact, references [24] and [25] consider the changes in Young's modulus as an indication (or measure) of the strengthening which reduces the creep rate. The secondary creep strain rate with respect to fluence, when normalized to unit stress, is the creep coefficient.

The existing creep model assumes that basal slip is the deformation mode for creep and is based on the possible relationship between this slip and the crystal shear stiffness C_{44}. The qualitative descriptions of this model are not persuasive and its reliability in interpolating or extrapolating available creep data is in question [27].

Kennedy et al. [27], recently have found that irradiation-induced density changes in graphite can describe the strengthening which affects the creep behavior. In other words, according to this simple concept, the volume change in graphite under irradiation, describes the internal strengthening (resistance to deformation) which changes the creep rate. This new model does not imply any alteration in the deformation process in the graphite. These researchers have found that the model can be represented as:

$$\frac{d\varepsilon_s}{d\phi} = K\left(\frac{\sigma}{E_o}\right) \tag{6-8}$$

where

$\frac{d\epsilon_s}{d\phi}$ = rate of change of secondary creep strain (ϵ_s) with respect to fast neutron fluence (Φ)

σ = uniaxial stress

E_o = preirradiation Young's Modulus

and the secondary creep coefficient

$$K = K_2 \left[1 - \mu \left(\frac{\Delta V / V_o}{(\Delta V / V_o)_m} \right) \right] \tag{6-9}$$

where

K_2 = a constant (essentially the secondary temperature-dependent creep constant determined in short term irradiation experiments)

μ = a constant (0.75)

V_o = original volume

$\frac{\Delta V}{V_0}$ = volume change with fluence

$\left(\frac{\Delta V}{V_{om}} \right)$ = maximum volume change

The irradiation-induced creep data obtained from the OC-series creep experiments at ORNL were analyzed based on the new creep model explained above.

CHAPTER 7

STATISTICAL ANALYSIS

7.1 Statistical Methods

This section provides information about the statistical methods employed in analyzing the temperature data (Chapter 5) as well as in determining the extent of the suitability of the linear and nonlinear creep models as applied to the data for grade H-451 graphite. Examination of the creep models and the associated results of statistical analyses are discussed in Chapters 8 and 9. The statistical terminology associated with both descriptive statistics and regression analysis will also be defined.

The SAS system was employed as the main tool for the statistical analyses required. This choice is justified by considering the fact that SAS is the most thoroughly-tested statistical package and its capability to manipulate multiple data sets surpasses that of other statistical packages such as SPSS-X and BMDP.

7.2 Descriptive Statistics

Descriptive statistics, as employed in the analysis of temperature data in Chapter 5, provides information about the measure of central tendency and degree of dispersion of the sample under consideration. PROC MEANS and PROC UNIVARITE are two procedures of SAS [43] that were used in the analysis of temperature data included in Chapter 5. Basically, the arithmetic mean or average is defined as

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{7-1}$$

where $\bar{x}$ is the arithmetic mean and x_i are the data points in a sample of size n. The variability present in a sample is determined by the variance of the sample defined as:

$$S^2 = \sqrt{\frac{\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2}{n - 1}} \tag{7-2}$$

where S^2 is the variance and x_i and n are the data points and the sample size, respectively. S is referred to as standard deviation and n-1 as the degrees of freedom. If a Gaussian or normal distribution is assumed for the population, the dispersion present in the sample can be gauged by considering the band $\bar{x} \pm S$. This band contains about 68% of the data. Therefore, the lower the standard deviation the lower the dispersion in the sample. Quartiles and range are also informative as they provide information about the sample. Range, the difference between the maximum and minimum values of a sample, provides some insight about the variability in the sample in a crude sense.

Quartiles, as measures of position are used to describe the location of a particular data point in relation to the rest of the sample. The first quartile, Q_1, is a data point such that at most one-fourth of the data fall below Q_1 in value and at most three-fourths above it. The second quartile, Q_2, is the data point in the sample that the number of data points above and below it is the same. The second quartile is also called median. The third quartile, Q_3, is a data point such that at most three-fourths of the data fall below Q_3 in value and at most one-fourth above it. In the temperature analyses included in Chapter 5 these quartiles as well as the ranges were computed and presented.

7.3 Inferential Statistics: Regression Analysis [42]

Regression procedure PROC REG of the SAS system was extensively used in the analysis of experimental data involving the linear and nonlinear creep models. This section, after a brief statistical background on regression, provides definitions of the terms involved in the analysis of variance (ANOVA) tables associated with the regression analyses performed.

7.3.1 Multiple Linear Regression Analysis [42]

To relate the behavior of a dependent variable y to a linear function of a set of independent variables (e.g., x_1, x_2, ..., x_m), in least squares sense, a multiple linear regression analysis considers the following model:

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_m x_m + \epsilon \qquad (7\text{-}3)$$

The nature of the relationship is specified by the parameters β_j and ε is the random error. The least squares method finds the "best curve". This "curve" is the one which is, on the average, closest to all the points in the data set. This is obtained by minimizing the sum of squares of the differences between ordinates of the data points and their counterparts on the "best curve" [44]. The dependent variable can also be called a response variable, observed variable, output variable, or predicted variable. The independent variables x_j, can also be referred to as input variables or predictor variables.

For a set of n observed values of y and the corresponding x_j, the principle of least squares provides estimates for the coefficients β_j. The best fit least squares model is then:

$$y = \hat{\beta}_o + \hat{\beta}_1 x_1 + \dots + \hat{\beta}_m x_m \qquad (7\text{-}4)$$

In matrix notations the model (7-3) can be written as:

$$Y = X \beta + \epsilon \qquad (7\text{-}5)$$

where

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{bmatrix}, \; X = \begin{bmatrix} 1 & x_{11} & & x_1m \\ 1 & x_{21} & & x_2m \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & & \cdot \\ 1 & x_{n1} & & x_{nm} \end{bmatrix}, \; \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_n \end{bmatrix}, \; \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \cdot \\ \cdot \\ \cdot \\ \beta_m \end{bmatrix} \qquad (7\text{-}6)$$

where y_i, x_{ij}, and ϵ_i represent the values of y, x_j, and ϵ, respectively, in the ith observation. ß is the parameter vector. Solution of the set of normal equations X'Xß = X'Y provides the vector of least squares estimates

$$\hat{\beta}' = (\hat{\beta}_o, \hat{\beta}_1, \ldots, \hat{\beta}_m) \qquad (7\text{-}7)$$

7.3.2 Partitioning the sums of squares

The least squares regression provides the following basic identity:

$$\sum (y-\bar{y})^2 = \sum (\hat{y}-\bar{y})^2 + \sum (y-\hat{y})^2 \qquad (7\text{-}8)$$

which can be written as:

total sum of squared deviations from the mean = sum of squared deviations from the regression line to the overall mean + sum of squared deviations from the observed y values to the regression line.

In shorter form the equality can be written:

Total sum of squares = sum of squares due to regression + residual (or error) sum of squares or,

Total SS = Model SS + Error SS

Total SS is independent of the model used for the same set of data. Generally, Model SS increases (Error SS decreases) by adding a new x variable to the model. Error SS is computed as

$$\begin{aligned} \text{Error SS} &= y'(I - x(x'x)^{-1}x')y \\ &= y'y - y'x(x'x)^{-1}x'y \\ &= y'y - \hat{\beta}'x'y \end{aligned} \tag{7-9}$$

The error mean square (or mean square error) is defined as

S^2 = MSE = Error SS / (n-m-1)

which is an unbiased estimate of σ^2, the variance of ε_i.

7.4 Simple Linear Regression Models

Simple linear regression is a special case of the multiple linear regression described in the subsection 7.3.1. The model for a simple linear regression is the reduced form of Eq. (7-3) given below

$$Y = \beta_0 + \beta_1 x + \varepsilon \tag{7-10}$$

and the associated fitted model [the reduced form of Eq. (7-4)] is

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X \qquad (7\text{-}11)$$

The simple linear regression was performed in the examination of the linear and nonlinear creep models (covered in Chapter 8 and 9). The choice of this model is justified by two reasons: first, the plots of creep strain versus neutron fluence indicated a "linear" relationship; second, there is just one independent variable in the creep model.

7.5 Polynomial Linear Regression Models [42]

A polynomial linear regression model of degree k can be written in the following general form

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \ldots + \beta_k x^k + \epsilon \qquad (7\text{-}12)$$

This model is actually a multiple linear regression model like Eq. (7-3), with $x_1 = x$, $x_2 = x^2$, ... , and $x_k = x^k$. It should be noted that the term linear refers to linearity in the parameters β_j and not the independent variable x.

The more complex the trend, the higher is the degree of the polynomial. Usually, the polynomial of lowest order that represents the trend in the plot of y versus x is chosen. No curvature can be represented by the simple linear regression model. In general, the maximum number of bends that a polynomial of degree k can have is k - 1.

In the analysis of the variation of the irradiation induced growth (change of volume of control specimens) of graphite with neutron fluence, a special case of PROC REG, the regression procedure of the SAS system, was employed. This case, very useful for exploratory regression analysis , for a polynomial of degree k, considers the most complete form of the regression model as well as all possible models obtained by different combinations of the terms involved. For example, as will be seen in Chapter 8, for a fourth order model, in addition to the complete model, the following different models are also examined (β_0 is not counted as a term):

1. four one-term models (e.g., $y = \beta_0 + \beta_1 x^2$),
2. six two-term models (e.g., $y = \beta_0 + \beta_1 x + \beta_4 x^4$),
3. four three-term models (e.g., $y = \beta_0 + \beta_2 x^2 + \beta_3 x^3 + \beta_4 x^4$).

7.6 Analysis of Variance and Parameter Estimation

To interpret the output of a typical ANOVA table for a regression model with one independent variable, the different sections and headings/labels involved in the output must be well defined. This section provides explanations and/or definitions necessary for such an interpretation.

A typical ANOVA table generated by SAS for a simple linear regression and the parameter estimates are depicted in Figure 7-1. The underlined numbers have been added to this figure to facilitate the descriptions of different values involved in the figure as given below.

```
                    OC1, OC3, OC5 (900 C)
  REGRESSION FOR LINEAR MODEL (NORCREEP = A + B KEV_50)
          40-A-2, 40-A-3, 41-A-2, & 41-A2-2

   Model: MODEL1
 1 Dependent Variable: NORCREEP   Creep (EU)

                      Analysis of Variance

                         3  Sum of    4   Mean
    Source        2 DF      Squares       Square   5 F Value    6 Prob>F

    Model            1    274.21224    274.21224     130.426      0.0001
    Error           34     71.48257      2.10243
    C Total         35    345.69481

 7       Root MSE       1.44998  10 R-square       0.7932
   8     Dep Mean       8.10483  11 Adj R-sq       0.7871
     9   C.V.          17.89026

                      Parameter Estimates

                   13 Parameter  14 Standard 15  T for H0:
 12 Variable  DF      Estimate         Error    Parameter=0    Prob > |T|

    INTERCEP   1      2.883364    0.51714203          5.576        0.0001
    KEV_50     1     19.227982    1.68364646         11.420        0.0001
```

Figure 7-1. A typical output of PROC REG of SAS for simple linear regression showing the ANOVA table and parameter estimates.

1. The name of the dependent variable (NORCREEP).

2. The degrees of freedom (DF) for the corresponding sums of squares (SS). The DF associated with the regression model is equal to the number of independent variables involved in the model. The DF for the c total (corrected total) SS is one less than the sample size. The DF associated with the error SS is equal to the difference between the DF for total SS and the DF for model SS.

3. The values 274.21224, 71.48257, and 345.69481 are the Regression SS (MODEL SS), the Residual SS (ERROR SS), and the c TOTAL (corrected total) SS, respectively. According to the basic identity in regression analysis, the Total SS = Model SS + Error SS. The larger the ratio Model SS/Total SS the better the fit of the specified model.

4. MEAN SQUARE (MS) = SUM OF SQUARES/DF. If the model is correctly specified, the MS for ERROR is an unbiased estimate of σ^2, the variance of error.

5. The value of the F statistic, 130.426 = Model MS/Error MS (MSE). This statistic is used to test the hypothesis:

$$H_0 : \beta_j = 0, j \neq 0$$

For the present case of simple linear regression the hypothesis is

$$H_0 : \beta_1 = 0$$

6. The p value (Prob > F) of 0.0001 indicates that to obtain an F value of this size or larger by chance alone, the chance is 1 in 10,000 if, in fact, $\beta_1 = 0$. This leads to the conclusion that β_1 is not equal to zero.
7. The root mean squares Error = 1.44998 is the square root of the Error Mean Squares (2.10243). The Root MSE is an estimate of the standard deviation of error, σ (provided the model is adequate).
8. The Dep Mean = 8.10483 is the arithmetic mean of the dependent variable in the data set, or in this example NORCREEP.
9. The C.V. = 17.89026 (in percent) is the coefficient of variation which is equal to Root MSE/Dep Mean x 100. In this example, the error standard deviation is 17.89026% of the average value of NORCREEP. In comparing similar studies, C.V. is sometimes used as a standard for the relative magnitude of error.
10. The R-square = 0.7932 is the square of the multiple correlation coefficient. As a measure of goodness of fit, it can also be computed as Model SS/Total SS and as such represents the fraction of total variation in the values of the independent variable explained by, or due to, the linear relationship to the dependent variable [42].

11. The Adj R-sq = 0.7871 is the adjusted R-square. Adjustment is for the number of parameters in the model according to the formula

$$Adj\ R\text{-}sq = 1 - (1 - R\text{-}square)((n - 1)/(n - m - 1)) \qquad (7\text{-}13)$$

where

n = number of observations in the data set,

m = number of regression parameters in the model including the intercept [42].

12. The INTERCEPT and KEV-50 (the name of the independent variable in the simple linear regression model) are the intercept and slope of the regression line.

13. β_0 = intercept = 2.883364 and β_1 = slope = 19.227982.

14. The (estimated) Standard Errors of the estimates of β_0 and β_1 are 0.51714203 and 1.68364646, respectively. These values can be utilized to construct confidence intervals for β_0 and β_1. Generally, the confidence interval for a model parameter can be constructed in the following manner:

Parameter estimate $\pm$t (DF, $\alpha/2$) Standard Error

where t(DF, $\alpha/2$) is the α level tabulated t value with DF degrees of freedom (DF is the degrees of freedom associated with the Error SS).

The confidence interval constructed above means that it can be inferred, with $(1 - \alpha)\%$ confidence, that the true value of the parameter is somewhere between the two bounds.

15. The value of the t statistic for testing the null hypothesis that a parameter is zero. For example, the t statistic for the null hypothesis that $\beta_0 = 0$ is $t = 5.576$ with a p-value (Prob > |T|) of 0.0001. It should be noted that for one-variable models the t test is equivalent to its F test because $F = t^2$.

CHAPTER 8

EXAMINATION AND ANALYSIS OF PRE- AND POSTIRRADIATION MEASUREMENT DATA

Having examined and analyzed the temperature data in Chapter 5, and having been introduced to approaches in creep studies and the newly proposed model for creep in Chapter 6, the present chapter mainly looks at the pre- and postirradiation measurement data related to irradiation-induced creep in nuclear graphite.

8.1 Measurement Data

Pre- and postirradiation raw data were provided by C. R. Kennedy who is with the Metals and Ceramics (M&C) Division of ORNL. Figure 8-1 presents some information about that part of the data that were involved in the creep analysis for the 900°C experiments and Figure 8-2 shows the ranges of variation for the variables of interest. Table 8-1 describes the items in the first column of Figure 8-1 which are graphite specimens and their condition during the creep test. Table 8-2 provides descriptions for the variables involved in Figures 8-1 and 8-2. Figures 8-3 and 8-4 and Tables 8-3 and 8-4 are the counterparts of Figures 8-1 and 8-2 and Tables 8-1 and 8-2 for the 600°C experiments, respectively.

OC1, OC3, OC5 (900 C)

OBS	GRAPHITE	SPECNO	LENGTHPC	DIAPC	VOLPC	DENSITY	KEV_50	SONIC_E0
1	40-A-C	1101.10900	-0.093	-0.018	-0.174	1.702	0.064	8.27400
2	40-A-C	1103.09700	-0.073	0.024	-0.040	1.709	0.080	8.41190
3	40-A-C	1104.11200	-0.110	0.014	-0.088	1.723	0.085	8.61875
4	40-A-C	1105.09900	-0.090	-0.037	-0.191	1.704	0.095	8.34295
5	40-A-C	1108.08600	-0.120	0.012	0.110	1.706	0.113	8.89455
6	40-A-C	1110.11400	-0.130	0.035	-0.076	1.719	0.115	8.48085
7	40-A-C	1111.10100	-0.127	0.040	0.005	1.703	0.113	8.34295
8	40-A-C	1112.11600	-0.127	0.031	-0.085	1.717	0.109	8.68770
9	40-A-C	1201.11100	-0.087	-0.031	-0.197	1.702	0.064	8.34295
10	40-A-C	1203.09800	-0.097	0.017	-0.089	1.704	0.080	8.41190
11	40-A-C	1204.11300	-0.087	0.025	-0.065	1.721	0.085	8.54980
12	40-A-C	1205.10000	-0.115	0.022	0.040	1.703	0.095	8.34295
13	40-A-C	1208.08700	-0.110	0.018	-0.042	1.706	0.113	8.48085
14	40-A-C	1210.11500	-0.105	0.024	-0.145	1.722	0.115	8.54980
15	40-A-C	1211.10200	-0.118	0.037	-0.061	1.704	0.113	8.34295
16	40-A-C	1212.11700	-0.097	0.043	-0.033	1.705	0.109	8.41190
17	40-A-C	3101.12400	-0.180	-0.119	-0.480	1.719	0.140	8.96350
18	40-A-C	3103.09700	-0.395	-0.222	-1.108	1.727	0.260	8.27400
19	40-A-C	3112.12600	-0.220	-0.132	-0.549	1.720	0.240	8.96350
20	40-A-C	3201.11100	-0.312	-0.210	-1.030	1.720	0.210	8.34295
21	40-A-C	3203.20600	-0.190	-0.119	-0.496	1.706	0.170	8.96350
22	40-A-C	3204.12500	-0.195	-0.121	-0.497	1.721	0.190	8.96350
23	40-A-C	3205.20700	-0.238	-0.133	-0.577	1.708	0.210	8.96350
24	40-A-C	3208.08700	-0.535	-0.293	-1.347	1.730	0.350	8.48085
25	40-A-C	3210.11500	-0.522	-0.283	-1.427	1.741	0.370	8.54980
26	40-A-C	3211.10200	-0.465	-0.253	-1.295	1.725	0.370	8.34295
27	40-A-C	3212.11700	-0.400	-0.221	-1.134	1.721	0.350	8.41190
28	40-A-C	5101.12400	-0.313	-0.190	-0.786	1.724	0.230	8.96350
29	40-A-C	5103.09700	-0.710	-0.419	-1.713	1.738	0.370	8.41190
30	40-A-C	5104.11200	-0.247	-0.107	-0.327	1.727	0.200	8.61875
31	40-A-C	5105.09900	-0.260	-0.186	-0.935	1.717	0.230	8.34295
32	40-A-C	5108.08600	-0.322	-0.165	-0.739	1.717	0.270	8.89455
33	40-A-C	5110.11400	-0.320	-0.151	-0.695	1.729	0.270	8.48085
34	40-A-C	5111.10100	-0.290	-0.129	-0.550	1.712	0.270	8.34295
35	40-A-C	5112.12600	.	.	.	1.731	0.490	8.96350
36	40-A-C	5201.11100	-0.522	-0.461	-1.653	1.723	0.300	8.34295
37	40-A-C	5203.20600	-0.470	-0.250	-1.117	1.716	0.280	8.96350
38	40-A-C	5204.12500	-0.483	-0.283	-1.165	1.732	0.310	8.96350
39	40-A-C	5205.20700	-0.578	-0.329	-1.366	1.722	0.341	8.96350
40	40-A-C	5208.08700	-1.069	-0.596	-2.383	1.747	0.520	8.48085
41	40-A-C	5210.11500	-0.995	-0.568	-2.363	1.761	0.530	8.54980
42	40-A-C	5211.10200	-0.895	-0.503	-2.128	1.739	0.520	8.34295
43	40-A-C	5212.11700	-0.767	-0.443	-1.857	1.736	0.500	8.41190
44	40-A-2	1301.04600	-0.653	0.150	-0.360	1.714	0.064	8.20505
45	40-A-2	1303.03400	-0.707	0.197	-0.331	1.713	0.080	8.27400
46	40-A-2	1305.03600	-0.740	0.208	-0.346	1.712	0.095	8.20505
47	40-A-2	1308.02300	-0.802	0.200	-0.418	1.723	0.113	8.61875
48	40-A-2	1311.03800	-0.780	0.186	-0.434	1.714	0.113	8.27400
49	40-A-2	3301.04600	-1.450	0.203	-1.097	1.727	0.210	8.20505
50	40-A-2	3303.03400	-1.700	0.246	-1.260	1.723	0.170	8.27400
51	40-A-2	3305.17200	-1.394	0.217	-1.007	1.730	0.310	8.82560
52	40-A-2	3308.02300	-2.002	0.247	-1.566	1.742	0.360	8.61875
53	40-A-2	3311.03800	-1.900	0.204	-1.562	1.734	0.370	8.27400
54	40-A-2	3403.17100	-1.361	0.194	-1.038	1.719	0.170	8.82560
55	40-A-2	3405.17300	-1.496	0.179	-1.157	1.724	0.210	8.82560
56	40-A-2	5301.04600	-2.070	0.101	-1.979	1.742	0.230	8.20505

Figure 8-1. Graphite grades/specimens and the values of the variables involved in the creep analysis for the 900°C experiments. The definition of the variables and their units are given in Tables 8-1 and 8-2.

OC1, OC3, OC5 (900 C)

OBS	GRAPHITE	SPECNO	LENGTHPC	DIAPC	VOLPC	DENSITY	KEV_50	SONIC_E0
57	40-A-2	5303.03400	-2.4570	0.133	-2.330	1.747	0.370	8.2740
58	40-A-2	5305.17200	-2.3350	0.128	-2.191	1.738	0.340	8.8256
59	40-A-2	5308.02300	-2.9970	0.043	-3.086	1.769	0.520	8.6188
60	40-A-2	5311.03800	-2.7910	0.072	-2.813	1.755	0.520	8.2740
61	40-A-2	5403.17100	-2.1900	0.107	-2.082	1.736	0.280	8.8256
62	40-A-2	5405.17300	-2.6030	0.058	-2.581	1.748	0.340	8.8256
63	40-A-3	1304.04900	-0.9960	0.217	-0.599	1.735	0.085	8.4809
64	40-A-3	1310.05100	-1.0870	0.224	-0.678	1.734	0.115	8.4809
65	40-A-3	1312.05300	-1.0200	0.214	-0.621	1.731	0.109	8.4809
66	40-A-3	3304.06100	-1.7920	0.428	-1.013	1.736	0.190	8.8256
67	40-A-3	3310.05100	-2.6990	0.469	-1.821	1.754	0.370	8.4809
68	40-A-3	3312.05300	-2.3950	0.443	-1.552	1.748	0.350	8.4809
69	40-A-3	3404.06200	-1.9420	0.449	-1.141	1.738	0.190	8.8946
70	40-A-3	5304.06100	-2.9220	0.352	-2.390	1.759	0.310	8.8256
71	40-A-3	5310.05100	-3.8840	0.304	-3.529	1.783	0.530	8.4809
72	40-A-3	5312.05300	-3.4420	0.321	-3.007	1.755	0.500	8.4809
73	40-A-3	5404.06200	-3.2560	0.321	-2.820	1.766	0.310	8.8946
74	40-R-C	1109.09100	-0.0770	0.017	-0.057	1.699	0.116	7.6535
75	40-R-C	1209.09200	-0.0650	0.022	-0.039	1.704	0.116	7.5845
76	40-R-C	3109.09500	-0.1700	-0.240	-0.728	1.712	0.260	7.6535
77	40-R-C	3209.09200	-0.3350	-0.357	-1.476	1.723	0.370	7.5845
78	40-R-C	5109.09500	-0.4100	-0.567	-1.712	1.728	0.420	7.6535
79	40-R-C	5209.09200	-0.6780	-0.709	-2.341	1.743	0.530	7.5845
80	40-R-2	1309.02800	-0.8500	0.183	-0.502	1.713	0.116	7.5845
81	40-R-2	3309.02800	-2.0870	0.151	-1.847	1.737	0.370	7.5845
82	40-R-2	5309.02800	-2.9770	-0.017	-3.187	1.759	0.530	7.5845
83	41-A-C	1106.07600	-0.0800	0.021	-0.052	1.713	0.101	8.3430
84	41-A-C	1206.07700	-0.0970	0.001	-0.114	1.712	0.101	8.4119
85	41-A-C	3106.08000	-0.3670	-0.171	-0.804	1.706	0.225	8.8946
86	41-A-C	3206.07600	-0.4400	-0.330	-1.140	1.731	0.210	8.3430
87	41-A-C	5106.08000	-0.7110	-0.375	-1.628	1.720	0.360	8.8946
88	41-A-C	5206.07600	-0.8000	-0.593	-2.199	1.750	0.360	8.3430
89	41-A-2	1306.01300	-0.7850	0.200	-0.399	1.712	0.101	8.6188
90	41-A-2	3306.01300	-1.9430	0.236	-1.521	1.739	0.330	8.6188
91	41-A-2	5306.01300	-2.8430	0.028	-2.875	1.762	0.460	8.6188
92	41-A2-C	1107.08100	-0.0950	0.039	-0.034	1.728	0.111	8.8946
93	41-A2-C	1207.08200	-0.0900	0.019	-0.069	1.726	0.111	8.6877
94	41-A2-C	3107.08500	-0.2575	-0.168	-3.703	1.730	0.240	8.3430
95	41-A2-C	3207.08200	-0.4470	-0.282	-1.346	1.744	0.350	8.6877
96	41-A2-C	5107.08500	-0.5980	-0.379	-1.493	1.744	0.390	8.3430
97	41-A2-C	5207.08200	-0.8950	-0.554	-2.224	1.763	0.500	8.6877
98	41-A2-2	1307.01800	-0.6870	0.196	-0.308	1.739	0.111	8.9635
99	41-A2-2	3307.01800	-1.7600	0.217	-1.356	1.756	0.350	8.9635
100	41-A2-2	5307.01800	-2.6720	0.036	-2.728	1.780	0.500	8.9635
101	3-A-C	1102.06800	-0.1820	0.001	-0.216	1.768	0.072	12.1352
102	3-A-C	1202.06600	-0.1450	0.040	-0.090	1.773	0.072	12.2731
103	3-A-C	3102.06900	-0.2720	-0.139	-0.629	1.773	0.160	12.8937
104	3-A-C	3202.06600	-0.4820	-0.179	-1.049	1.788	0.230	12.1352
105	3-A-C	5102.06900	-0.2820	-0.226	-0.755	1.775	0.260	12.8937
106	3-A-C	5202.06600	-0.7970	-0.278	-1.495	1.798	0.330	12.1352
107	3-A-2	1302.00500	-0.6000	0.111	-0.392	1.776	0.072	11.9284
108	3-A-2	3302.00500	-1.3570	0.121	-1.129	1.790	0.230	11.9284
109	3-A-2	5302.00500	-1.9590	0.082	-1.856	1.802	0.330	11.9284
110	3-R-C	1113.07000	-0.0650	0.061	-0.053	1.760	0.097	5.8608
111	3-R-C	1213.07100	-0.0430	0.054	-0.049	1.770	0.097	5.8608
112	3-R-C	3113.07400	-0.1350	-0.137	-0.477	1.772	0.210	5.8608

Figure 8-1 (continued)

OC1, OC3, OC5 (900 C)

OBS	GRAPHITE	SPECNO	LENGTHPC	DIAPC	VOLPC	DENSITY	KEV_50	SONIC_E0
113	3-R-C	3213.07100	-0.223	-0.229	-0.955	1.785	0.290	5.86075
114	3-R-C	5113.07400	-0.245	-0.304	-0.972	1.781	0.330	8.34295
115	3-R-C	5213.07100	-0.375	-0.530	-1.581	1.799	0.410	5.86075
116	3-R-2	1313.00700	-1.110	0.160	-0.813	1.775	0.097	7.17080
117	3-R-2	3313.00700	-2.017	0.154	-1.743	1.792	0.290	7.17080
118	3-R-2	5313.00700	-2.600	0.175	-2.329	1.802	0.410	7.17080

Figure 8-1 (continued)

OC1, OC3, OC5 (900 C)

OBS	GRAPHITE	SPECNO	SONIC_E	G	R_SIDE	R_ENDS	CTE_800	AXPC_CRE	PC_PER_S
1	40-A-C	1101.10900	10.90	4.48	14.26	.	3.89	0.000	0.00000
2	40-A-C	1103.09700	11.08	4.58	15.84	.	3.85	0.000	0.00000
3	40-A-C	1104.11200	11.83	4.87	16.04	.	3.82	0.000	0.00000
4	40-A-C	1105.09900	11.54	4.78	16.34	.	3.74	0.000	0.00000
5	40-A-C	1108.08600	11.49	4.73	16.46	.	4.28	0.000	0.00000
6	40-A-C	1110.11400	11.90	4.92	15.83	.	4.04	0.000	0.00000
7	40-A-C	1111.10100	11.26	4.65	16.46	.	4.16	0.000	0.00000
8	40-A-C	1112.11600	11.72	4.80	15.27	.	4.16	0.000	0.00000
9	40-A-C	1201.11100	11.06	4.57	13.48	.	3.81	0.000	0.00000
10	40-A-C	1203.09800	11.23	4.69	15.45	.	4.03	0.000	0.00000
11	40-A-C	1204.11300	11.86	4.89	13.38	.	4.21	0.000	0.00000
12	40-A-C	1205.10000	11.39	4.74	14.87	.	3.87	0.000	0.00000
13	40-A-C	1208.08700	11.62	4.82	16.60	.	3.79	0.000	0.00000
14	40-A-C	1210.11500	11.91	4.93	18.02	.	3.92	0.000	0.00000
15	40-A-C	1211.10200	11.49	4.74	15.54	.	3.69	0.000	0.00000
16	40-A-C	1212.11700	11.34	4.70	14.24	.	3.96	0.000	0.00000
17	40-A-C	3101.12400	13.11	5.42	18.20	21.7	3.90	0.000	0.00000
18	40-A-C	3103.09700	13.95	5.81	20.90	26.3	3.99	0.000	0.00000
19	40-A-C	3112.12600	13.47	5.57	18.50	17.7	4.00	0.000	0.00000
20	40-A-C	3201.11100	13.30	5.50	19.60	20.0	3.60	0.000	0.00000
21	40-A-C	3203.20600	12.99	5.44	18.20	18.4	4.21	0.000	0.00000
22	40-A-C	3204.12500	13.33	5.55	18.40	18.4	4.20	0.000	0.00000
23	40-A-C	3205.20700	13.21	5.53	18.60	19.2	4.35	0.000	0.00000
24	40-A-C	3208.08700	14.35	6.04	20.90	21.3	4.00	0.000	0.00000
25	40-A-C	3210.11500	14.49	5.99	19.90	20.4	3.99	0.000	0.00000
26	40-A-C	3211.10200	14.22	5.93	20.50	21.2	4.14	0.000	0.00000
27	40-A-C	3212.11700	13.98	5.83	20.60	20.8	3.89	0.000	0.00000
28	40-A-C	5101.12400	15.85	7.03	21.10	28.2	3.99	0.000	0.00000
29	40-A-C	5103.09700	16.73	6.61	23.00	30.4	4.33	0.000	0.00000
30	40-A-C	5104.11200	16.96	6.57	21.30	26.8	3.93	0.000	0.00000
31	40-A-C	5105.09900	15.21	6.23	22.80	29.1	4.29	0.000	0.00000
32	40-A-C	5108.08600	16.97	6.70	22.20	29.1	4.64	0.000	0.00000
33	40-A-C	5110.11400	16.08	6.74	21.90	21.0	4.93	0.000	0.00000
34	40-A-C	5111.10100	16.10	6.44	22.30	22.7	4.84	0.000	0.00000
35	40-A-C	5112.12600	16.39	6.31	22.10	21.4	4.11	0.000	0.00000
36	40-A-C	5201.11100	14.82	6.05	22.50	22.6	3.99	0.000	0.00000
37	40-A-C	5203.20600	14.22	5.84	21.30	22.4	4.04	0.000	0.00000
38	40-A-C	5204.12500	14.64	5.99	21.30	21.3	3.98	0.000	0.00000
39	40-A-C	5205.20700	14.54	5.99	21.80	22.2	4.04	0.000	0.00000
40	40-A-C	5208.08700	15.75	6.44	22.80	23.5	3.83	0.000	0.00000
41	40-A-C	5210.11500	16.16	6.63	22.30	19.3	3.96	0.000	0.00000
42	40-A-C	5211.10200	15.77	6.51	22.90	23.2	4.19	0.000	0.00000
43	40-A-C	5212.11700	15.15	6.20	23.00	23.4	4.55	0.000	0.00000
44	40-A-2	1301.04600	10.39	4.67	15.80	15.9	4.59	-0.563	-0.04083
45	40-A-2	1303.03400	11.25	4.73	17.30	17.5	4.54	-0.622	-0.04510
46	40-A-2	1305.03600	11.32	4.79	17.60	18.2	4.53	-0.615	-0.04460
47	40-A-2	1308.02300	11.89	4.96	18.20	18.2	4.56	-0.687	-0.04982
48	40-A-2	1311.03800	11.37	4.83	17.50	18.0	4.54	-0.660	-0.04786
49	40-A-2	3301.04600	13.50	5.66	15.20	20.8	4.39	-1.140	-0.08267
50	40-A-2	3303.03400	13.30	5.51	20.50	20.4	4.65	-1.300	-0.09427
51	40-A-2	3305.17200	13.18	5.66	19.20	21.4	4.51	-1.154	-0.08368
52	40-A-2	3308.02300	13.91	5.81	20.00	20.3	4.50	-1.462	-0.10602
53	40-A-2	3311.03800	13.05	5.34	21.10	20.1	4.97	-1.430	-0.10370
54	40-A-2	3403.17100	11.42	4.51	19.10	23.4	4.92	-1.171	-0.08492
55	40-A-2	3405.17300	11.70	4.67	19.80	20.0	4.35	-1.256	-0.09108
56	40-A-2	5301.04600	14.89	6.22	22.70	22.4	4.74	-1.550	-0.11240

Figure 8-1 (continued)

OC1, OC3, OC5 (900 C)

OBS	GRAPHITE	SPECNO	SONIC_E	G	R_SIDE	R_ENDS	CTE_800	AXPC_CRE	PC_PER_S
57	40-A-2	5303.03400	15.330	6.44	23.60	23.0	4.95	-1.747	-0.12669
58	40-A-2	5305.17200	14.460	6.05	23.20	22.7	5.00	-1.745	-0.12654
59	40-A-2	5308.02300	16.130	6.76	23.90	23.1	5.10	-1.927	-0.13974
60	40-A-2	5311.03800	15.480	6.44	23.50	23.2	5.29	-1.891	-0.13713
61	40-A-2	5403.17100	14.130	5.88	22.30	22.2	4.89	-1.720	-0.12473
62	40-A-2	5405.17300	14.620	6.11	23.00	22.7	4.83	-2.013	-0.14597
63	40-A-3	1304.04900	11.820	5.07	17.50	18.5	4.57	-0.896	-0.04332
64	40-A-3	1310.05100	11.840	5.00	18.10	19.1	4.71	-0.940	-0.04540
65	40-A-3	1312.05300	11.520	4.92	17.10	18.2	4.35	-0.905	-0.04375
66	40-A-3	3304.06100	12.980	5.53	19.80	22.0	5.10	-1.597	-0.07721
67	40-A-3	3310.05100	13.880	5.94	21.90	19.5	5.45	-2.290	-0.11070
68	40-A-3	3312.05300	13.100	5.41	21.50	19.7	5.32	-1.995	-0.09645
69	40-A-3	3404.06200	11.810	4.73	20.50	24.7	5.14	-1.747	-0.08446
70	40-A-3	5304.06100	14.800	6.25	23.90	23.0	5.59	-2.442	-0.11806
71	40-A-3	5310.05100	16.270	6.92	25.50	24.0	5.80	-2.884	-0.13942
72	40-A-3	5312.05300	15.800	6.70	25.20	23.8	5.66	-2.772	-0.13401
73	40-A-3	5404.06200	14.900	6.38	25.20	23.0	5.36	-2.776	-0.13420
74	40-R-C	1109.09100	10.320	4.47	18.29	.	4.68	0.000	0.00000
75	40-R-C	1209.09200	10.520	4.54	19.76	.	4.51	0.000	0.00000
76	40-R-C	3109.09500	11.730	5.01	20.70	23.7	4.70	0.000	0.00000
77	40-R-C	3209.09200	12.560	5.37	21.50	19.9	4.65	0.000	0.00000
78	40-R-C	5109.09500	13.330	5.60	24.10	29.1	4.41	0.000	0.00000
79	40-R-C	5209.09200	14.320	6.13	23.90	21.9	4.45	0.000	0.00000
80	40-R-2	1309.02800	10.570	4.63	18.50	17.5	5.19	-0.780	-0.05656
81	40-R-2	3309.02800	12.250	5.17	21.80	20.9	5.56	-1.747	-0.12669
82	40-R-2	5309.02800	14.600	6.28	24.50	22.2	6.16	-2.297	-0.16657
83	41-A-C	1106.07600	11.770	4.84	16.35	.	3.78	0.000	0.00000
84	41-A-C	1206.07700	11.750	4.90	15.36	.	3.79	0.000	0.00000
85	41-A-C	3106.08000	13.150	5.37	19.90	24.7	3.95	0.000	0.00000
86	41-A-C	3206.07600	14.210	5.86	20.30	21.1	4.20	0.000	0.00000
87	41-A-C	5106.08000	16.290	6.37	23.60	30.6	4.18	0.000	0.00000
88	41-A-C	5206.07600	15.700	6.38	22.20	22.8	3.60	0.000	0.00000
89	41-A-2	1306.01300	11.700	4.98	17.30	17.6	4.52	-0.700	-0.05076
90	41-A-2	3306.01300	14.150	5.98	20.60	20.4	4.59	-1.503	-0.10899
91	41-A-2	5306.01300	15.860	6.63	23.90	22.8	4.93	-2.088	-0.15141
92	41-A2-C	1107.08100	12.250	5.08	16.05	.	3.66	0.000	0.00000
93	41-A2-C	1207.08200	12.300	5.11	15.77	.	3.73	0.000	0.00000
94	41-A2-C	3107.08500	14.210	5.92	18.60	23.7	3.90	0.000	0.00000
95	41-A2-C	3207.08200	14.960	6.20	19.70	20.3	4.15	0.000	0.00000
96	41-A2-C	5107.08500	17.240	6.80	22.30	29.1	3.88	0.000	0.00000
97	41-A2-C	5207.08200	16.770	6.91	21.90	22.2	3.81	0.000	0.00000
98	41-A2-2	1307.01800	12.620	5.27	19.70	17.4	4.59	-0.597	-0.04329
99	41-A2-2	3307.01800	14.770	6.17	19.70	20.9	4.79	-1.310	-0.09500
100	41-A2-2	5307.01800	17.190	7.26	22.50	22.1	4.80	-1.772	-0.12850
101	3-A-C	1102.06800	10.720	4.28	10.63	.	1.57	0.000	0.00000
102	3-A-C	1202.06600	11.830	4.99	8.42	.	1.90	0.000	0.00000
103	3-A-C	3102.06900	17.660	7.38	16.90	26.8	1.75	0.000	0.00000
104	3-A-C	3202.06600	17.990	7.22	18.50	23.2	2.15	0.000	0.00000
105	3-A-C	5102.06900	17.510	6.68	20.90	34.9	1.79	0.000	0.00000
106	3-A-C	5202.06600	14.570	5.32	20.70	27.9	1.80	0.000	0.00000
107	3-A-2	1302.00500	11.010	4.57	15.40	18.8	1.88	-0.450	-0.03263
108	3-A-2	3302.00500	15.760	6.39	15.70	18.4	2.50	-0.877	-0.06360
109	3-A-2	5302.00500	18.890	7.35	21.30	25.6	2.65	-1.159	-0.08405
110	3-R-C	1113.07000	6.820	3.43	21.13	.	3.38	0.000	0.00000
111	3-R-C	1213.07100	8.218	3.48	18.63	.	3.41	0.000	0.00000
112	3-R-C	3113.07400	0.520	7.48	18.90	15.8	.	0.000	0.00000

Figure 8-1 (continued)

OC1, OC3, OC5 (900 C)

OBS	GRAPHITE	SPECNO	SONIC_E	G	R_SIDE	R_ENDS	CTE_800	AXPC_CRE	PC_PER_S
113	3-R-C	3213.07100	.	8.52	22.8	17.4	3.56	0.000	0.00000
114	3-R-C	5113.07400	10.380	4.28	22.9	22.7	3.71	0.000	0.00000
115	3-R-C	5213.07100	11.020	4.55	22.5	19.7	3.55	0.000	0.00000
116	3-R-2	1313.00700	6.457	3.81	16.4	15.9	4.24	-1.055	-0.07650
117	3-R-2	3313.00700	9.790	6.71	23.3	21.9	5.07	-1.797	-0.13031
118	3-R-2	5313.00700	11.870	5.06	23.5	21.8	5.15	-2.220	-0.16099

Figure 8-1 (continued)

OC1, OC3, OC5 (900 C)

GRAPHITE=3-A-2

Variable	Minimum	Maximum
LENGTHPC	-1.9590000	-0.6000000
DIAPC	0.0820000	0.1210000
VOLPC	-1.8560000	-0.3920000
DENSITY	1.7760000	1.8020000
KEV_50	0.0720000	0.3300000
SONIC_E0	11.9283500	11.9283500
SONIC_E	11.0100000	18.8900000
G	4.5700000	7.3500000
R_SIDE	15.4000000	21.3000000
R_ENDS	18.4000000	25.6000000
CTE_800	1.8800000	2.6500000
AXPC_CRE	-1.1590000	-0.4500000
PC_PER_S	-0.0840500	-0.0326300

GRAPHITE=3-A-C

Variable	Minimum	Maximum
LENGTHPC	-0.7970000	-0.1450000
DIAPC	-0.2780000	0.0400000
VOLPC	-1.4950000	-0.0900000
DENSITY	1.7680000	1.7980000
KEV_50	0.0720000	0.3300000
SONIC_E0	12.1352000	12.8936500
SONIC_E	10.7200000	17.9900000
G	4.2800000	7.3800000
R_SIDE	8.4200000	20.9000000
R_ENDS	23.2000000	34.9000000
CTE_800	1.5700000	2.1500000
AXPC_CRE	0	0
PC_PER_S	0	0

GRAPHITE=3-R-2

Variable	Minimum	Maximum
LENGTHPC	-2.6000000	-1.1100000
DIAPC	0.1540000	0.1750000
VOLPC	-2.3290000	-0.8130000
DENSITY	1.7750000	1.8020000
KEV_50	0.0970000	0.4100000
SONIC_E0	7.1708000	7.1708000
SONIC_E	6.4570000	11.8700000
G	3.8100000	6.7100000
R_SIDE	16.4000000	23.5000000
R_ENDS	15.9000000	21.9000000
CTE_800	4.2400000	5.1500000
AXPC_CRE	-2.2200000	-1.0550000
PC_PER_S	-0.1609900	-0.0765000

GRAPHITE=3-R-C

Variable	Minimum	Maximum
LENGTHPC	-0.3750000	-0.0430000
DIAPC	-0.5300000	0.0610000
VOLPC	-1.5810000	-0.0490000
DENSITY	1.7600000	1.7990000
KEV_50	0.0970000	0.4100000
SONIC_E0	5.8607500	8.3429500
SONIC_E	0.5200000	11.0200000
G	3.4300000	8.5200000
R_SIDE	18.6300000	22.9000000
R_ENDS	15.8000000	22.7000000
CTE_800	3.3800000	3.7100000
AXPC_CRE	0	0
PC_PER_S	0	0

GRAPHITE=40-A-2

Variable	Minimum	Maximum
LENGTHPC	-2.9970000	-0.6530000
DIAPC	0.0430000	0.2470000
VOLPC	-3.0860000	-0.3310000
DENSITY	1.7120000	1.7690000
KEV_50	0.0640000	0.5200000
SONIC_E0	8.2050500	8.8256000
SONIC_E	10.3900000	16.1300000
G	4.5100000	6.7600000
R_SIDE	15.2000000	23.9000000
R_ENDS	15.9000000	23.4000000
CTE_800	4.3500000	5.2900000
AXPC_CRE	-2.0130000	-0.5630000
PC_PER_S	-0.1459700	-0.0408300

GRAPHITE=40-A-3

Variable	Minimum	Maximum
LENGTHPC	-3.8840000	-0.9960000
DIAPC	0.2140000	0.4690000
VOLPC	-3.5290000	-0.5990000
DENSITY	1.7310000	1.7830000
KEV_50	0.0850000	0.5300000
SONIC_E0	8.4808500	8.8945500
SONIC_E	11.5200000	16.2700000
G	4.7300000	6.9200000
R_SIDE	17.1000000	25.5000000
R_ENDS	18.2000000	24.7000000
CTE_800	4.3500000	5.8000000
AXPC_CRE	-2.8840000	-0.8960000
PC_PER_S	-0.1394200	-0.0433200

Figure 8-2. Ranges of variation for the variables of interest in the data used for the creep analysis at 900°C. The definition of the variables and their units are given in Tables 8-1 and 8-2.

OC1, OC3, OC5 (900 C)

----------- GRAPHITE=40-A-C ----------

Variable	Minimum	Maximum
LENGTHPC	-1.0690000	-0.0730000
DIAPC	-0.5960000	0.0430000
VOLPC	-2.3830000	0.1100000
DENSITY	1.7020000	1.7610000
KEV_50	0.0640000	0.5300000
SONIC_E0	8.2740000	8.9635000
SONIC_E	10.9000000	16.9700000
G	4.4800000	7.0300000
R_SIDE	13.3800000	23.0000000
R_ENDS	17.7000000	30.4000000
CTE_800	3.6000000	4.9300000
AXPC_CRE	0	0
PC_PER_S	0	0

----------- GRAPHITE=41-A-2 ----------

Variable	Minimum	Maximum
LENGTHPC	-2.8430000	-0.7850000
DIAPC	0.0280000	0.2360000
VOLPC	-2.8750000	-0.3990000
DENSITY	1.7120000	1.7620000
KEV_50	0.1010000	0.4600000
SONIC_E0	8.6187500	8.6187500
SONIC_E	11.7000000	15.8600000
G	4.9800000	6.6300000
R_SIDE	17.3000000	23.9000000
R_ENDS	17.6000000	22.8000000
CTE_800	4.5200000	4.9300000
AXPC_CRE	-2.0880000	-0.7000000
PC_PER_S	-0.1514100	-0.0507600

----------- GRAPHITE=40-R-2 ---------

Variable	Minimum	Maximum
LENGTHPC	-2.9770000	-0.8500000
DIAPC	-0.0170000	0.1830000
VOLPC	-3.1870000	-0.5020000
DENSITY	1.7130000	1.7590000
KEV_50	0.1160000	0.5300000
SONIC_E0	7.5845000	7.5845000
SONIC_E	10.5700000	14.6000000
G	4.6300000	6.2800000
R_SIDE	18.5000000	24.5000000
R_ENDS	17.5000000	22.2000000
CTE_800	5.1900000	6.1600000
AXPC_CRE	-2.2970000	-0.7800000
PC_PER_S	-0.1665700	-0.0565600

----------- GRAPHITE=41-A-C ----------

Variable	Minimum	Maximum
LENGTHPC	-0.8000000	-0.0800000
DIAPC	-0.5930000	0.0210000
VOLPC	-2.1990000	-0.0520000
DENSITY	1.7060000	1.7500000
KEV_50	0.1010000	0.3600000
SONIC_E0	8.3429500	8.8945500
SONIC_E	11.7500000	16.2900000
G	4.8400000	6.3800000
R_SIDE	15.3600000	23.6000000
R_ENDS	21.1000000	30.6000000
CTE_800	3.6000000	4.2000000
AXPC_CRE	0	0
PC_PER_S	0	0

----------- GRAPHITE=40-R-C ---------

Variable	Minimum	Maximum
LENGTHPC	-0.6780000	-0.0650000
DIAPC	-0.7090000	0.0220000
VOLPC	-2.3410000	-0.0390000
DENSITY	1.6990000	1.7430000
KEV_50	0.1160000	0.5300000
SONIC_E0	7.5845000	7.6534500
SONIC_E	10.3200000	14.3200000
G	4.4700000	6.1300000
R_SIDE	18.2900000	24.1000000
R_ENDS	19.9000000	29.1000000
CTE_800	4.4100000	4.7000000
AXPC_CRE	0	0
PC_PER_S	0	0

----------- GRAPHITE=41-A2-2 ---------

Variable	Minimum	Maximum
LENGTHPC	-2.6720000	-0.6870000
DIAPC	0.0360000	0.2170000
VOLPC	-2.7280000	-0.3080000
DENSITY	1.7390000	1.7800000
KEV_50	0.1110000	0.5000000
SONIC_E0	8.9635000	8.9635000
SONIC_E	12.6200000	17.1900000
G	5.2700000	7.2600000
R_SIDE	19.7000000	22.5000000
R_ENDS	17.4000000	22.1000000
CTE_800	4.5900000	4.8000000
AXPC_CRE	-1.7720000	-0.5970000
PC_PER_S	-0.1285000	-0.0432900

Figure 8-2 (continued)

OC1, OC3, OC5 (900 C)

----------- GRAPHITE=41-A2-C ---------

Variable	Minimum	Maximum
LENGTHPC	-0.8950000	-0.0900000
DIAPC	-0.5540000	0.0390000
VOLPC	-3.7030000	-0.0340000
DENSITY	1.7260000	1.7630000
KEV_50	0.1110000	0.5000000
SONIC_E0	8.3429500	8.8945500
SONIC_E	12.2500000	17.2400000
G	5.0800000	6.9100000
R_SIDE	15.7700000	22.3000000
R_ENDS	20.3000000	29.1000000
CTE_800	3.6600000	4.1500000
AXPC_CRE	0	0
PC_PER_S	0	0

Figure 8-2 (continued)

Table 8-1. Definition of the Numeric and/or Alphabetic Codes Involved in the Items of the Second Column of Figure 8-1.

Code	Description
40	Graphite grade H-451 obtained from block 40
A	Sample has been taken from the block in axial direction
C	Control specimen (no external stress)
-2	Creep (test) specimen subjected to a compressive stress of 13.79 MPa
-3	Creep (test) specimen subjected to a compressive stress of 20.68 MPa
R	Sample has been taken from the block in radial direction
41	Graphite grade H-451 obtained from block 41
A2	Sample has been taken from the block in axial direction (different from A)
3-	Graphite grade H-327

Table 8-2. Definition of Variables of Interest Involved in the Pre- and Postirradiation Measurement Data for 900°C Experiments

Variable	Description
SPECNO	A code indicating the irradiation experiment number (the first digit from left), specimen column number (the second digit from left), specimen position in the column (the third and fourth digits from left), and the specimen identification number (the last five digits)
LENGTHPC	Change in length (%)
DIAPC	Change in diameter (%)
VOLPC	Change in volume (%)
DENSITY	Density of graphite specimen (g/cm^3)
KEV_50	Neutron fluence (10^{26} neutrons/m^2, E > 50 KeV)
SONIC_E0	Preirradiation dynamic Young's modulus (GPa)
SONIC_E	Dynamic Young's modulus (GPa)
G	Shear modulus (GPa)
R_SIDE	Electrical resistivity in with-grain direction (μOhm.m)
R_ENDS	Electrical resistivity in against-grain direction (μOhm.m)
CTE_800	Coefficient of thermal expension at 800°C (x 10^{-6} 1/°C)
AXPC_CRE	Creep strain in axial direction (%)
PC_PER_S	Creep strain per unit of stress (%/MPa)

OC2, OC4 (600 C)

OBS	GRAPHITE	SPECNO	PCLENGTH	PCDIA	PCVOL	DEN	KEV_50	E
1	40-AX-CON	2101.10700	-0.068	-0.082	-0.269	1.7058	0.095	15.70
2	40-AX-CON	2201.10800	-0.078	-0.092	-0.291	1.7069	0.095	15.77
3	40-AX-CON	2103.10300	-0.120	-0.125	-0.407	1.7120	0.152	16.20
4	40-AX-CON	2203.10400	-0.130	-0.117	-0.398	1.7128	0.152	16.11
5	40-AX-CON	2104.11800	-0.133	-0.150	-0.475	1.7099	0.177	16.09
6	40-AX-CON	2204.11900	-0.150	-0.150	-0.495	1.7119	0.177	16.08
7	40-AX-CON	2112.12200	-0.168	-0.164	-0.540	1.7226	0.206	16.64
8	40-AX-CON	2212.12300	-0.268	-0.175	-0.677	1.7260	0.206	15.49
9	40-AX-CON	2205.10600	-0.183	-0.176	-0.590	1.7144	0.199	16.30
10	40-AX-CON	2105.10500	-0.163	-0.160	-0.529	1.7131	0.199	16.44
11	40-AX-CON	2111.09000	-0.182	-0.187	-0.609	1.7135	0.225	16.27
12	40-AX-CON	2211.11000	-0.133	-0.201	-0.587	1.7120	0.225	16.43
13	40-AX-CON	2110.12000	-0.203	-0.193	-0.645	1.7134	0.237	16.24
14	40-AX-CON	2210.12100	-0.225	-0.212	-0.715	1.7129	0.237	16.35
15	40-AX-CON	2108.08800	-0.205	-0.205	-0.672	1.7141	0.239	16.55
16	40-AX-CON	2208.08900	-0.235	-0.215	-0.735	1.7164	0.239	16.52
17	40-AX-CON	4201.10800	-0.198	-0.221	-0.727	1.7143	0.261	17.62
18	40-AX-CON	4101.10700	-0.228	-0.226	-0.776	1.7146	0.261	17.58
19	40-AX-CON	4203.10400	-0.245	-0.330	-1.011	1.7233	0.363	18.16
20	40-AX-CON	4103.10300	-0.348	-0.318	-1.098	1.7238	0.363	18.19
21	40-AX-CON	4104.11800	-0.433	-0.379	-1.319	1.7243	0.408	18.18
22	40-AX-CON	4204.11900	-0.405	-0.384	-1.308	1.7258	0.408	18.09
23	40-AX-CON	4112.12200	-0.470	-0.379	-1.355	1.7366	0.438	18.77
24	40-AX-CON	4212.12300	-0.470	-0.417	-1.451	1.7393	0.438	18.98
25	40-AX-CON	4205.10600	-0.468	-0.438	-1.499	1.7299	0.446	18.52
26	40-AX-CON	4105.10500	-0.475	-0.409	-1.435	1.7285	0.446	18.29
27	40-AX-CON	4111.09000	-0.512	-0.444	-1.552	1.7296	0.477	18.36
28	40-AX-CON	4211.11000	-0.503	-0.474	-1.616	1.7295	0.477	18.36
29	40-AX-CON	4210.12100	-0.528	-0.504	-1.711	1.7298	0.502	18.71
30	40-AX-CON	4110.12000	-0.543	-0.465	-1.634	1.7302	0.502	18.31
31	40-AX-CON	4108.08800	-0.590	-0.530	-1.740	1.7323	0.512	18.45
32	40-AX-CON	4208.08900	-0.573	-0.530	-1.812	1.7347	0.512	18.94
33	40-AX-2	2301.04400	-0.710	0.065	-0.595	1.7158	0.095	15.29
34	40-AX-2	2401.04500	-0.680	0.065	-0.574	1.7141	0.095	15.52
35	40-AX-2	2303.04000	-0.830	0.049	-0.760	1.7212	0.152	15.95
36	40-AX-2	2403.04100	-0.820	0.049	-0.710	1.7199	0.152	16.00
37	40-AX-2	2305.04200	-0.950	0.042	-0.889	1.7229	0.199	16.14
38	40-AX-2	2405.04300	-0.960	0.033	-0.916	1.7244	0.199	16.28
39	40-AX-2	2411.04700	-1.060	0.024	-1.040	1.7219	0.225	16.30
40	40-AX-2	2311.02700	-1.010	0.035	-0.962	1.7259	0.225	16.40
41	40-AX-2	2408.02600	-1.050	0.021	-1.033	1.7259	0.239	16.56
42	40-AX-2	2308.02500	-1.050	0.019	-1.042	1.7241	0.239	16.43
43	40-AX-2	4301.04400	-1.180	-0.017	-1.231	1.7266	0.261	17.14
44	40-AX-2	4401.04500	-1.170	-0.033	-1.287	1.7262	0.261	17.26
45	40-AX-2	4403.04100	-1.430	-0.079	-1.659	1.7361	0.363	18.03
46	40-AX-2	4303.04000	-1.425	-0.072	-1.561	1.7349	0.363	17.62
47	40-AX-2	4405.04300	-1.690	-0.136	-2.000	1.7429	0.446	18.26
48	40-AX-2	4305.04200	-1.660	-0.125	-1.987	1.7416	0.446	18.13
49	40-AX-2	4311.02700	-1.680	-0.135	-2.038	1.7443	0.477	18.37
50	40-AX-2	4411.04700	-1.780	-0.147	-2.162	1.7411	0.477	18.49
51	40-AX-2	4408.02600	-1.860	-0.185	-2.330	1.7480	0.512	18.38
52	40-AX-2	4308.02500	-1.760	-0.176	-2.209	1.7440	0.512	18.56
53	40-AX-3	2404.05600	-1.280	0.144	-1.027	1.7327	0.177	15.76
54	40-AX-3	2304.05500	-1.350	0.139	-1.132	1.7334	0.177	15.83
55	40-AX-3	2312.05900	-1.340	0.104	-1.095	1.7354	0.206	16.13
56	40-AX-3	2412.06000	-1.390	0.114	-1.206	1.7411	0.206	16.24

Figure 8-3. Graphite grades/specimens and the values of the variables involved in the creep analysis for the 600°C experiments. The definition of the variables and their units are given in Tables 8-3 and 8-4.

OC2, OC4 (600 C)

OBS	GRAPHITE	SPECNO	PCLENGTH	PCDIA	PCVOL	DEN	KEV_50	E
57	40-AX-3	2410.05800	-1.550	0.131	-1.335	1.7362	0.237	16.01
58	40-AX-3	2310.05700	-1.530	0.111	-1.364	1.7374	0.237	16.04
59	40-AX-3	4304.05500	-2.150	0.008	-2.238	1.7523	0.408	17.96
60	40-AX-3	4404.05600	-2.190	0.029	-2.234	1.7534	0.408	17.70
61	40-AX-3	4412.06000	-2.240	-0.003	-2.371	1.7612	0.438	18.28
62	40-AX-3	4312.05900	-2.140	-0.027	-2.222	1.7547	0.438	17.79
63	40-AX-3	4410.05800	-2.540	-0.024	-2.724	1.7600	0.502	17.88
64	40-AX-3	4310.05700	-2.400	-0.039	-2.065	1.7587	0.502	17.89
65	40-RA-CON	2209.09400	-0.192	-0.236	-0.730	1.7086	0.241	14.91
66	40-RA-CON	2109.09300	-0.175	-0.225	-0.681	1.7094	0.241	14.93
67	40-RA-CON	4109.09300	-0.505	-0.523	-1.722	1.7271	0.513	16.95
68	40-RA-CON	4209.09400	-0.462	-0.544	-1.729	1.7255	0.513	.
69	40-RA-2	2409.03100	-1.240	-0.006	-1.285	1.7251	0.241	14.80
70	40-RA-2	2309.03000	-1.180	0.018	-1.182	1.7235	0.241	14.87
71	40-RA-2	4309.03000	-1.900	-0.169	-2.336	1.7431	0.513	.
72	40-RA-2	4409.03100	-2.020	-0.193	-2.526	1.7463	0.513	16.00
73	41-AX-CON	2106.07800	-0.180	-0.161	-0.551	1.7101	0.217	16.61
74	41-AX-CON	2206.07900	-0.195	-0.186	-0.622	1.7084	0.217	16.49
75	41-AX-CON	4206.07900	-0.470	-0.464	-1.553	1.7242	0.477	18.68
76	41-AX-CON	4106.07800	-0.512	-0.433	-1.535	1.7268	0.477	18.47
77	41-AX-2	2306.01500	-0.990	0.022	-0.973	1.7256	0.217	16.40
78	41-AX-2	2406.01600	-0.980	0.031	-0.944	1.7224	0.217	16.34
79	41-AX-2	4306.01500	-1.650	-0.154	-1.944	1.7422	0.477	18.51
80	41-AX-2	4406.01600	-1.740	-0.136	-2.102	1.7422	0.477	18.25
81	41-AX2-CON	2207.08400	-0.205	-0.197	-0.657	1.7331	0.230	17.50
82	41-AX2-CON	2107.08300	-0.185	-0.189	-0.629	1.7317	0.230	17.45
83	41-AX2-CON	4207.08400	-0.439	-0.498	-1.644	1.7501	0.499	19.82
84	41-AX2-CON	4107.08300	-0.530	-0.462	-1.601	1.7484	0.499	18.86
85	41-AX2-2	2307.02000	-0.940	0.015	-0.938	1.7410	0.230	17.36
86	41-AX2-2	2407.02100	-0.960	0.007	-0.969	1.7438	0.230	17.44
87	41-AX2-2	4407.02100	-1.680	-0.176	-2.111	1.7636	0.499	19.22
88	41-AX2-2	4307.02100	-1.600	-0.174	-2.022	1.7597	0.499	18.99
89	327-AX-CON	2102.06500	-0.098	-0.087	-0.301	1.7691	0.125	14.47
90	327-AX-CON	2202.06700	-0.075	-0.087	-0.275	1.7732	0.125	18.89
91	327-AX-CON	4202.06700	-0.310	-0.271	-0.729	1.7812	0.314	22.05
92	327-AX-CON	4102.06500	-0.305	-0.265	-0.921	1.7800	0.314	23.22
93	327-AX-2	2402.00400	-0.630	0.039	-0.567	1.7772	0.125	18.98
94	327-AX-2	2302.00200	-0.680	0.043	-0.607	1.7779	0.125	22.20
95	327-AX-2	4402.00400	-1.180	-0.076	-1.374	1.7914	0.314	21.36
96	327-AX-2	4302.00200	-1.200	-0.075	-1.385	1.7916	0.314	23.24
97	327-RA-CON	2213.07300	-0.128	-0.050	-0.513	1.7655	0.177	12.37
98	327-RA-CON	2113.07200	-0.112	-0.050	-0.430	1.7703	0.177	11.27
99	327-RA-CON	2113.07200	-0.112	-0.133	-0.430	1.7703	0.177	11.27
100	327-RA-CON	2213.07300	-0.128	-0.100	-0.513	1.7655	0.177	12.37
101	327-RA-CON	4113.07200	-0.355	-0.433	-1.235	1.7845	0.382	13.66
102	327-RA-CON	4113.07200	-0.355	-0.300	-1.235	1.7845	0.382	13.66
103	327-RA-CON	4213.07300	-0.330	-0.355	-1.260	1.7786	0.382	13.92
104	327-RA-CON	4213.07300	-0.330	-0.480	-1.260	1.7786	0.382	13.92
105	327-RA-2	2413.01000	-1.350	-0.133	-1.415	1.7936	0.177	11.72
106	327-RA-2	2313.00900	-1.360	-0.133	-1.446	1.8030	0.177	12.20
107	327-RA-2	2313.00900	-1.360	0.017	-1.446	1.8030	0.177	12.20
108	327-RA-2	2413.01000	-1.350	0.117	-1.415	1.7936	0.177	11.72
109	327-RA-2	4313.00900	-1.960	-0.267	-2.141	1.8153	0.382	13.26
110	327-RA-2	4313.00900	-1.960	0.117	2.141	1.8153	0.382	13.26
111	327-RA-2	4413.01000	-2.140	0.100	-2.388	1.8109	0.382	13.33
112	327-RA-2	4413.01000	-2.140	-0.267	-2.388	1.8109	0.382	13.33

Figure 8-3 (continued)

OC2, OC4 (600 C)

OBS	GRAPHITE	SPECNO	G	RES_W_G	RES_A_G	CTE_500	CREEPPC	CR_PER_S
1	40-AX-CON	2101.10700	6.48	21.0	23.4	3.65	.	.
2	40-AX-CON	2201.10800	6.50	21.2	23.0	3.55	.	.
3	40-AX-CON	2103.10300	6.69	22.2	23.9	3.72	.	.
4	40-AX-CON	2203.10400	6.66	21.9	23.6	3.65	.	.
5	40-AX-CON	2104.11800	6.64	23.0	24.2	3.83	.	.
6	40-AX-CON	2204.11900	6.65	23.5	24.0	3.67	.	.
7	40-AX-CON	2112.12200	6.88	22.2	23.8	3.86	.	.
8	40-AX-CON	2212.12300	6.16	22.5	24.3	3.67	.	.
9	40-AX-CON	2205.10600	6.74	22.0	24.6	3.62	.	.
10	40-AX-CON	2105.10500	6.80	22.8	24.4	3.86	.	.
11	40-AX-CON	2111.09000	6.71	22.5	24.9	3.71	.	.
12	40-AX-CON	2211.11000	6.82	24.9	24.9	3.52	.	.
13	40-AX-CON	2110.12000	6.69	23.2	24.8	3.61	.	.
14	40-AX-CON	2210.12100	6.80	23.2	25.3	3.70	.	.
15	40-AX-CON	2108.08800	6.82	22.9	24.9	3.60	.	.
16	40-AX-CON	2208.08900	6.83	23.4	25.3	3.60	.	.
17	40-AX-CON	4201.10800	7.52	23.7	25.7	3.60	.	.
18	40-AX-CON	4101.10700	7.53	24.0	26.2	3.15	.	.
19	40-AX-CON	4203.10400	7.78	24.0	26.0	3.42	.	.
20	40-AX-CON	4103.10300	7.79	24.5	26.5	3.06	.	.
21	40-AX-CON	4104.11800	7.82	25.3	26.8	3.35	.	.
22	40-AX-CON	4204.11900	7.68	23.5	27.1	3.52	.	.
23	40-AX-CON	4112.12200	8.10	23.6	26.2	3.36	.	.
24	40-AX-CON	4212.12300	8.11	23.9	26.4	3.32	.	.
25	40-AX-CON	4205.10600	7.92	24.3	26.9	3.40	.	.
26	40-AX-CON	4105.10500	7.81	24.3	26.5	3.33	.	.
27	40-AX-CON	4111.09000	7.92	23.7	27.3	3.94	.	.
28	40-AX-CON	4211.11000	8.00	25.4	27.1	3.55	.	.
29	40-AX-CON	4210.12100	8.03	24.6	27.3	3.97	.	.
30	40-AX-CON	4110.12000	7.81	24.0	26.9	3.68	.	.
31	40-AX-CON	4108.08800	7.86	25.0	26.9	3.68	.	.
32	40-AX-CON	4208.08900	8.10	23.6	27.7	3.60	.	.
33	40-AX-2	2301.04400	6.30	18.6	23.0	4.30	-0.637	-0.04620
34	40-AX-2	2401.04500	6.46	21.6	23.2	4.28	-0.607	-0.04402
35	40-AX-2	2303.04000	6.65	24.2	23.3	4.50	-0.705	-0.05113
36	40-AX-2	2403.04100	6.65	24.2	23.6	4.07	-0.695	-0.05040
37	40-AX-2	2305.04200	6.74	25.1	23.9	4.56	-0.777	-0.05635
38	40-AX-2	2405.04300	6.81	24.2	23.8	4.20	-0.787	-0.05707
39	40-AX-2	2411.04700	6.87	27.2	24.6	4.73	-0.902	-0.06541
40	40-AX-2	2311.02700	6.88	24.9	24.1	4.08	-0.852	-0.06179
41	40-AX-2	2408.02600	6.93	26.0	24.4	4.12	-0.830	-0.06019
42	40-AX-2	2308.02500	6.86	26.4	24.3	4.68	-0.830	-0.06019
43	40-AX-2	4301.04400	7.33	25.1	25.4	4.79	-0.967	-0.07013
44	40-AX-2	4401.04500	7.43	25.1	25.7	4.51	-0.957	-0.06940
45	40-AX-2	4403.04100	7.88	24.4	25.9	4.13	-1.082	-0.07847
46	40-AX-2	4303.04000	7.51	24.7	25.8	3.95	-1.077	-0.07810
47	40-AX-2	4405.04300	7.87	24.6	25.8	4.33	-1.218	-0.08833
48	40-AX-2	4305.04200	7.98	25.0	26.0	4.00	-1.188	-0.08615
49	40-AX-2	4311.02700	7.91	25.8	26.2	4.59	-1.172	-0.08499
50	40-AX-2	4411.04700	8.09	25.5	26.6	4.35	-1.272	-0.09225
51	40-AX-2	4408.02600	7.93	24.6	26.1	3.93	-1.279	-0.09275
52	40-AX-2	4308.02500	8.14	25.6	26.3	4.68	-1.179	-0.08550
53	40-AX-3	2404.05600	6.61	24.1	25.4	4.93	-1.139	-0.05507
54	40-AX-3	2304.05500	6.69	23.6	25.7	4.87	-1.209	-0.05785
55	40-AX-3	2312.05900	6.82	25.9	24.9	3.58	-1.172	-0.05667
56	40-AX-3	2412.06000	6.86	24.6	25.2	4.78	-1.222	-0.05908

Figure 8-3 (continued)

OC2, OC4 (600 C)

OBS	GRAPHITE	SPECNO	G	RES_W_G	RES_A_G	CTE_500	CREEPPC	CR_PER_S
57	40-AX-3	2410.05800	6.79	24.7	26.0	4.75	-1.336	-0.06459
58	40-AX-3	2310.05700	6.80	24.9	25.9	4.87	-1.316	-0.06363
59	40-AX-3	4304.05500	7.95	25.9	27.4	4.66	-1.731	-0.08369
60	40-AX-3	4404.05600	7.80	25.8	27.2	4.95	-1.771	-0.08563
61	40-AX-3	4412.06000	8.06	26.4	27.4	4.94	-1.770	-0.08558
62	40-AX-3	4312.05900	7.96	26.7	26.9	5.08	-1.670	-0.08074
63	40-AX-3	4410.05800	7.59	26.2	27.7	4.93	-2.005	-0.09694
64	40-AX-3	4310.05700	7.91	26.2	27.8	5.06	-1.865	-0.09017
65	40-RA-CON	2209.09400	6.38	26.1	24.3	4.37	.	.
66	40-RA-CON	2109.09300	6.36	26.7	24.0	4.20	.	.
67	40-RA-CON	4109.09300	7.47	24.7	27.8	4.25	.	.
68	40-RA-CON	4209.09400	.	25.1	27.8	4.26	.	.
69	40-RA-2	2409.03100	6.48	27.4	24.1	5.13	-1.057	-0.07665
70	40-RA-2	2309.03000	6.51	28.9	23.5	5.24	-0.997	-0.07230
71	40-RA-2	4309.03000	.	25.3	27.9	5.27	-1.417	-0.10276
72	40-RA-2	4409.03100	.	25.5	26.9	5.00	-1.537	-0.11146
73	41-AX-CON	2106.07800	6.86	23.0	24.7	3.81	.	.
74	41-AX-CON	2206.07900	6.82	22.9	24.4	3.65	.	.
75	41-AX-CON	4206.07900	7.97	24.8	26.8	3.74	.	.
76	41-AX-CON	4106.07800	7.84	24.2	27.1	3.50	.	.
77	41-AX-2	2306.01500	6.84	24.7	24.0	4.50	-0.803	-0.05823
78	41-AX-2	2406.01600	6.82	25.0	23.8	4.45	-0.793	-0.05751
79	41-AX-2	4306.01500	8.02	25.4	26.1	4.61	-1.158	-0.08398
80	41-AX-2	4406.01600	8.94	25.1	25.7	4.49	-1.248	-0.09050
81	41-AX2-CON	2207.08400	7.30	21.4	23.8	3.55	.	.
82	41-AX2-CON	2107.08300	7.21	22.5	23.3	3.72	.	.
83	41-AX2-CON	4207.08400	8.51	24.0	25.3	3.70	.	.
84	41-AX2-CON	4107.08300	7.89	24.0	25.1	3.26	.	.
85	41-AX2-2	2307.02000	7.26	23.5	23.0	4.57	-0.745	-0.05403
86	41-AX2-2	2407.02100	7.30	23.6	23.2	4.01	-0.765	-0.05548
87	41-AX2-2	4407.02100	8.27	24.1	25.0	3.94	-1.195	-0.08666
88	41-AX2-2	4307.02100	8.52	24.8	25.0	4.31	-1.115	-0.08086
89	327-AX-CON	2102.06500	5.31	16.7	27.9	1.26	.	.
90	327-AX-CON	2202.06700	7.35	16.7	27.9	1.60	.	.
91	327-AX-CON	4202.06700	8.58	17.7	32.9	1.31	.	.
92	327-AX-CON	4102.06500	9.17	17.8	33.3	0.96	.	.
93	327-AX-2	2402.00400	7.52	18.0	27.7	1.85	-0.543	-0.03938
94	327-AX-2	2302.00200	8.84	18.6	27.0	2.00	-0.593	-0.04300
95	327-AX-2	4402.00400	9.31	18.8	30.7	1.75	-0.873	-0.06331
96	327-AX-2	4302.00200	9.44	19.1	29.6	1.57	-0.893	-0.06476
97	327-RA-CON	2213.07300	5.67	32.3	24.9	3.08	.	.
98	327-RA-CON	2113.07200	5.67	32.3	25.2	3.21	.	.
99	327-RA-CON	2113.07200	5.67	32.3	25.2	3.21	.	.
100	327-RA-CON	2213.07300	5.67	32.3	24.9	3.08	.	.
101	327-RA-CON	4113.07200	7.36	21.4	29.2	2.87	.	.
102	327-RA-CON	4113.07200	7.36	21.4	29.2	2.87	.	.
103	327-RA-CON	4213.07300	7.48	19.1	31.1	2.59	.	.
104	327-RA-CON	4213.07300	7.48	19.1	31.1	2.59	.	.
105	327-RA-2	2413.01000	4.95	18.9	25.5	4.00	-1.230	-0.08920
106	327-RA-2	2313.00900	5.28	19.2	24.5	4.28	-1.240	-0.08992
107	327-RA-2	2313.00900	5.28	19.2	24.5	4.28	-1.240	-0.08992
108	327-RA-2	2413.01000	4.95	18.9	25.5	4.00	-1.230	-0.08920
109	327-RA-2	4313.00900	5.62	19.5	30.6	4.30	-1.618	-0.11734
110	327-RA-2	4313.00900	5.62	19.5	30.6	4.30	-1.618	-0.11734
111	327-RA-2	4413.01000	9.37	20.3	30.0	4.25	-1.798	-0.13039
112	327-RA-2	4413.01000	9.37	20.3	30.0	4.25	-1.798	-0.13039

Figure 8-3 (continued)

OC2, OC4 (600 C)

GRAPHITE=327-AX-2

Variable	Minimum	Maximum
PCLENGTH	-1.2000000	-0.6300000
PCDIA	-0.0760000	0.0430000
PCVOL	-1.3850000	-0.5670000
DEN	1.7772000	1.7916000
KEV_50	0.1250000	0.3140000
E	18.9800000	23.2400000
G	7.5200000	9.4400000
RES_W_G	18.0000000	19.1000000
RES_A_G	27.0000000	30.7000000
CTE_500	1.5700000	2.0000000
CREEPPC	-0.8930000	-0.5430000
CR_PER_S	-0.0647600	-0.0393800

GRAPHITE=327-RA-CON

Variable	Minimum	Maximum
PCLENGTH	-0.3550000	-0.1120000
PCDIA	-0.4800000	-0.0500000
PCVOL	-1.2600000	-0.4300000
DEN	1.7655000	1.7845000
KEV_50	0.1770000	0.3820000
E	11.2700000	13.9200000
G	5.6700000	7.4800000
RES_W_G	19.1000000	32.3000000
RES_A_G	24.9000000	31.1000000
CTE_500	2.5900000	3.2100000
CREEPPC	.	.
CR_PER_S	.	.

GRAPHITE=327-AX-CON

Variable	Minimum	Maximum
PCLENGTH	-0.3100000	-0.0750000
PCDIA	-0.2710000	-0.0870000
PCVOL	-0.9210000	-0.2750000
DEN	1.7691000	1.7812000
KEV_50	0.1250000	0.3140000
E	14.4700000	23.2200000
G	5.3100000	9.1700000
RES_W_G	16.7000000	17.8000000
RES_A_G	27.9000000	33.3000000
CTE_500	0.9600000	1.6000000
CREEPPC	.	.
CR_PER_S	.	.

GRAPHITE=40-AX-2

Variable	Minimum	Maximum
PCLENGTH	-1.8600000	-0.6800000
PCDIA	-0.1850000	0.0650000
PCVOL	-2.3300000	-0.5740000
DEN	1.7141000	1.7480000
KEV_50	0.0950000	0.5120000
E	15.2900000	18.5600000
G	6.3000000	8.1400000
RES_W_G	18.6000000	27.2000000
RES_A_G	23.0000000	26.6000000
CTE_500	3.9300000	4.7900000
CREEPPC	-1.2790000	-0.6070000
CR_PER_S	-0.0927500	-0.0440200

GRAPHITE=327-RA-2

Variable	Minimum	Maximum
PCLENGTH	-2.1400000	-1.3500000
PCDIA	-0.2670000	0.1170000
PCVOL	-2.3880000	2.1410000
DEN	1.7936000	1.8153000
KEV_50	0.1770000	0.3820000
E	11.7200000	13.3300000
G	4.9500000	9.3700000
RES_W_G	18.9000000	20.3000000
RES_A_G	24.5000000	30.6000000
CTE_500	4.0000000	4.3000000
CREEPPC	-1.7980000	-1.2300000
CR_PER_S	-0.1303900	-0.0892000

GRAPHITE=40-AX-3

Variable	Minimum	Maximum
PCLENGTH	-2.5400000	-1.2800000
PCDIA	-0.0390000	0.1440000
PCVOL	-2.7240000	-1.0270000
DEN	1.7327000	1.7612000
KEV_50	0.1770000	0.5020000
E	15.7600000	18.2800000
G	6.6100000	8.0600000
RES_W_G	23.6000000	26.7000000
RES_A_G	24.9000000	27.8000000
CTE_500	3.5800000	5.0800000
CREEPPC	-2.0050000	-1.1390000
CR_PER_S	-0.0969400	-0.0550700

Figure 8-4. Ranges of variation for the variables of interest in the data used for the creep analysis at 600°C. The definition of the variables and their units are given in Tables 8-3 and 8-4.

OC2, OC4 (600 C)

--------- GRAPHITE=40-AX-CON ---------

Variable	Minimum	Maximum
PCLENGTH	-0.5900000	-0.0680000
PCDIA	-0.5300000	-0.0820000
PCVOL	-1.8120000	-0.2690000
DEN	1.7058000	1.7393000
KEV_50	0.0950000	0.5120000
E	15.4900000	18.9800000
G	6.1600000	8.1100000
RES_W_G	21.0000000	25.4000000
RES_A_G	23.0000000	27.7000000
CTE_500	3.0600000	3.9700000
CREEPPC	.	.
CR_PER_S	.	.

--------- GRAPHITE=41-AX-2 ---------

Variable	Minimum	Maximum
PCLENGTH	-1.7400000	-0.9800000
PCDIA	-0.1540000	0.0310000
PCVOL	-2.1020000	-0.9440000
DEN	1.7224000	1.7422000
KEV_50	0.2170000	0.4770000
E	16.3400000	18.5100000
G	6.8200000	8.9400000
RES_W_G	24.7000000	25.4000000
RES_A_G	23.8000000	26.1000000
CTE_500	4.4500000	4.6100000
CREEPPC	-1.2480000	-0.7930000
CR_PER_S	-0.0905000	-0.0575100

--------- GRAPHITE=40-RA-2 ---------

Variable	Minimum	Maximum
PCLENGTH	-2.0200000	-1.1800000
PCDIA	-0.1930000	0.0180000
PCVOL	-2.5260000	-1.1820000
DEN	1.7235000	1.7463000
KEV_50	0.2410000	0.5130000
E	14.8000000	16.0000000
G	6.4800000	6.5100000
RES_W_G	25.3000000	28.9000000
RES_A_G	23.5000000	27.9000000
CTE_500	5.0000000	5.2700000
CREEPPC	-1.5370000	-0.9970000
CR_PER_S	-0.1114600	-0.0723000

--------- GRAPHITE=41-AX-CON ---------

Variable	Minimum	Maximum
PCLENGTH	-0.5120000	-0.1800000
PCDIA	-0.4640000	-0.1610000
PCVOL	-1.5530000	-0.5510000
DEN	1.7084000	1.7268000
KEV_50	0.2170000	0.4770000
E	16.4900000	18.6800000
G	6.8200000	7.9700000
RES_W_G	22.9000000	24.8000000
RES_A_G	24.4000000	27.1000000
CTE_500	3.5000000	3.8100000
CREEPPC	.	.
CR_PER_S	.	.

--------- GRAPHITE=40-RA-CON ---------

Variable	Minimum	Maximum
PCLENGTH	-0.5050000	-0.1750000
PCDIA	-0.5440000	-0.2250000
PCVOL	-1.7290000	-0.6810000
DEN	1.7086000	1.7271000
KEV_50	0.2410000	0.5130000
E	14.9100000	16.9500000
G	6.3600000	7.4700000
RES_W_G	24.7000000	26.7000000
RES_A_G	24.0000000	27.8000000
CTE_500	4.2000000	4.3700000
CREEPPC	.	.
CR_PER_S	.	.

--------- GRAPHITE=41-AX2-2 ---------

Variable	Minimum	Maximum
PCLENGTH	-1.6800000	-0.9400000
PCDIA	-0.1760000	0.0150000
PCVOL	-2.1110000	-0.9380000
DEN	1.7410000	1.7636000
KEV_50	0.2300000	0.4990000
E	17.3600000	19.2200000
G	7.2600000	8.5200000
RES_W_G	23.5000000	24.8000000
RES_A_G	23.0000000	25.0000000
CTE_500	3.9400000	4.5700000
CREEPPC	-1.1950000	-0.7450000
CR_PER_S	-0.0866600	-0.0540300

Figure 8-4 (continued)

OC2, OC4 (600 C)

--------- GRAPHITE=41-AX2-CON ---------

Variable	Minimum	Maximum
PCLENGTH	-0.5300000	-0.1850000
PCDIA	-0.4980000	-0.1890000
PCVOL	-1.6440000	-0.6290000
DEN	1.7317000	1.7501000
KEV_50	0.2300000	0.4990000
E	17.4500000	19.8200000
G	7.2100000	8.5100000
RES_W_G	21.4000000	24.0000000
RES_A_G	23.3000000	25.3000000
CTE_500	3.2600000	3.7200000
CREEPPC	.	.
CR_PER_S	.	.

Figure 8-4 (continued)

Table 8-3. Definition of the Numeric and/or Alphabetic Codes Involved in the Items of the Second Column of Figure 8-3.

Code	Description
40	Graphite grade H-451 obtained from block 40
AX	Sample has been taken from the block in axial direction
CON	Control specimen (no external stress)
-2	Creep (test) specimen subjected to a compressive stress of 13.79 MPa
-3	Creep (test) specimen subjected to a compressive stress of 20.68 MPa
RA	Sample has been taken from the block in radial direction
41	Graphite grade H-451 obtained from block 41
AX2	Sample has been taken from the block in axial direction (different from AX)
327	Graphite grade H-327

Table 8-4. Definition of Variables of Interest Involved in the Pre- and Postirradiation Measurement Data for 600°C Experiments

Variable	Description
SPECNO	A code indicating the irradiation experiment number (the first digit from left), specimen column number (the second digit from left), specimen position in the column (the third and fourth digits from left), and the specimen identification number (the last five digits)
PCLENGTH	Change in length (%)
PCDIA	Change in diameter (%)
PCVOL	Change in volume (%)
DEN	Specimen density (g/cm^3)
KEV_50	Neutron fluence (10^{26} $neutrons/m^2$, E > 50 KeV)
E	Dynamic Young's modulus (GPa)
CTE_500	Coefficient of thermal expansion at 500°C ($x10^{-6}$ 1/°C)
G	Shear modulus
RES_W_G	Electrical resistivity in with-grain direction (μOhm.m)
RES_A_G	Electrical resistivity in against-grain direction (μOhm.m)
CREEPPC	Creep strain (%)
CR_PER_S	Creep strain per unit stress (%/MPa)

8.2 Purpose of the Analysis

The main objective in examining and analyzing the measurement creep data is to see to what extent the secondary creep coefficient (K in Eq. 8-1), involved in a linear model and in a nonlinear model, can explain the observed behavior of the graphites under consideration. Then the results of the temperature analyses would be invoked to find out more about the dependence of creep coefficient on irradiation temperature. Of special interest is to determine whether the Kennedy model, which considers the densification of graphite (volume shrinkage) with fluence as an explanation for resistance to creep, has any conflict with the provided data.

8.3 Linear Model for Creep Coefficient

The Viscoelastic creep model explained in Chapter 6 has been under investigation by many researchers for the past few years. Reference [29] is the most recent reference found in this regard. The linear model for creep in equation (6-7), repeated here,

$$\epsilon = \frac{\sigma}{E_o} + \frac{a\sigma}{E_o}\left[1 - EXP\ (-b\phi)\right] + K\sigma\phi \tag{8-1}$$

assumes that K is a constant, referred to as the secondary creep coefficient, as explained in Chapter 6. Considering the fact that the first term in Eq. 8-1 is the elastic strain, of primary interest are the primary and secondary creep coefficients mainly a and K. The coefficient b with a value of about 5 would not be as important as K, because it has been determined that [30], primary creep saturates very fast and with the range of neutron fluences available the exponential term assumes a very small value compared to the other terms involved in the equation. Therefore, as total irradiation-induced creep strain we can have:

$$\epsilon_T = \frac{a\sigma}{E_o} + K\sigma\phi \qquad (8\text{-}2)$$

where the first and the second terms are the saturated primary creep and the secondary creep, respectively. To simplify the analysis of data and explanation of the secondary creep coefficient, usually, the creep strain is normalized with respect to stress (σ) and the preirradiation value of the Young's modulus. In other words the variation of creep strain per unit elastic strain with neutron fluence, at a constant irradiation temperature, is considered. The normalization with respect to the Young's modulus is justified if an inverse relationship between K and E_o exists.

8.4 The Relationship Between K and E_o

To investigate the relationship between K and E_o, the following model was used to find the value of K for different grades of graphite:

$$\frac{\epsilon_T}{\sigma} = a_1 + K\phi \tag{8-3}$$

where $a_1 = a/E_o$. No information regarding the origin was provided to the model. Figure 8-5 shows the values of K obtained for grades of graphite with different average E_o. A regression analysis, regressing K with $1/E_o$ revealed that the inverse relationship between K and E_o does exist. Figure 8-6 depicts the variation of K with $1/E_o$ for the 900°C experiments. The observation number 6, an outlier, was not involved in the analysis.

8.5 Linear Creep Model

The following model was fit to available data for graphite grade H-451 (axial directions) to obtain an overall K:

$$\frac{\varepsilon_T E_0}{\sigma} = a + K\phi \tag{8-4}$$

The above equation was used as the simple linear regression model with the normalized creep (creep per unit initial elastic strain $\varepsilon_T/\sigma/E_0$) as the predicted variable and neutron fluence (ϕ) as the predictor variable. a and k are the intercept and slope (regression analysis of the regression line. From this point on, the value of σ/E_0 (unitless) will be referred to as elastic unit (EU). (Regression analysis and the interpretation of its results have been discussed in Chapter 7.)

OBSERVATION	GRAPHITE	MEAN E0 (MPa)	K (600 C) (1/MPa/(10**26 n/m**2))	K (900 C) (1/MPa/(10**26 n/m**2))
1	327-AX-2	11928.35	0.0012087	0.0019901
2	327-RA-2	7170.80	0.0016734	0.0027077
3	40-AX-2	8503.83	0.0011121	0.0021519
4	40-AX-3	8632.54	0.0011377	0.0021492
5	40-RA-2	7584.50	0.0011998	0.0026667
6	41-AX-2	8618.75	0.0011296	0.0027738
7	41-AX2-2	8963.50	0.0010513	0.0021880

Figure 8-5. Values of creep coefficient (K) and preirradiation Young's Moduli for different grades of graphite at 600°C and 900°C.

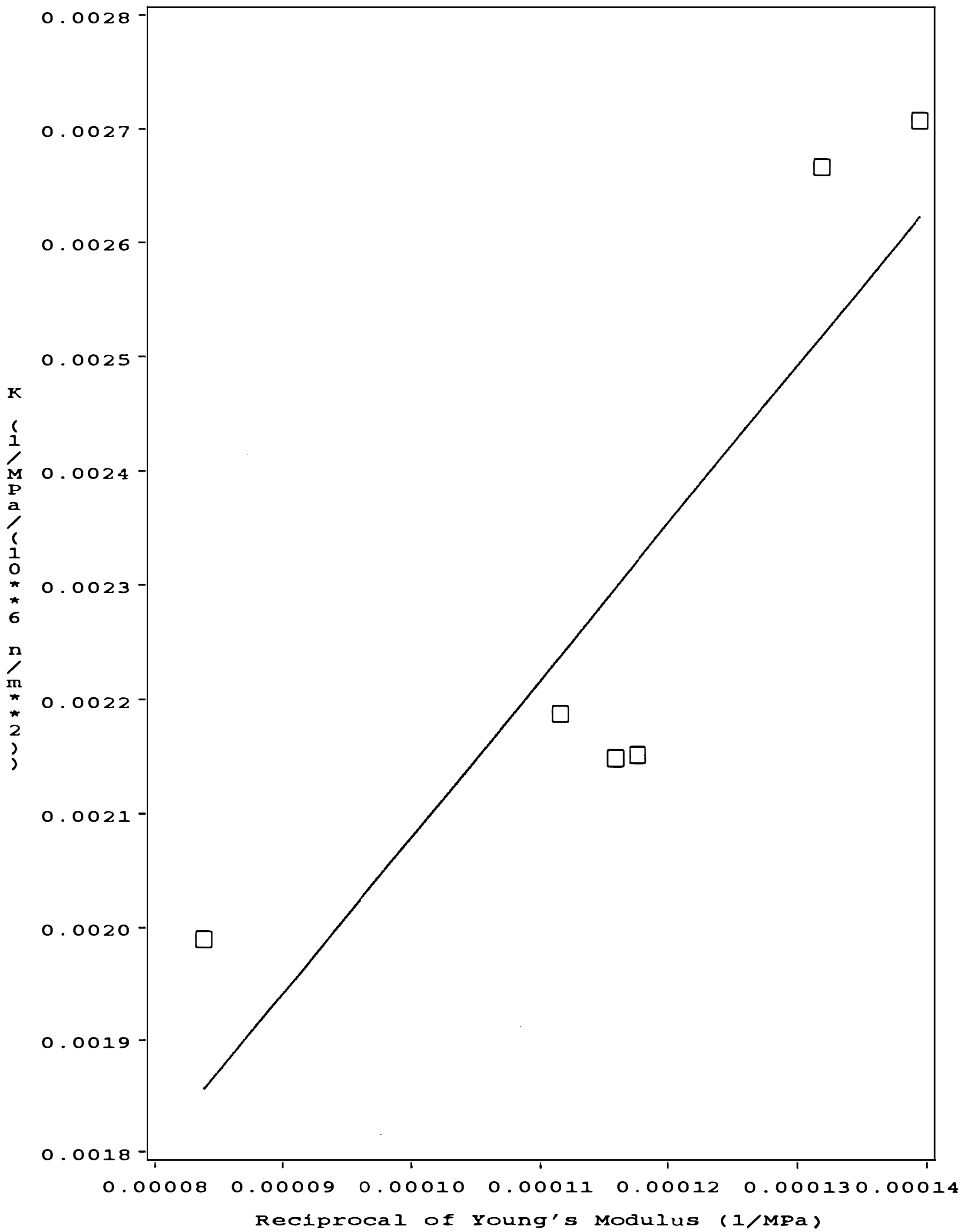


Figure 8-6. Variation of creep coefficient with the reciprocal of Young's modulus.

The results of the regression analyses are shown in Figures 8-7 and 8-8 for the 900°C experiment and in Figures 8-9 and 8-10 for the 600°C experiment. The R-square value obtained for the 900°C experiments is 0.7932, as indicated in the "Analysis of Variance" portion of Figure 8-7. This value indicates that about 79% of the variation of the normalized creep with neutron fluence is explained by the linear creep model.

For the 900°C experiments the estimates for the intercept and the slope are 2.883364 and 19.227982, respectively. The 95% Confidence Intervals (CI) for these estimates are given below as indicated in the "Parameter Estimates" section of Figure 8-7.

95% CI on intercept:

(parameter estimate ± (t value for 95% confidence with 34 degrees of freedom (DF)) x (standard error of the estimate):

2.883364 ± 2.03224 (0.51714203).

95% CI on slope:

19.227982 ± 2.03224 (1.68364646)

The R-square value for the 600°C experiments is 0.9567 as indicated in Figure 8-9. This means that about 96% of the variation of the normalized creep with neutron fluence is explained by the linear creep model at this temperature.

OC1, OC3, OC5 (900 C)
REGRESSION FOR LINEAR MODEL (NORCREEP = A + B KEV_50)
40-A-2, 40-A-3, 41-A-2, & 41-A2-2

Model: MODEL1
Dependent Variable: NORCREEP   Creep (EU)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	274.21224	274.21224	130.426	0.0001
Error	34	71.48257	2.10243		
C Total	35	345.69481			

Root MSE	1.44998	R-square	0.7932
Dep Mean	8.10483	Adj R-sq	0.7871
C.V.	17.89026		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.883364	0.51714203	5.576	0.0001
KEV_50	1	19.227982	1.68364646	11.420	0.0001

Figure 8-7. Results of regression analysis for 900°C experiments using the linear creep model.

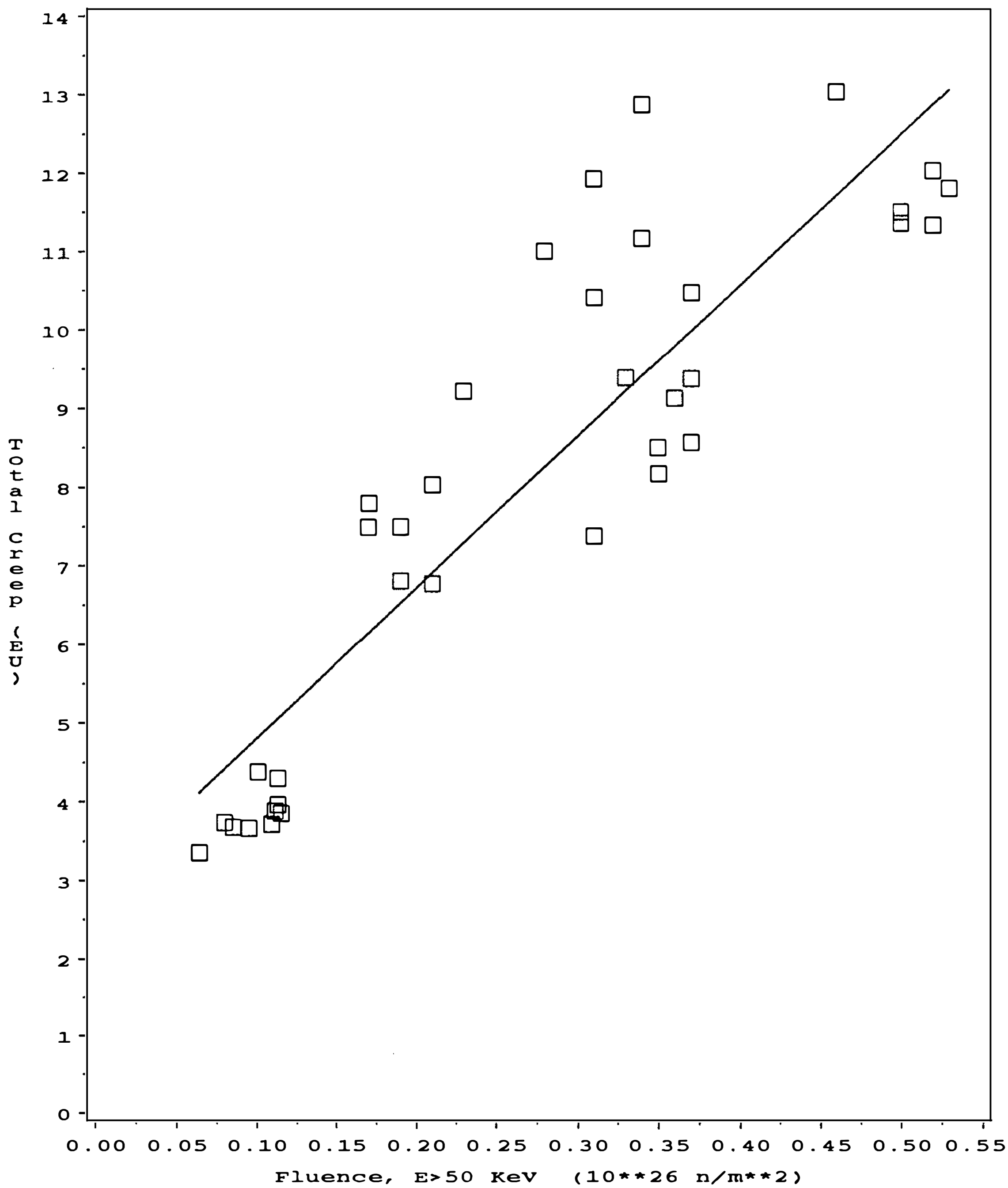


Figure 8-8. Least squares fit of linear model to data for 900°C experiments.

OC1, OC3, OC5 (600 C)
REGRESSION FOR LINEAR MODEL (NORCREEP = A + K KEV_50)
40-AX-2, 40-AX-3, 41-AX-2, & 41-AX2-2

Model: MODEL1
Dependent Variable: NORCREEP   Creep (EU)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	65.79879	65.79879	839.030	0.0001
Error	38	2.98005	0.07842		
C Total	39	68.77885			

Root MSE	0.28004	R-square	0.9567
Dep Mean	6.06737	Adj R-sq	0.9555
C.V.	4.61551		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	3.036806	0.11360848	26.730	0.0001
KEV_50	1	9.530063	0.32900844	28.966	0.0001

Figure 8-9. Results of regression analysis for 600°C experiments using the linear creep model.

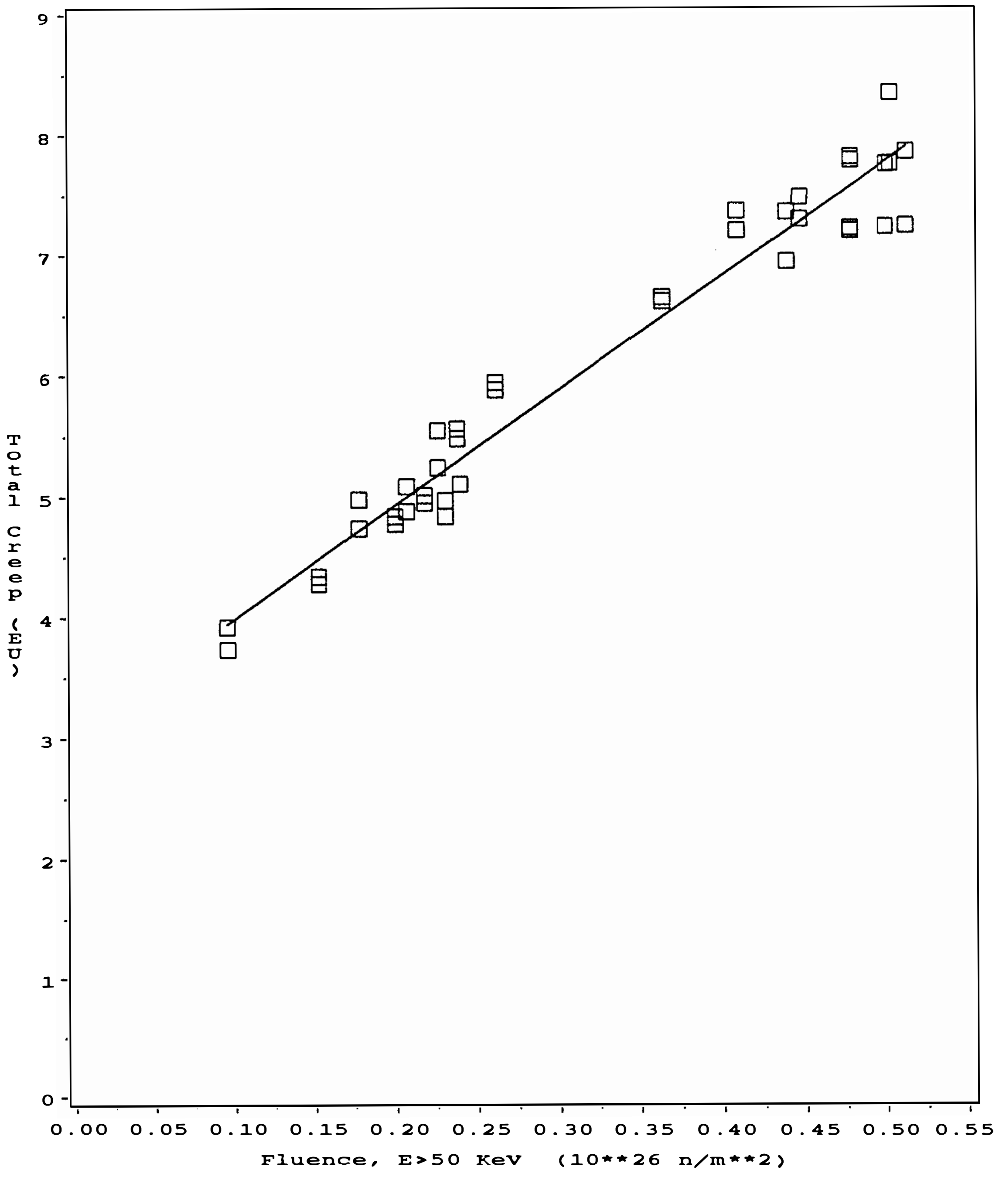


Figure 8-10. Least squares fit of linear model to data for 600°C experiments.

For the 600°C experiments the estimates for intercept and slope are 3.036806 and 9.530063, respectively (see Figure 8-9). The 95% CI for these estimates are given below:

95% CI on intercept:

Parameter estimate ± (t value for 95% CI with 41 DF) x (standard error of the estimate).

3.036806 ± (2.02439) (0.11360848)

95% CI on slope:

9.530063 ± (2.02439) (0.32900844)

Researchers in the field [29] have found that using the linear creep model applied to the secondary creep strain should result in a y-intercept very close to one elastic unit (EU): (σ/E_o). This would be true if the secondary creep rate remains constant.

Examination of results of the linear model analyses reveals that the intercept mentioned above is far from the value of unity in both 900°C and 600°C experiments (see the corresponding confidence intervals). The departure of the y-intercept from one elastic unit (having an upward trend) indicates that the linear model is affected by the fact that K decreases with fluence. In other words, for high fluence data, the linear model, which assumes a constant K, is not adequate. Kennedy, by his model, explains that variation of K with fluence should be considered. In the next section

Kennedy's model will be considered to see if it has any conflict with the data under consideration.

8.6. Nonlinear Creep Model

The nonlinear creep model (Kennedy's model) was introduced in Section 6.4. In this section the model is critically examined to see if it has any conflict with the experimental data. The model is given below again for discussion. The variables involved have already been defined in Section 6.4:

$$\frac{d\epsilon_s}{d\phi} = K(\phi)\frac{\sigma}{E_o} \tag{8-5}$$

where

$$K(\phi) = K_2\left[1 - \mu\,\frac{\frac{\Delta V}{V_0}(\phi)}{\left(\frac{(\Delta V(\phi)}{V_0}\right)_{max}}\right] \tag{8-6}$$

It is recalled that the above model does not include the mechanism responsible for creep at atomistic level, but rather tries to relate the decrease in K with fluence to the change in volume of the graphite. The volume of graphite shrinks due to irradiation to a fluence level referred to as the turn-around fluence at which the volume change "reverses" its trend and increases toward the zero-volume-change line as depicted, schematically, in Figure 8-11. Considering the range of fluence in the provided data, the volume change

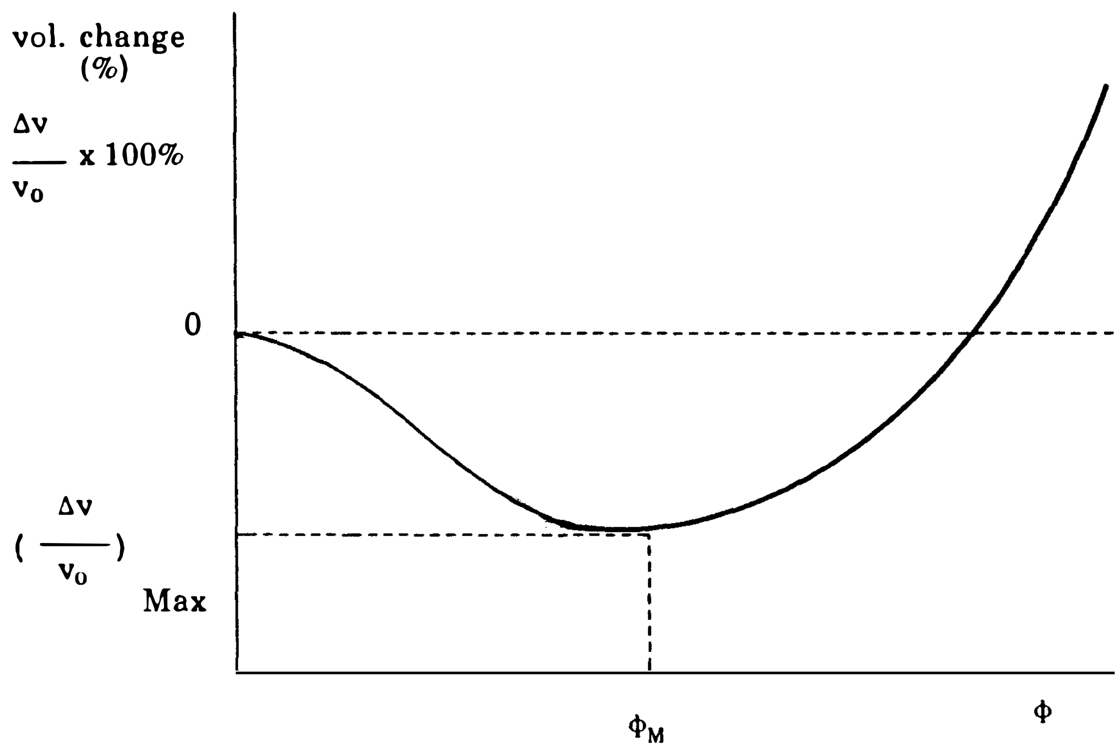


Figure 8-11. Variation of volume change (densification) in graphite with fast-neutron fluence (schematic).

does not reach a maximum as will be shown later in this chapter. A comprehensive examination of different fitting models was performed to find the best model representing the change of volume with fluence. The models examined were the ones obtained by considering all combinations of terms in a fourth-order polynomial. The results of such an analysis for 900°C experiments are given in Figures 8-12 and 8-13. The results of a similar analysis for the 600°C experiments are given in Figures 8-14 and 8-15. The headings involved in Figures 8-12 and 8-14 are explained below:

In	=	Number of terms involved in the model
Rsq	=	The value of R-square, indicating the percent of variation of volume with fluence explained by the model
Adj Rsq	=	Adjusted R-square (related to multiple regression)
MSE	=	Mean square error
Intercept	=	Intercept term
KEV_50	=	Coefficient of the First power of fluence
KEVSQ	=	Coefficient of the Second power of fluence
KEVCUBIC	=	Coefficient of the Third power of fluence
KEVQUART	=	Coefficient of the Fourth power of fluence

As indicated in Figures 8-12 and 8-14, the following equations were chosen as the best fit least squares models because of their highest values of R-square (Rsq).

OC1, OC3, OC5 (900 C)
STEP BY STEP TEST OF REGRESSION MODEL FOR VOLPC = f(FLUENCE)
40-A-C, 41-A-C, & 41-A2-C

N = 81 Regression Models for Dependent Variable: VOLPC

	In	Rsq	Adj Rsq	MSE	Parameter Estimates Intercept	KEV_50	KEVSQ	KEVCUBIC	KEVQUART
	1	0.7606	0.7575	0.1496	0.1204	-4.3948	.	.	.
	1	0.7207	0.7172	0.1745	-0.1111	.	-9.3832	.	.
	1	0.6041	0.5991	0.2474	-0.2476	.	.	-17.7443	.
	1	0.5054	0.4992	0.3091	-0.3266	.	.	.	-32.4054
*	2	0.7830	0.7774	0.1374	0.0243	.	-22.1648	27.0093	.
	2	0.7796	0.7739	0.1395	0.00439	.	-16.5829	.	31.6836
	2	0.7674	0.7614	0.1472	0.0701	-3.2320	-2.7087	.	.
	2	0.7638	0.7578	0.1495	0.0909	-3.9155	.	-2.5320	.
	2	0.7625	0.7564	0.1504	0.1008	-4.1189	.	.	-3.1813
	2	0.7598	0.7536	0.1520	-0.0625	.	.	-78.4962	122.6
	3	0.7852	0.7769	0.1377	0.0507	.	-31.0308	71.9617	-54.5978
	3	0.7831	0.7746	0.1391	0.0166	0.3237	-23.8135	29.0807	.
	3	0.7802	0.7716	0.1409	0.0244	-0.6778	-14.0623	.	26.7511
	3	0.7750	0.7662	0.1443	0.0417	-2.2700	.	-39.4792	61.6690
	4	0.7949	0.7842	0.1332	-0.00511	6.1451	-93.0985	267.3	-244.1

Figure 8-12. Results of fitting different regression models, obtained from the combination of terms in a fourth order model, for change of volume of unstressed graphite with fluence at 900°C.

*The regression model chosen.

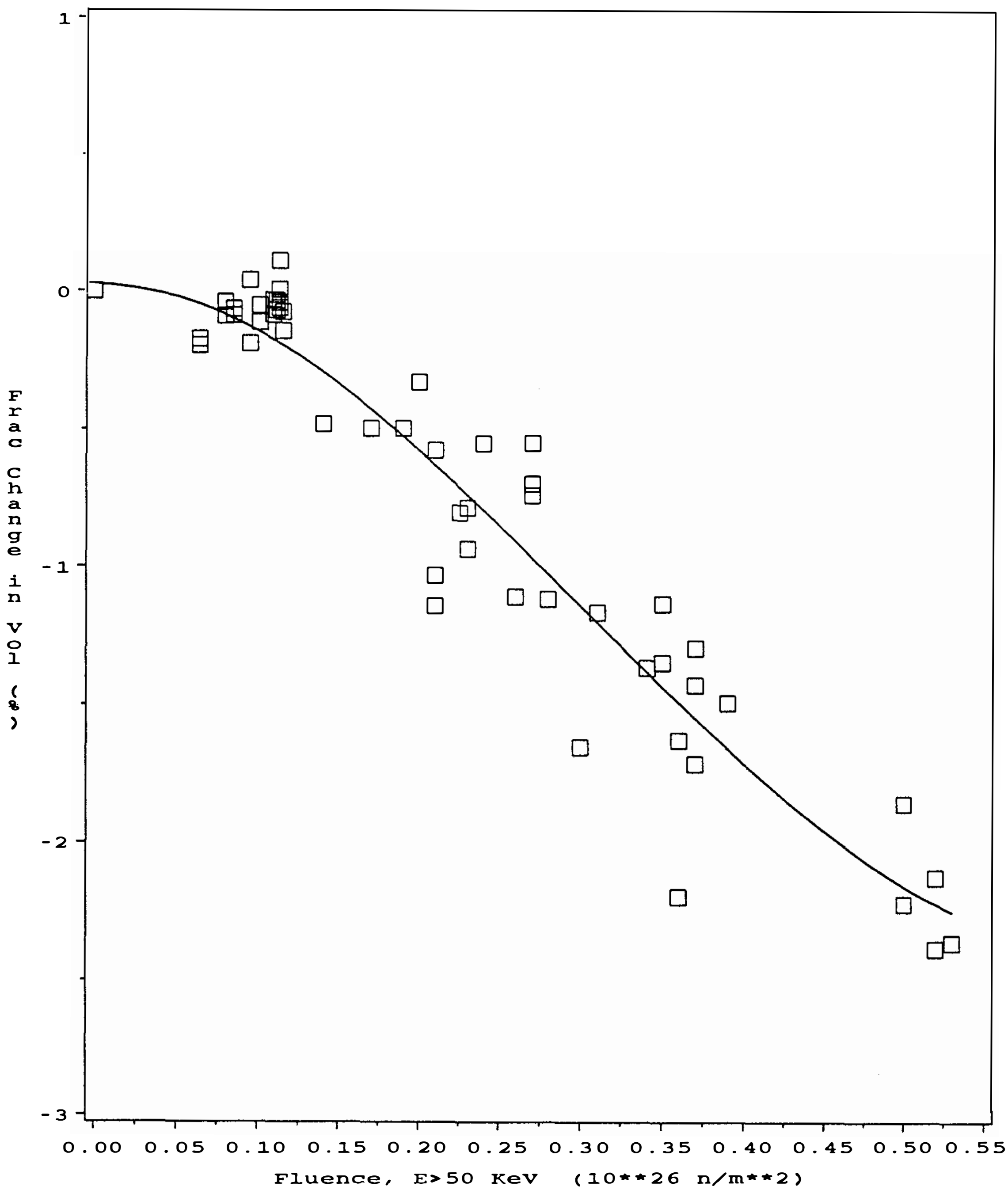


Figure 8-13. Least squares fit to data for volume change for the 900°C experiments.

OC2 & OC4 (600 C)
STEP BY STEP TEST OF REGRESSION MODEL FOR PCVOL = f(FLUENCE)
40-AX-CON, 41-AX-CON, & 41-AX2-CON

N = 60 Regression Models for Dependent Variable: PCVOL

	In	Rsq	Adj Rsq	MSE	Parameter Estimates Intercept	KEV_50	KEVSQ	KEVCUBIC	KEVQUART
	1	0.9897	0.9895	0.0040	0.0376	-3.2803	.	.	.
	1	0.9529	0.9521	0.0183	-0.1402	.	-6.5116	.	.
	1	0.8796	0.8775	0.0468	-0.2418	.	.	-12.5376	.
	1	0.8240	0.8209	0.0684	-0.2964	.	.	.	-24.4893
*	2	0.9970	0.9968	0.0012	-0.00077	-2.6770	.	-2.6980	.
	2	0.9969	0.9967	0.0012	0.00142	-2.7866	.	.	-4.6398
	2	0.9968	0.9967	0.0013	-0.00245	-2.3677	-1.9302	.	.
	2	0.9896	0.9892	0.0041	-0.0340	.	-15.1732	17.5468	.
	2	0.9848	0.9842	0.0060	-0.0503	.	-11.4780	.	20.6555
	2	0.9590	0.9575	0.0162	-0.1093	.	.	-53.0516	82.1136
	3	0.9970	0.9968	0.0012	-0.00062	-2.6974	0.1230	-2.8671	.
	3	0.9970	0.9968	0.0012	-0.00088	-2.6701	.	-2.8771	0.3118
	3	0.9969	0.9968	0.0012	-0.00086	-2.5852	-0.8978	.	-2.5434
	3	0.9955	0.9952	0.0018	-0.00955	.	-24.3039	66.4003	-62.3238
	4	0.9970	0.9968	0.0012	-0.00013	-3.0630	3.7027	-13.6943	10.2828

Figure 8-14. Results of fitting different regression models, obtained from the combination of terms in a fourth order model, for change of volume of unstressed graphite with fluence at 600oC.

*The regression model chosen.

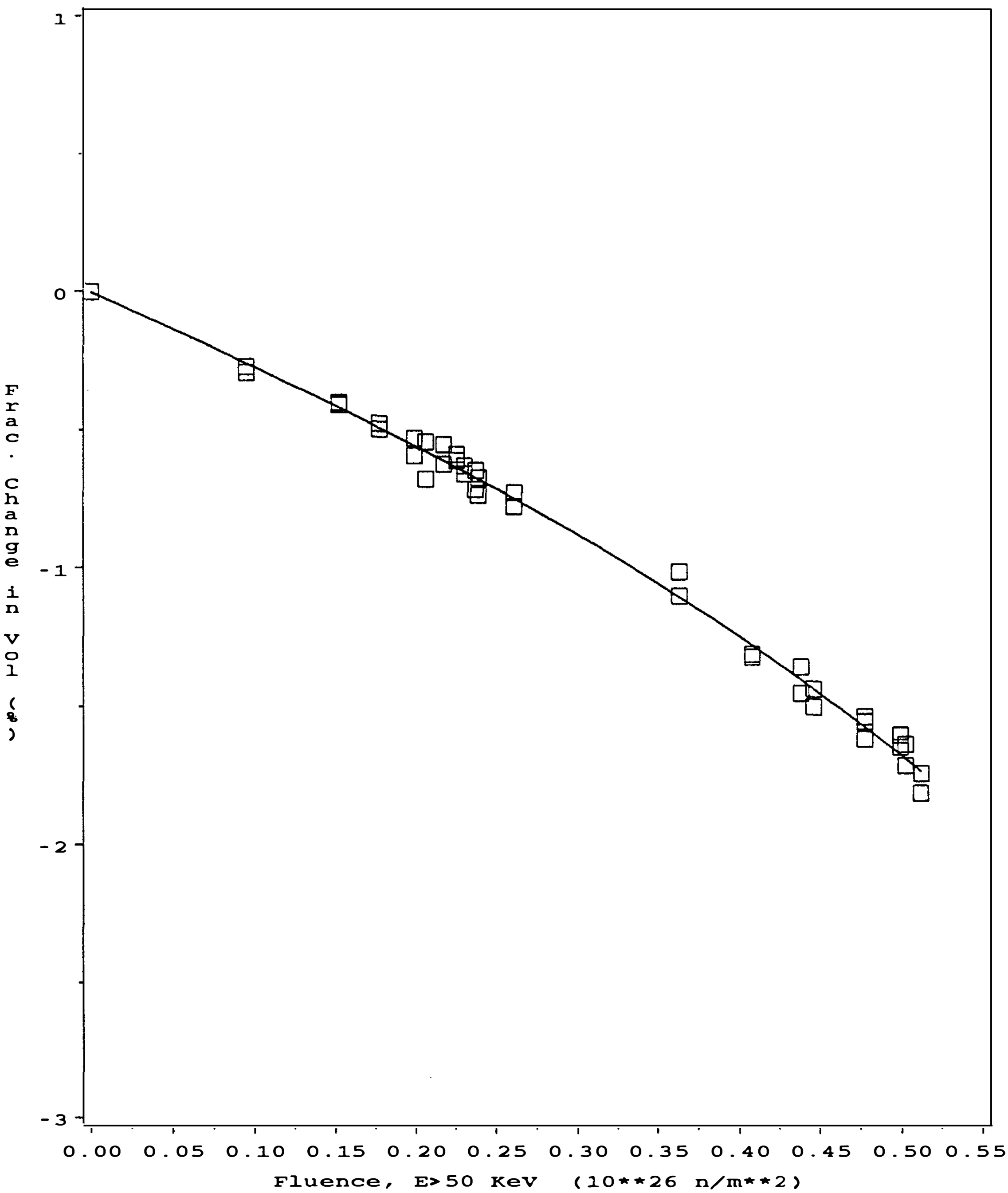


Figure 8-15. Least squares fit to data for volume change for the 600°C experiments.

For the 900°C experiments the function is

$$\frac{\Delta V(\phi)}{V_o} = 0.0243 - 22.1648\phi^2 + 27.0093\phi^3 \tag{8-7}$$

and for the 600°C experiments the function is

$$\frac{\Delta V}{V_o}(\phi) = -0.00077 - 2.6770\phi - 2.6980\phi^3 \tag{8-8}$$

It should be noted that due to lack of high fluence data (being far from the maximum volume change), the above equations are not suitable for extrapolation.

Considering the variation of volume with ϕ as f (ϕ), this function is supposed to be divided by the corresponding maximum volume change. Due to the lack of high fluence data, the values for maximum change in volume for graphite grade H-451 at 600°C and 900°C were obtained from reference [30]. These values are 8.7% and 6%, respectively. By dividing f(x) by its maximum value the dependence of secondary creep rate on fluence in the nonlinear model is completely known, as shown below:

For 900°C experiments

$$K(\phi) = K_2 \; [1 - 0.75f(\phi)/(-6)] \tag{8-9}$$

where

$$f(\phi) = 0.0243 - 22.1648\;\phi^2 + 27.0093\;\phi^3 \tag{8-10}$$

By substituting the function obtained above in the nonlinear creep model, the secondary creep curve for 900°C experiments can be obtained by integration. From the nonlinear creep model

$$\frac{d\varepsilon_s(\phi)}{d\phi} = K(\phi)\frac{\sigma}{E_0} \qquad (8\text{-}11)$$

Integration with respect to ϕ and normalization with respect to initial elastic strain provides:

$$\varepsilon_s(\phi) = K_2[\phi - 0.75g(\phi)] \qquad (8\text{-}12)$$

where

$$g(\phi) = \frac{1}{6}(-0.0243\phi + 7.3883\phi^3 - 6.7523\phi^4) \qquad (8\text{-}13)$$

and $\epsilon_s(\phi)$ is in EU. Since the creep strains given are total creep the suitable model to be fit to the data should contain a term for primary creep,

$$\epsilon_T(\phi) = a + K_2[\phi - 0.75g(\phi)] \qquad (8\text{-}14)$$

For the 600°C experiments, following the steps similar to those given above resulted in the following regression model for the nonlinear creep:

$$\varepsilon_T(\phi) = a + k_2[\phi - 0.75g(\phi)] \qquad (8\text{-}15)$$

where

$$g(\phi) = \frac{1}{8.7}\,(0.00077\phi + 1.3385\phi^2 + 0.6745\phi^4) \qquad (8\text{-}16)$$

By fitting the above model to the data, K_2 and a can be determined. This was accomplished by considering the $\epsilon_T(\phi)$ as the dependent variable and the whole bracket as the independent variable. In other words since K_2 is not a function of ϕ, in effect, a simple linear regression is being considered. Figures 8-16 and 8-17 show the results of regression analysis for the 900°C experiments. The results of regression analysis for the 600°C experiments are shown in Figures 8-18 and 8-19. Figures 8-16 and 8-18 indicate an R-square value of 0.78 for the 900°C experiments and an R-square value of 0.95 for the 600°C experiments.

As indicated in Figure 8-16, for the 900°C experiments the estimates for the intercept and the slope are 2.388268 and 22.743795, respectively. The 95% CI for these estimates are given below:

95% CI on Intercept:

2,388268 ± (2.03224) (0.52120636)

95% CI on slope:

22.743795 ± (2.03224) (1.86274662)

For the 600 °C experiments, as indicated in Figure 8-18, the estimates for the intercept and the slope are 2.906617 and 10.433818, respectively. The 95% CI for these estimates are given below:

OC1, OC3, OC5 (900 C)
REGRESSION FOR NONLINEAR MODEL (NORCREEP = A + K (BRACKET)
40-A-2, 40-A-3, 41-A-2, & 41-A2-2

Model: MODEL1
Dependent Variable: NORCREEP Creep (EU)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	281.49530	281.49530	149.080	0.0001
Error	34	64.19952	1.88822		
C Total	35	345.69481			

Root MSE	1.37413	R-square	0.8143
Dep Mean	8.10483	Adj R-sq	0.8088
C.V.	16.95440		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.388268	0.52120636	4.582	0.0001
BRACKET	1	22.743795	1.86274662	12.210	0.0001

Figure 8-16. Results of regression analysis for 900°C experiments using the nonlinear creep model.

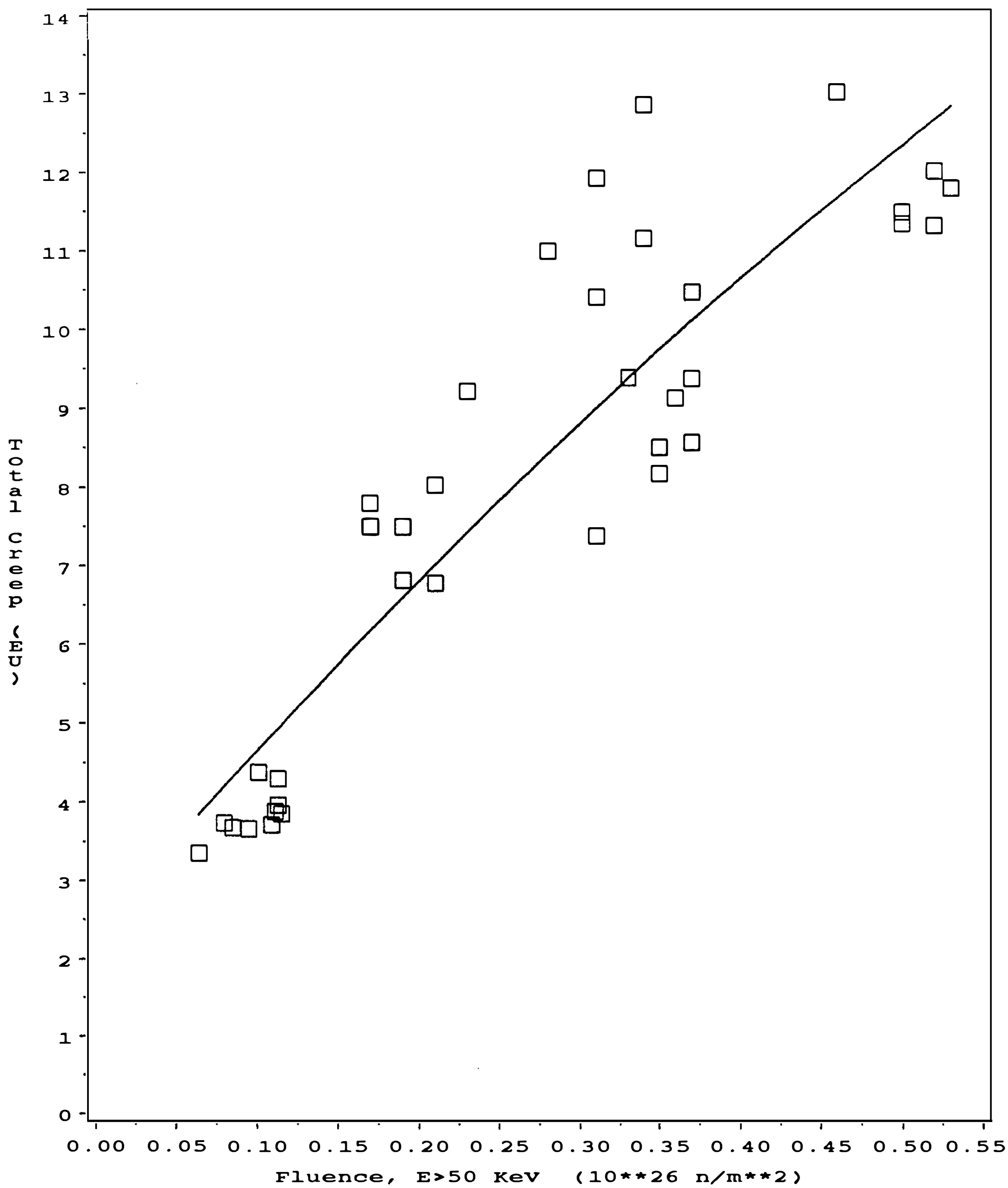


Figure 8-17. Least squares fit of nonlinear model to data for the 900°C experiments.

OC2 & OC4 (600 C)
REGRESSION FOR NONLINEAR MODEL (NORCREEP = A + K (BRACKET)
40-AX-2, 40-AX-3, 41-AX-2, & 41-AX2-2

Model: MODEL1
Dependent Variable: NORCREEP   Creep (EU)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	65.93089	65.93089	879.708	0.0001
Error	38	2.84796	0.07495		
C Total	39	68.77885			

Root MSE	0.27376	R-square	0.9586
Dep Mean	6.06737	Adj R-sq	0.9575
C.V.	4.51206		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.906617	0.11502207	25.270	0.0001
BRACKET	1	10.433818	0.35178228	29.660	0.0001

Figure 8-18. Results of regression analysis for 600°C experiments using the nonlinear creep model.

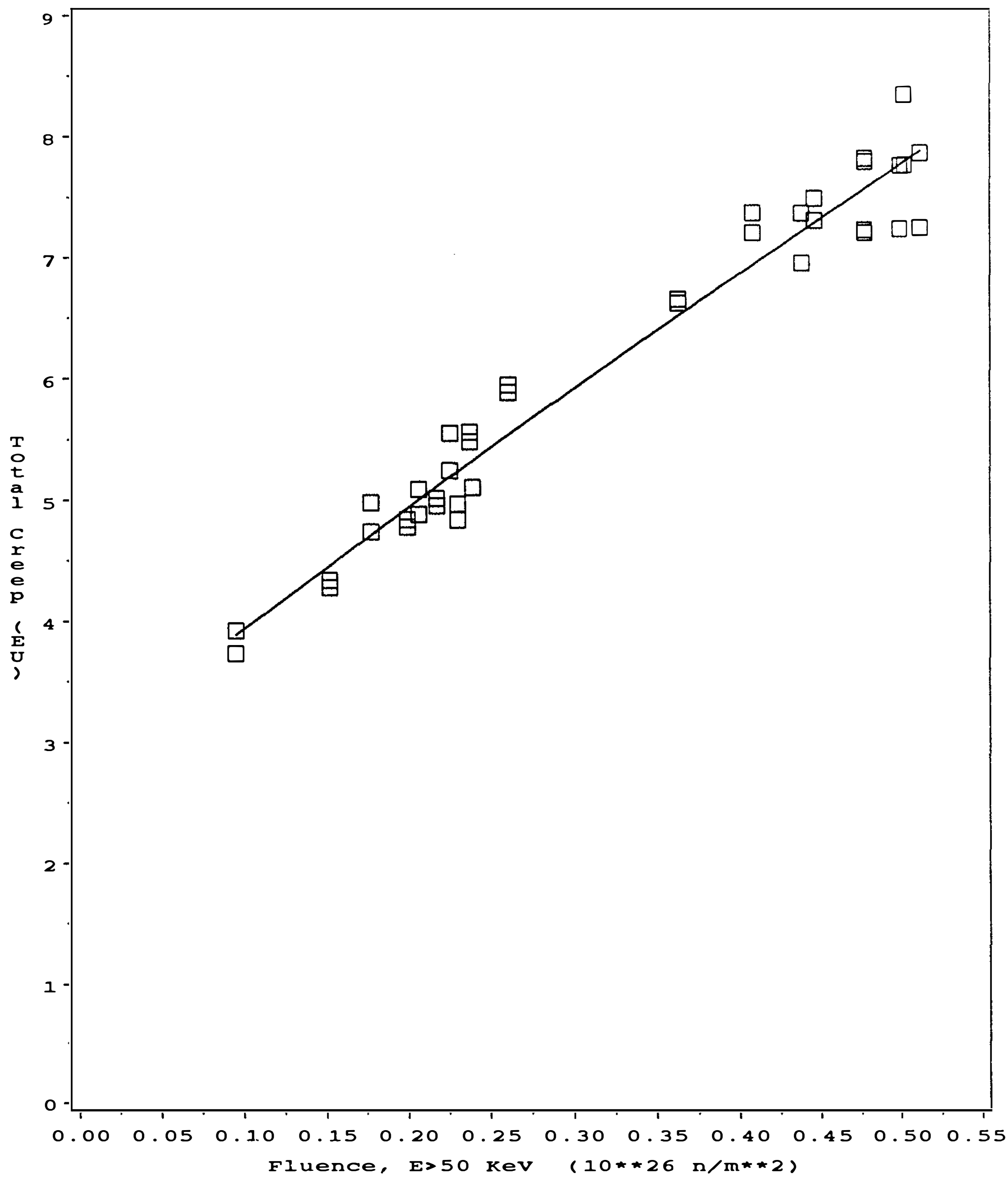


Figure 8-19. Least squares fit of nonlinear model to data for the 600°C experiments.

95% CI on intercept:

2.906617 ± (2.02439) (0.11502207)

95% CI on slope:

10.433818 ± (2.02439) (0.35178228)

8.7 Variation of Creep Coefficient with Temperature

In the present section the variation of the creep coefficient (K) with irradiation temperature in the linear model and the variation of the creep coefficient (K_2) with irradiation temperature in the nonlinear model are determined.

8.7.1 Variation of Creep Coefficient with Temperature in Linear Model.

Regarding the temperature range of 600 °C to 900 °C, the change of the creep coefficients with temperature mentioned above is linear to the first degree approximation. Based on this assumption, the linear relationship between the creep coefficients (K and K_2) and temperature are determined below. Employing the equation of a line passing through the points (x_1, y_1) and (x_2, y_2)

$$\frac{y-y_1}{x-x_1} = \frac{y_2-y_1}{x_2-x_1} \tag{8-17}$$

or

$$y = y_1 + \frac{y_2-y_1}{x_2-x_1}(x-x_1) \tag{8-18}$$

gives for the creep coefficient in the linear creep model:

$$K = -10.044 + 0.032\ T \tag{8-19}$$

The creep coefficient is in (in/in)/(initial elastic strain)/(10^{26} neutrons/m^2, E > 50 KeV) and the temperature in °C.

8.7.2 Variation of Creep Coefficient with Temperature in Nonlinear Model

Following the procedure used in Section 8.7.1, the relationship between K_2 in the nonlinear creep model and the irradiation temperature is found to be:

$$K_2 = -14.412 + 0.041\ T \tag{8-20}$$

The creep coefficient is in (in/in)/(initial elastic strain)/(10^{26} neutrons/m^2, E > 50 KeV) and the temperature in °C.

CHAPTER 9

DETERMINATION OF COEFFICIENTS FOR THE CONSTITUTIVE EQUATION

9.1 Constitutive Equation of Graphite

As introduced briefly in the introductory chapter, the constitutive equation of graphite, while subjected to neutron irradiation environment and under applied stress, is written as:

$$\epsilon_T = \epsilon_e + \epsilon_p + \epsilon_s + \epsilon_g + \epsilon_t \tag{9-1}$$

where,

ε_T = total strain,

ε_e = elastic strain,

ε_p = primary creep strain,

ε_s = secondary creep strain,

ε_g = irradiation growth,

ε_t = thermal strain.

The above strains, in the direction of the applied stress, e.g. x, can be determined by the following equations:

$$\epsilon_{e_x} = \frac{1}{E_x}(\sigma_x - \mu(\sigma_y + \sigma_z)) \tag{9-2}$$

$$\epsilon_{p_x} = \frac{F}{E_x}(\sigma_x - \mu'(\sigma_y + \sigma_z)) \tag{9-3}$$

$$\epsilon_{sx} = \frac{K}{E_x}(\sigma_x - \mu''(\sigma_y + \sigma_z))\phi \tag{9-4}$$

$$\epsilon_{g_x} = \dot{G}_x \, \phi \tag{9-5}$$

$$\epsilon_{tx} = (CTE)_x \, \Delta T \tag{9-6}$$

where, subscripts x, y, and z represent the three orthogonal directions of the Cartesian coordinates and

E = elastic modulus,

σ = applied stress,

μ = poisson's ratio,

F = a constant for the primary creep (primary creep coefficient),

μ' = poisson's ratio for the primary creep,

K = a constant for the secondary creep (secondary creep coefficient),

μ'' = poisson's ratio for the secondary creep,

$\dot{G}$ = shear rate,

ϕ = neutron fluence

CTE = coefficient of thermal expansion,

ΔT = temperature gradient.

Determination of the total strain requires the evaluation of the coefficients involved in the constitutive equations. This, in turn, justifies examination of the physical and mechanical properties of graphite to determine the extent of their dependence on neutron fluence or creep. The values of F and K have already been determined in Chapter 8.

In this chapter, the available experimental data for graphite grade H451 are examined with the following objectives:

1. To study the effect of neutron irradiation or creep on modulus of elasticity, shear modulus, thermal conductivity, and CTE.
2. To calculate the Poisson's ratios for the primary and the secondary creep (μ' and μ'')
3. To investigate whether the calculated μ' and μ'' are consistent with the volume change caused by creep at 600 and 900 °C.

9.2 Effect of Neutron Irradiation on Physical Properties of Graphite

To investigate the effect of neutron irradiation and/or creep on modulus of elasticity, shear modulus, thermal conductivity, and CTE, the measurement data available were examined by generating plots and performing statistical analysis. The physical properties of interest were plotted against neutron fluence or creep strain for both the control samples and the stressed samples on the same coordinates. Thermal conductivity data were not available for analysis, however, variation of electrical resistivity of graphite with neutron fluence was available and was considered. Figures 9-1 through 9-3 depict the generated plots with predicted points at different stress levels for the 900°C

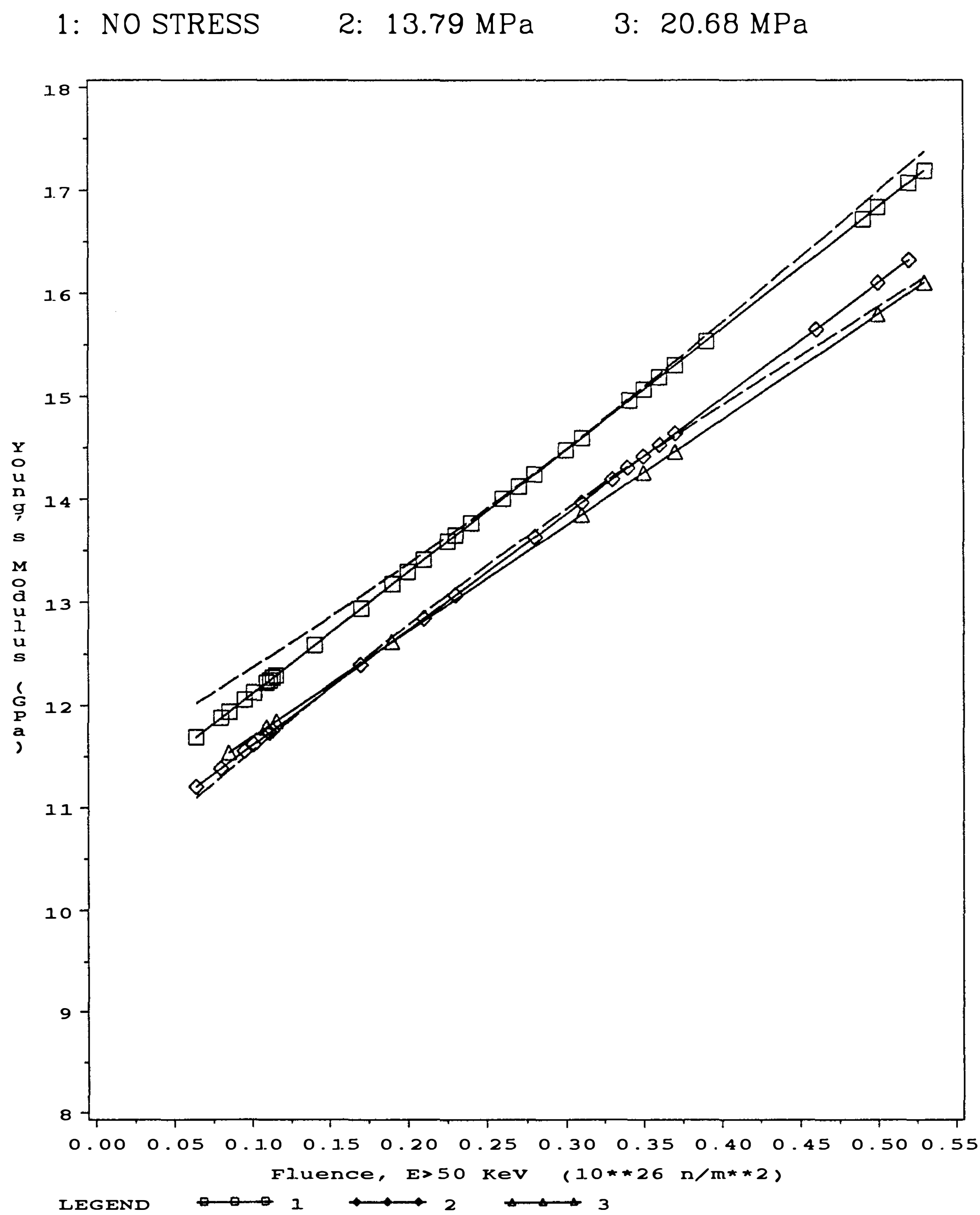


Figure 9-1. Variation of modulus of elasticity with neutron fluence for 900°C experiments.

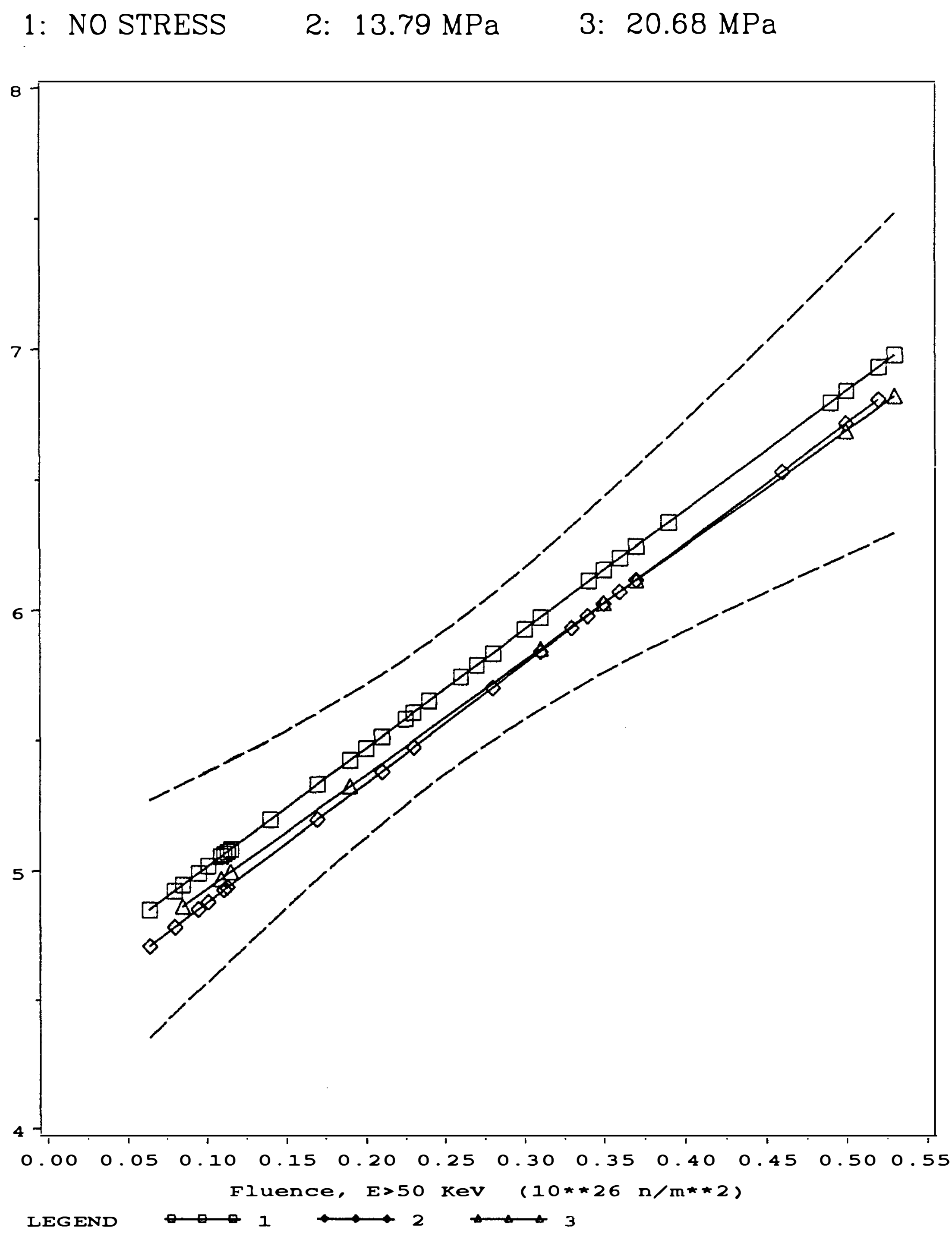


Figure 9-2. Variation of shear modulus with neutron fluence for 900°C experiments.

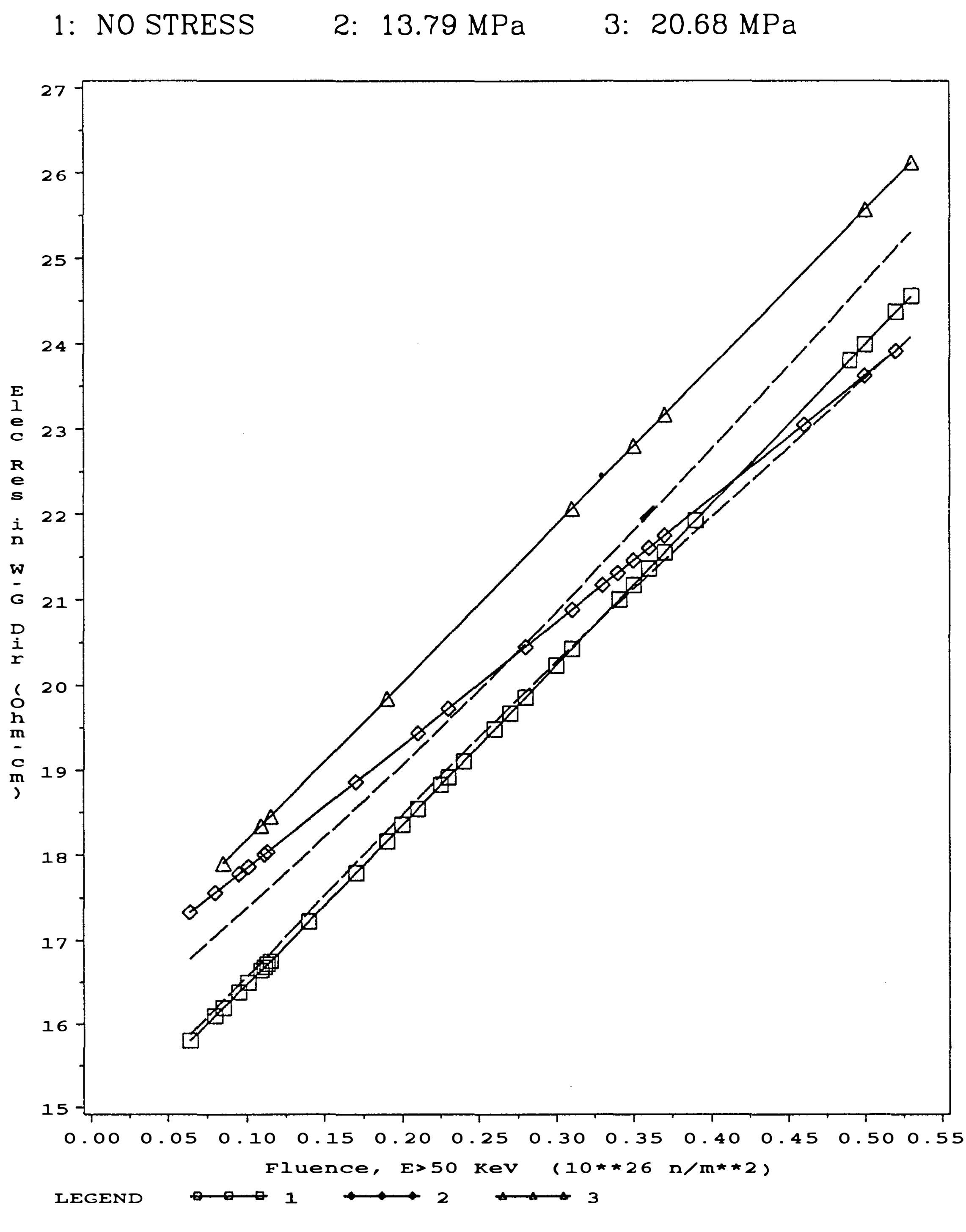


Figure 9-3. Variation of electrical resistivity in with-grain direction with neutron fluence for 900°C experiments.

experiments along with the 99% confidence limits (dashed lines) based on all data. Similar plots for 600°C experiments are shown in Figures 9-4 through 9-7.

As shown in Figures 9-1, 9-2, 9-4, and 9-5, the regression lines indicating the variation of Young's modulus and shear modulus with fluence fall within or near either the upper or lower 99% limits of the band for the expected value of the dependent variable for a particular value of fluence. Confidence limits were established after performing F-tests to test the equality of slopes for individual levels of stress. As sample results, the ANOVA tables obtained for variation of Young's moduli with neutron fluence for irradiation temperatures of 900°C and 600°C are shown in Figures 9-8 and 9-9. The variation of electrical resistivity with neutron fluence in with-grain direction is shown in Figures 9-3 and 9-6. Figure 9-7 depicts the variation of electrical resistivity with neutron fluence in against-grain direction at 600°C. The data points for similar variation at 900°C were too scattered to be conclusive. The F-tests performed to test the equality of slopes revealed that the trend and rate of change of electrical resistivity with fluence is the same for all stress levels. However, not all the regression lines fall within the 99% confidence limits for the overall regression line. If 99% confidence intervals for the estimates of the intercepts are established, it is revealed that these intervals do overlap. Compared with the other physical properties mentioned

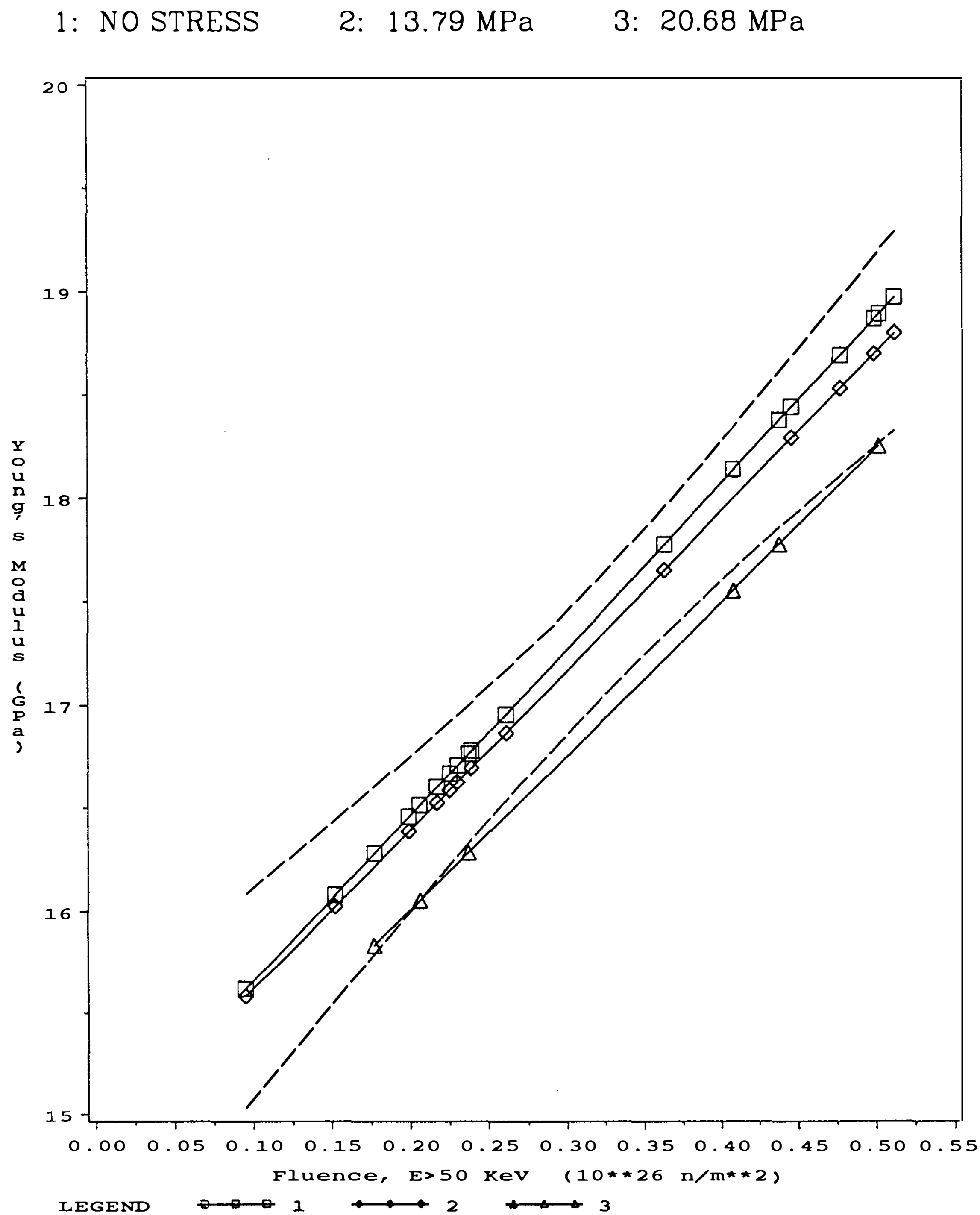


Figure 9-4. Variation of modulus of elasticity with neutron fluence for 600°C experiments.

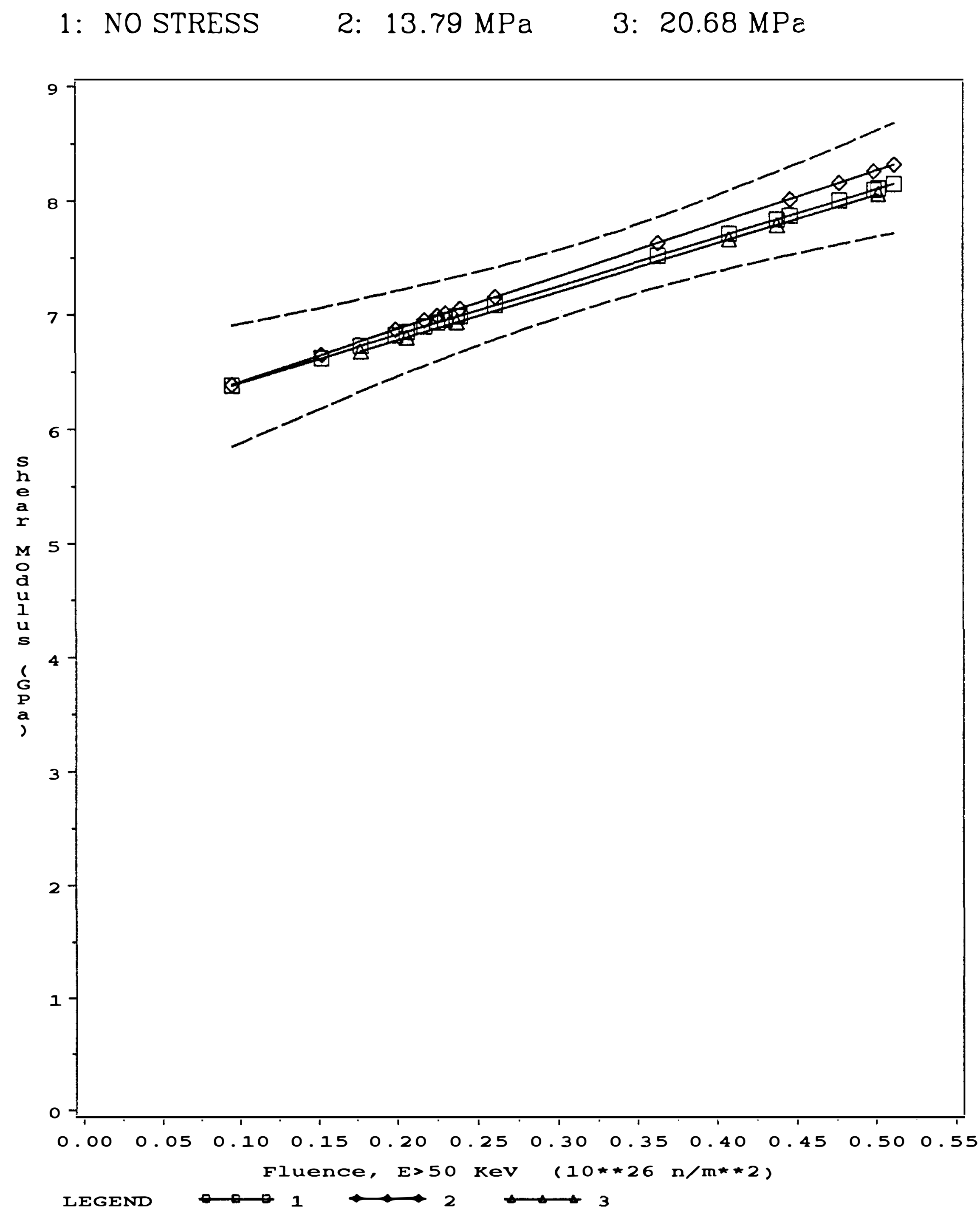


Figure 9-5. Variation of shear modulus with neutron fluence for 600°C experiments.

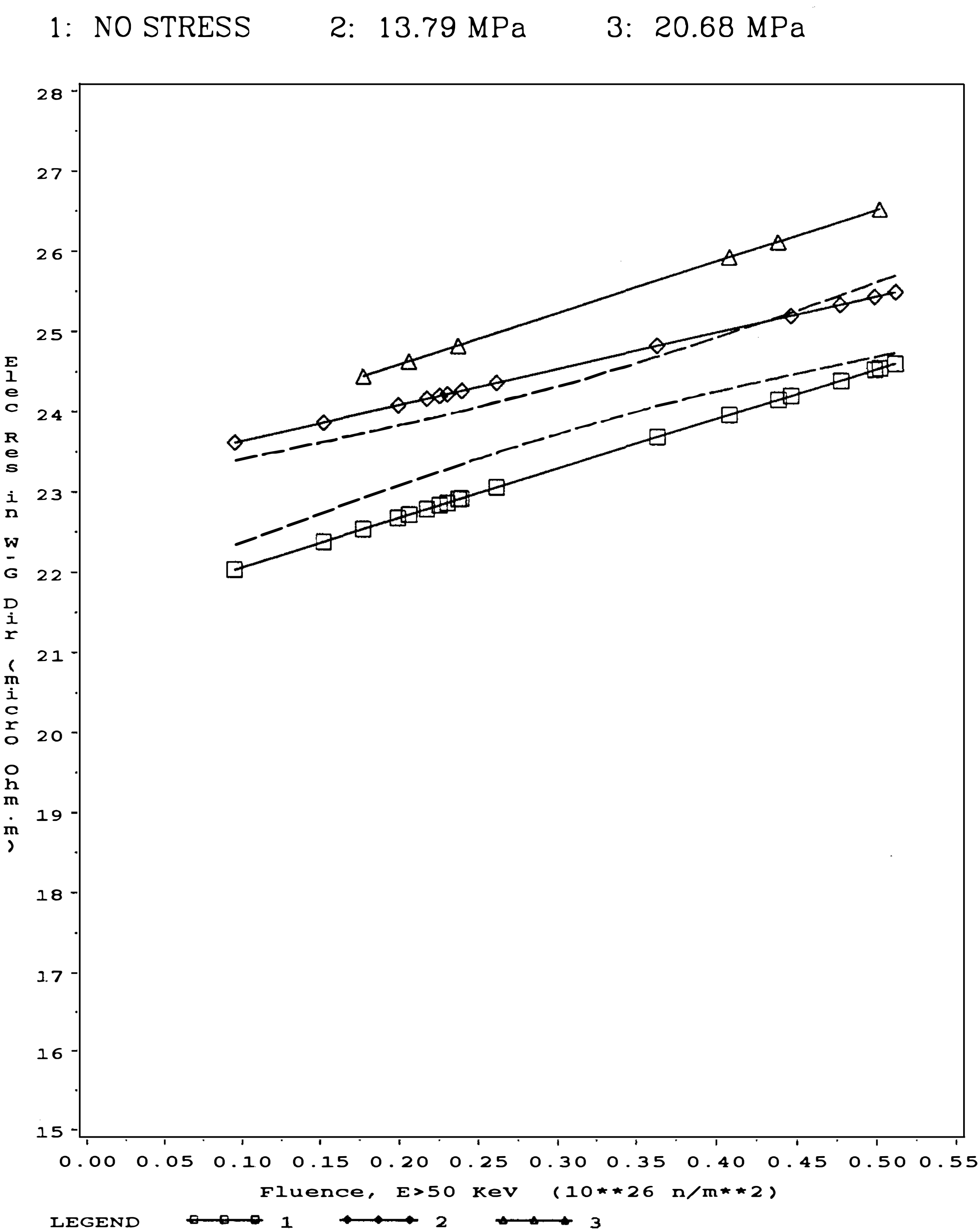


Figure 9-6. Variation of electrical resistivity in with-grain direction with neutron fluence for 600°C experiments.

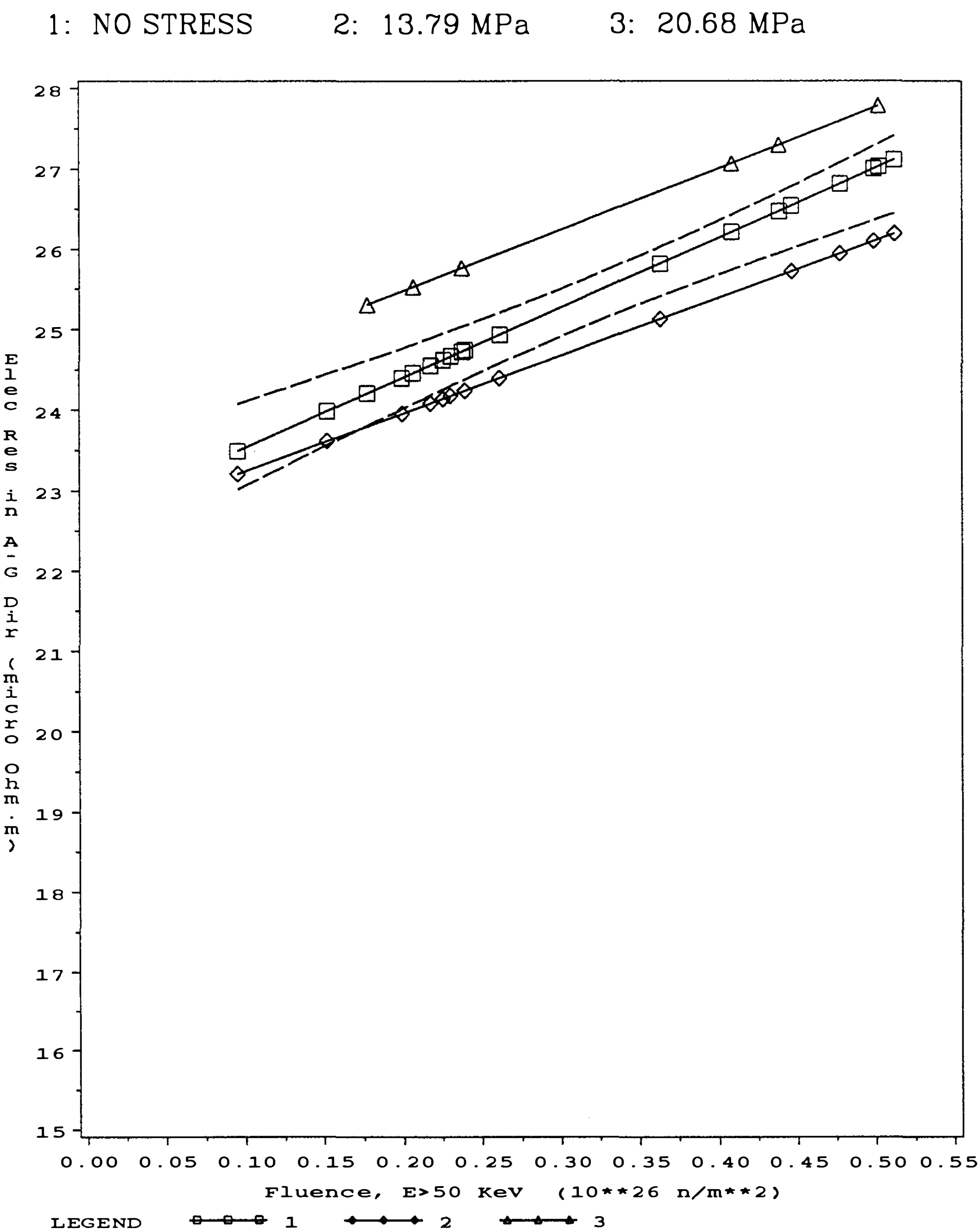


Figure 9-7. Variation of electrical resistivity in against-grain direction with neutron fluence for 600°C experiments.

------------------------------ LEGEND=1 ------------------------------

Model: MODEL1
Dependent Variable: SONIC_E Young's Modulus (GPa)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	143.10042	143.10042	120.739	0.0001
Error	53	62.81575	1.18520		
C Total	54	205.91617			

Root MSE	1.08867	R-square	0.6949
Dep Mean	13.74473	Adj R-sq	0.6892
C.V.	7.92064		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	10.934304	0.29490136	37.078	0.0001
KEV_50	1	11.801287	1.07400236	10.988	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

------------------------------ LEGEND=2 ------------------------------

Model: MODEL1
Dependent Variable: SONIC_E Young's Modulus (GPa)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	63.60793	63.60793	97.443	0.0001
Error	23	15.01369	0.65277		
C Total	24	78.62162			

Root MSE	0.80794	R-square	0.8090
Dep Mean	13.50440	Adj R-sq	0.8007
C.V.	5.98280		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	10.487974	0.34566801	30.341	0.0001
KEV_50	1	11.226834	1.13731665	9.871	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

Figure 9-8. ANOVA tables for variation of Young's modulus with neutron fluence at 900°C.

------------------------------ LEGEND=3 ------------------------------

Model: MODEL1
Dependent Variable: SONIC_E Young's Modulus (GPa)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	24.88296	24.88296	48.110	0.0001
Error	9	4.65484	0.51720		
C Total	10	29.53780			

Root MSE	0.71917	R-square	0.8424
Dep Mean	13.52000	Adj R-sq	0.8249
C.V.	5.31930		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	10.666623	0.46502591	22.938	0.0001
KEV_50	1	10.260591	1.47928729	6.936	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

General Linear Models Procedure

Dependent Variable: SONIC_E Young's Modulus (GPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	232.80051	46.56010	47.98	0.0001
Error	85	82.48427	0.97040		
Corrected Total	90	315.28478			

R-Square	C.V.	Root MSE	SONIC_E Mean
0.738382	7.215967	0.9851	13.652

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LEGEND	2	0.81852	0.40926	0.42	0.6573
KEV_50	1	154.21279	154.21279	158.92	0.0001
KEV_50*LEGEND	2	0.48569	0.24284	0.25	0.7792

Figure 9-8 (continued)

------------------------------ LEGEND=1 ------------------------------

Model: MODEL1
Dependent Variable: E   Young's Modulus (GPa)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	46.80391	46.80391	265.381	0.0001
Error	38	6.70187	0.17637		
C Total	39	53.50578			

Root MSE	0.41996	R-square	0.8747
Dep Mean	17.41425	Adj R-sq	0.8714
C.V.	2.41158		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	14.858285	0.17037143	87.211	0.0001
KEV_50	1	8.037627	0.49339309	16.291	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

------------------------------ LEGEND=2 ------------------------------

Model: MODEL1
Dependent Variable: E   Young's Modulus (GPa)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	31.72536	31.72536	302.555	0.0001
Error	26	2.72631	0.10486		
C Total	27	34.45167			

Root MSE	0.32382	R-square	0.9209
Dep Mean	17.27214	Adj R-sq	0.9178
C.V.	1.87480		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	14.852456	0.15197497	97.730	0.0001
KEV_50	1	7.713029	0.44342745	17.394	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

Figure 9-9. ANOVA tables for variation of Young's modulus with neutron fluence at 600°C.

------------------------------ LEGEND=3 ------------------------------

Model: MODEL1
Dependent Variable: E Young's Modulus (GPa)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	10.47284	10.47284	117.613	0.0001
Error	10	0.89045	0.08905		
C Total	11	11.36329			

Root MSE	0.29840	R-square	0.9216
Dep Mean	16.95917	Adj R-sq	0.9138
C.V.	1.75955		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	14.520683	0.24078599	60.305	0.0001
KEV_50	1	7.434401	0.68551791	10.845	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

General Linear Models Procedure

Dependent Variable: E Young's Modulus (GPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	90.938842	18.187768	130.43	0.0001
Error	74	10.318633	0.139441		
Corrected Total	79	101.257475			

R-Square	C.V.	Root MSE	E Mean
0.898095	2.158953	0.3734	17.296

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LEGEND	2	0.150762	0.075381	0.54	0.5847
KEV_50	1	62.996436	62.996436	451.78	0.0001
KEV_50*LEGEND	2	0.068064	0.034032	0.24	0.7841

Figure 9-9 (continued)

above, there is an indication of the effect of stress on electrical resistivity. By examining the corresponding plots this effect is about 5%.

The p-values for the t-tests in the ANOVA tables mentioned above indicate that slopes of the regression lines are significantly different from zero. This means that E does change with neutron fluence and since the extent of its change in control and creep specimens is the same, it is concluded that the Young's modulus is not affected by creep. Similar arguments can be made about the other physical properties (shear modulus, and electrical resistivity), leading to the conclusion that the properties investigated do change with fluence but not with creep strain in the range of available data.

Figures 9-10 and 9-11 show the variation of coefficient of thermal expansion with neutron fluence for 900°C and 600°C experiments, respectively. As indicated in these figures, the CTE of control (unstressed) specimens does not change with fluence whereas, that of creep specimens increases. Statistical analyses confirmed these observations as indicated by the ANOVA tables given in Figures 9-12 through 9-14. In Figure 9-12, the very low value of R-SQUARE (about 0.05) and the high p-value (about 0.099) for the t-test indicate that the slope of the line for control specimens is not significantly different from zero. The R-SQUARE values and the p-values corresponding to the lines for stressed specimens show that the slope of these lines are not zero and about 48% and 84% of the variations are explained for the

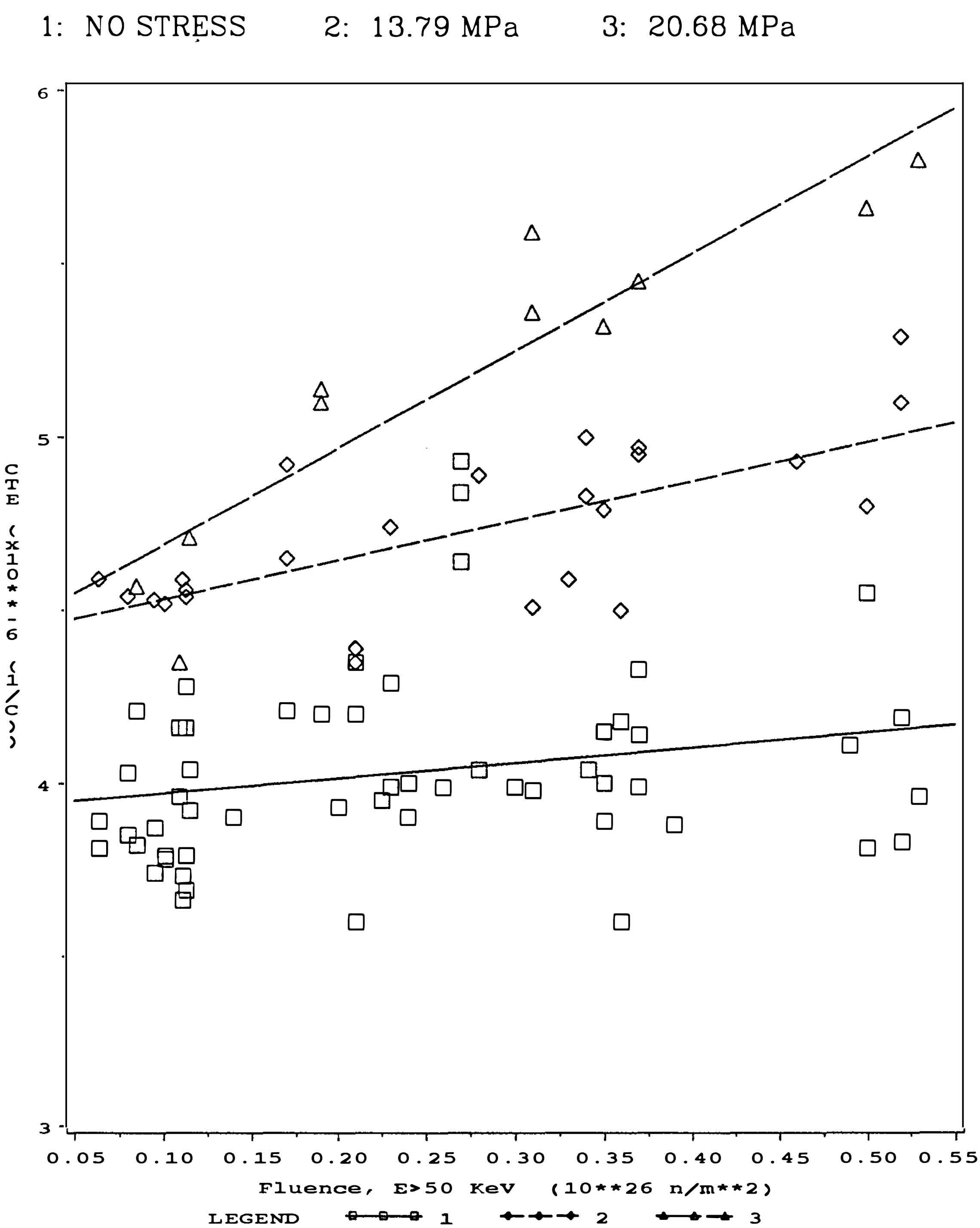


Figure 9-10. Variation of coefficient of thermal expansion with neutron fluence at 900°C.

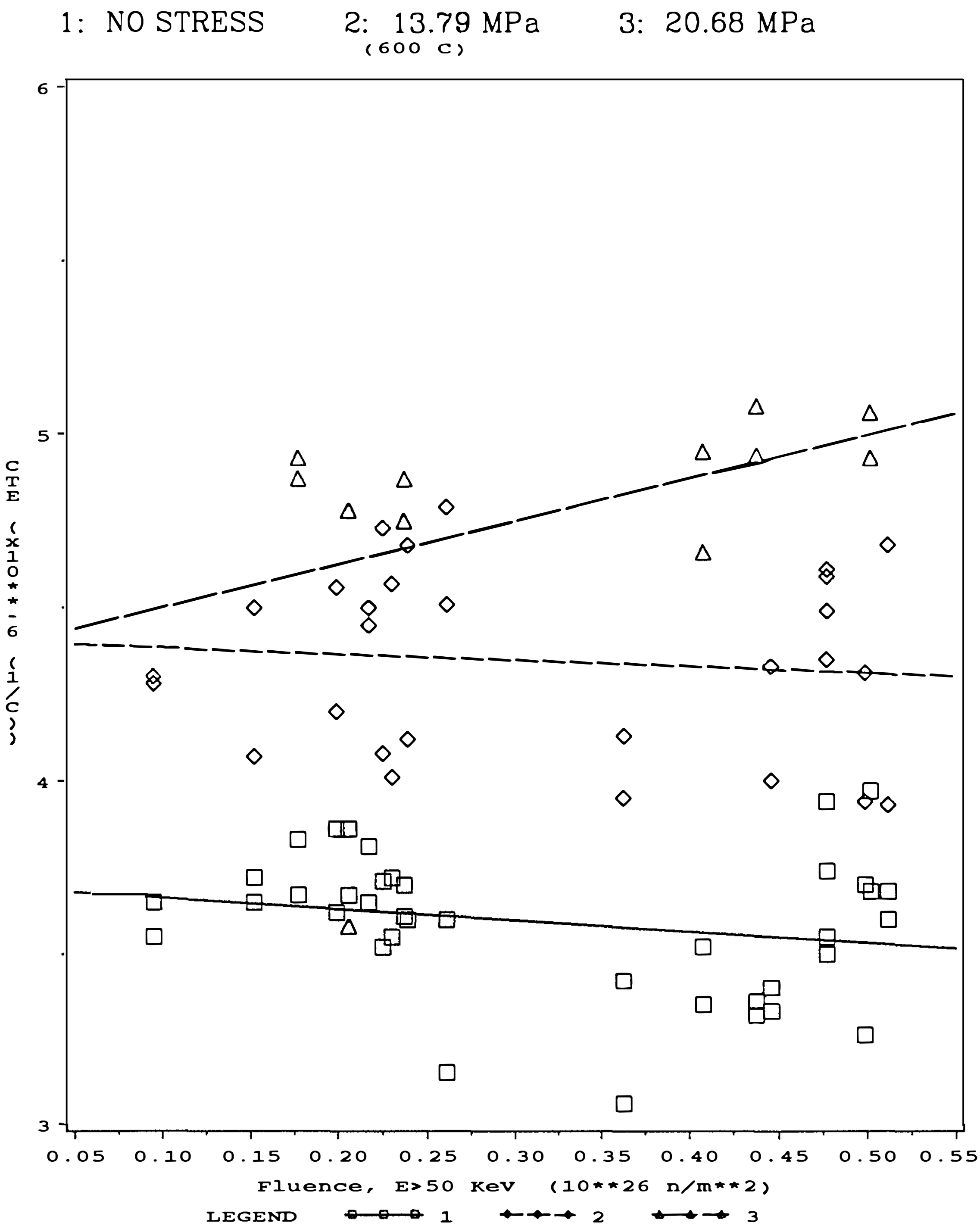


Figure 9-11. Variation of coefficient of thermal expansion with neutron fluence at 600°C.

------------------------------- LEGEND=1 ------------------------------

Model: MODEL1
Dependent Variable: CTE_800   CTE (x10**-6 (1/C))

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.20349	0.20349	2.821	0.0989
Error	53	3.82259	0.07212		
C Total	54	4.02608			

Root MSE	0.26856	R-square	0.0505
Dep Mean	4.03200	Adj R-sq	0.0326
C.V.	6.66071		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	3.926022	0.07274810	53.967	0.0001
KEV_50	1	0.445016	0.26494157	1.680	0.0989

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

Figure 9-12. ANOVA tables for variation of the CTE of control specimens with neutron fluence for 900°C experiments.

------------------------------- LEGEND=2 -------------------------------

Model: MODEL1
Dependent Variable: CTE_800 CTE (x10**-6 (1/C))

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.65008	0.65008	21.058	0.0001
Error	23	0.71002	0.03087		
C Total	24	1.36010			

Root MSE	0.17570	R-square	0.4780
Dep Mean	4.72280	Adj R-sq	0.4553
C.V.	3.72026		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	4.417856	0.07517124	58.771	0.0001
KEV_50	1	1.134973	0.24732838	4.589	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

Figure 9-13. ANOVA tables for variation of the CTE of creep specimens (13.79 MPa) with neutron fluence for 900°C experiments.

------------------------------ LEGEND=3 ------------------------------

Model: MODEL1
Dependent Variable: CTE_800   CTE (x10**-6 (1/C))

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	1.85289	1.85289	48.425	0.0001
Error	9	0.34437	0.03826		
C Total	10	2.19725			

Root MSE	0.19561	R-square	0.8433
Dep Mean	5.18636	Adj R-sq	0.8259
C.V.	3.77162		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	4.407731	0.12648439	34.848	0.0001
KEV_50	1	2.799920	0.40235771	6.959	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

Figure 9-14. ANOVA tables for variation of the CTE of creep specimens (20.68 MPa) with neutron fluence for 900°C experiments.

13.79 MPa and 20.68 MPa, respectively. This behavior of graphite reveals that irradiation-induced creep is responsible for the change in CTE.

To show the effect of creep on CTE more clearly, variation of CTE with creep strain (negative values because of copressive stress) is depicted in Figures 9-15 and 9-16 for 900°C and 600°C experiments, respectively. As these figures indicate, the coefficient of thermal expansion is affected by creep strain. CTE increases with creep. The increase in CTE is not as pronounced for the 600°C experiments as it is for the 900°C experiments. This is due to the fact that the specimens in the former experiment have not experienced enough creep to show its effect on CTE vividly.

A linear least squares regression was performed on the pooled data shown in Figure 9-15. The corresponding ANOVA table is given in Figure 9-17. The p-value for the t-test indicates that the slope of -0.510610 is significantly different from zero. The R-SQUARE value of 0.7504 indicates that about 75% of the variation of CTE with creep strain is explained by the regression line.

9.3 Determination of Poisson's Ratios

To determine the values of Poisson's ratios for the constitutive equation, the evaluation of strain in diametrical direction was required.

Statistical analyses similar to those performed for deformation in the axial direction resulted in the values of intercept and slope for the diametrical strain. The results of regression analyses are shown in Figures 9-18 through 9-21. A complete summary of the results of creep analyses, including the

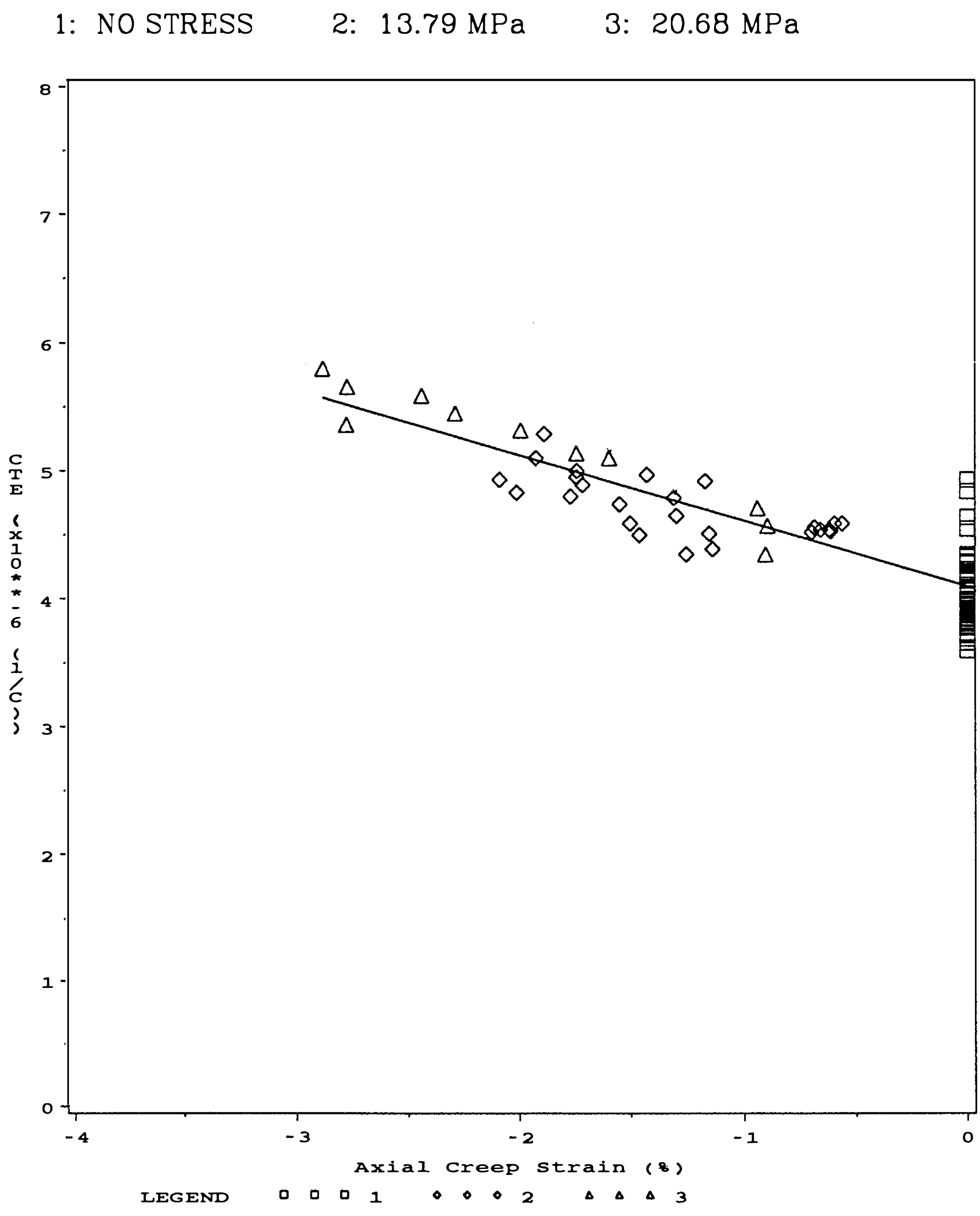


Figure 9-15. Variation of coefficient of thermal expansion with creep strain for 900°C.

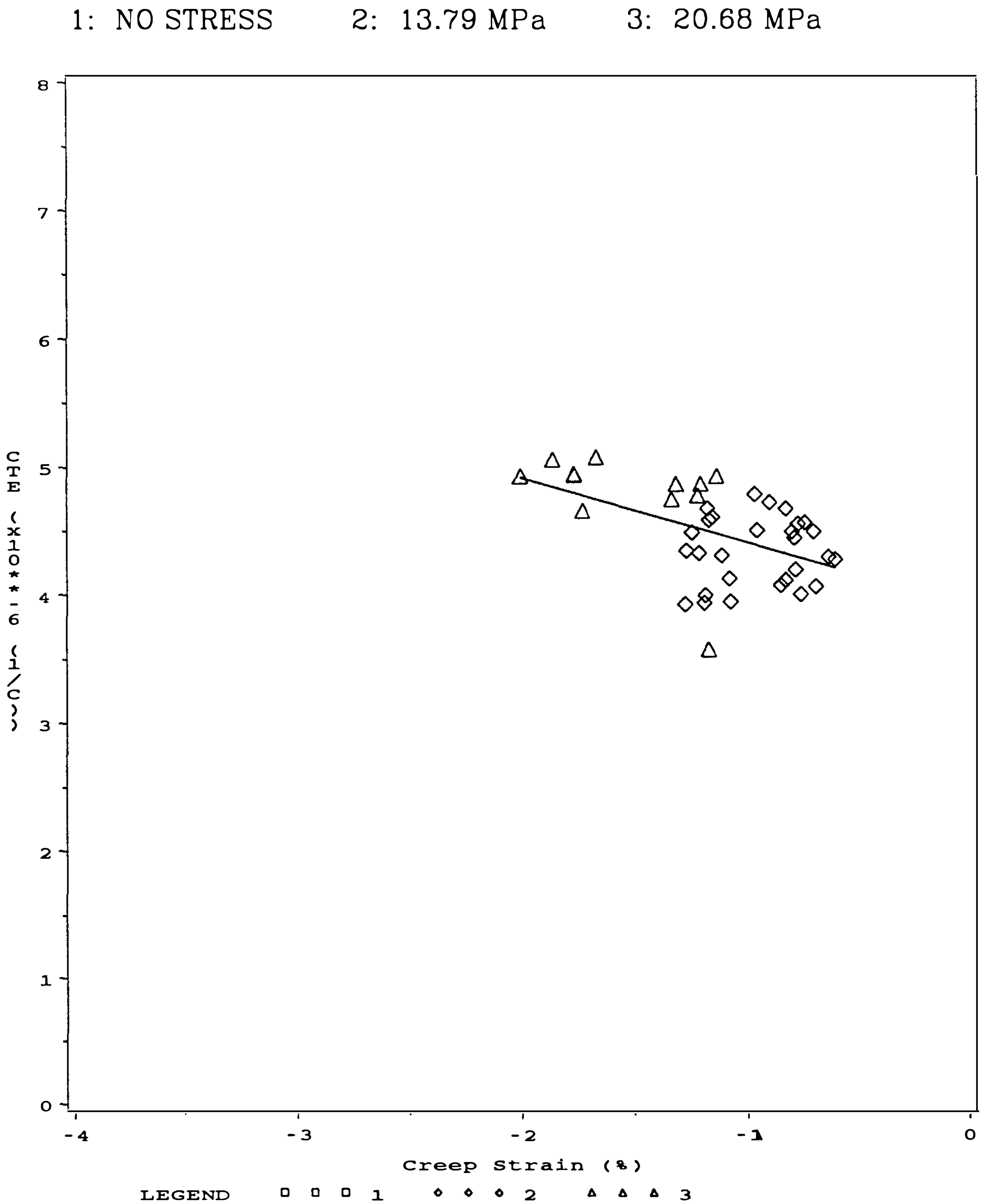


Figure 9-16. Variation of coefficient of thermal expansion with creep strain for 600°C.

Model: MODEL1
Dependent Variable: CTE_800   CTE (x10**-6 (1/C))

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	3.90149	3.90149	102.243	0.0001
Error	34	1.29740	0.03816		
C Total	35	5.19889			

Root MSE	0.19534	R-square	0.7504
Dep Mean	4.86444	Adj R-sq	0.7431
C.V.	4.01573		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	4.100415	0.08227575	49.837	0.0001
AXPC_CRE	1	-0.510610	0.05049778	-10.112	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
AXPC_CRE	1	Axial Creep Strain (%)

Figure 9-17. ANOVA tables for variation of coefficient of thermal expansion with creep strain for 900°C experiments.

DIACREEP FOR OC1, OC3, OC5 (900 C)
REGRESSION FOR LINEAR MODEL (NORDIACR = A + B KEV_50)
40-A-2, 40-A-3, 41-A-2, & 41-A2-2

Model: MODEL1
Dependent Variable: NORDIACR

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	15.25775	15.25775	66.214	0.0001
Error	34	7.83470	0.23043		
C Total	35	23.09245			

Root MSE	0.48003	R-square	0.6607
Dep Mean	2.17304	Adj R-sq	0.6507
C.V.	22.09038		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.941375	0.17120682	5.498	0.0001
KEV_50	1	4.535608	0.55739378	8.137	0.0001

Variable	DF	Variable Label
INTERCEP	1	Intercept
KEV_50	1	Fluence, E>50 KeV (10**26 n/m**2)

Figure 9-18. Results of regression analysis for linear model at 900°C.

DIACREEP FOR OC2 AND OC4 (600 C)
REGRESSION FOR LINEAR MODEL (NORDIACR = A + K KEV_50)
40-AX-2, 40-AX-3, 41-AX-2, & 41-AX2-2

Model: MODEL1
Dependent Variable: NORDIACR

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	4.29427	4.29427	481.840	0.0001
Error	38	0.33866	0.00891		
C Total	39	4.63294			

Root MSE	0.09440	R-square	0.9269
Dep Mean	1.50161	Adj R-sq	0.9250
C.V.	6.28687		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.727404	0.03829866	18.993	0.0001
KEV_50	1	2.434622	0.11091235	21.951	0.0001

Figure 9-19. Results of regression analysis for linear model at 600°C.

DIACREEP FOR OC1, OC3, OC5 (900 C)
REGRESSION FOR NONLINEAR MODEL (NORDIACR = A + K (BRACKET)
40-A-2, 40-A-3, 41-A-2, & 41-A2-2

Model: MODEL1
Dependent Variable: NORDIACR

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	15.95330	15.95330	75.977	0.0001
Error	34	7.13915	0.20997		
C Total	35	23.09245			

Root MSE	0.45823	R-square	0.6908
Dep Mean	2.17304	Adj R-sq	0.6818
C.V.	21.08701		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.812150	0.17380691	4.673	0.0001
BRACKET	1	5.414429	0.62117092	8.716	0.0001

Figure 9-20. Results of regression analysis for nonlinear model at 900°C.

DIACREEP FOR OC2 & OC4 (600 C)
REGRESSION FOR NONLINEAR MODEL (NORDIACR = A + K (BRACKET)
40-AX-2, 40-AX-3, 41-AX-2, & 41-AX2-2

Model: MODEL1
Dependent Variable: NORDIACR

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	4.28530	4.28530	468.428	0.0001
Error	38	0.34763	0.00915		
C Total	39	4.63294			

Root MSE	0.09565	R-square	0.9250
Dep Mean	1.50161	Adj R-sq	0.9230
C.V.	6.36958		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.695798	0.04018606	17.314	0.0001
BRACKET	1	2.660048	0.12290464	21.643	0.0001

Figure 9-21. Results of regression analysis for nonlinear model at 600°C.

Poisson ratios, at the two irradiation temperatures of 900 and 600°C is shown in Figures 9-22 and 9-23.

9.4 Consistency of μ' and μ'' with Volume Change

The Poisson's ratios calculated (Figures 9-22 and 9-23) are indicated to be less than 0.5. This implies that volume or density changes as the result of deformation. Volume changes that occur should be consistent with the calculated volume changes using Poisson's ratios.

Figures 9-24 and 9-25 show the computations required for checking the consistency of Poisson's ratios with volume change. The existence of this consistency for two temperature levels and two stress levels is shown in Figures 9-26 through 9-29, based on linear model, and in Figures 9-30 through 9-33, based on nonlinear model.

RESULTS OF 900 C EXPERIMENTS

MODEL	TEMP	STR (MPa)	DIR.	EO (GPa)	EU (x10**-3)	INTERCEPT (EU)	SLOPE
LINEAR	900	13.79	AX	8.6901193	1.5868597	2.883364	19.227982
		20.68		8.6187500	2.3994199		
NONLINEAR	"	"	"	"	"	2.388268	22.743795
LINEAR	"	0	RA	"	"	0.941375	4.535608
NONLINEAR	"	0	RA	"	"	0.812150	5.414429

POISSON'S RATIOS

LINEAR MODEL:

$\mu' = 0.941375/2.883364$
$= 0.326485$

$\mu'' = 4.535608/19.227982$
$= 0.2358858$

NONLINEAR MODEL:

$\mu' = 0.812150/2.388268$
$= 0.3400582$

$\mu'' = 5.414429/22.743795$
$= 0.2380618$

Figure 9-22. Complete summary of the results of creep analysis at 900°C.

RESULTS OF 600 C EXPERIMENTS

MODEL	TEMP	STR (MPa)	DIR.	EO (GPa)	EU (x10**-3)	INTERCEPT (EU)	SLOPE
LINEAR	600	13.79 20.68	AX	8.6901193 8.6187500	1.5868597 2.3994199	3.036806	9.530063
NONLINEAR	"	"	"	"	"	2.906617	10.433818
LINEAR	"	0	RA	"	"	0.727404	2.434622
NONLINEAR	"	0	RA	"	"	0.695798	2.660048

POISSON'S RATIOS

LINEAR MODEL:

$\mu' = 0.727404/3.036806 = 0.2395293$ $\mu'' = 2.434622/9.530063 = 0.2554676$

NONLINEAR MODEL:

$\mu' = 0.695798/2.906617 = 0.2393841$ $\mu'' = 2.660048/10.433818 = 0.2549448$

Figure 9-23. Complete summary of the results of creep analysis at 600°C.

PRIDICTION OF VOLUME CHANGE BASED ON POISSON'S RATIOS

VOL CHANGE (%) = ((1-2 μ')*INTERCEPT + (1-2 μ")*SLOPE*FLUENCE) * EU

LINEAR MODEL:

```
VOL CHANGE (%) =(1-2*0.326485)*2.883364 + (1-2*0.2358858)*19.227982*F)*EU/10
               =(1-0.65297)*2.883364 + (1-0.4717716)*19.227982*F) * EU/10
               =(0.34703*2.883364 + 0.5282284*19.227982*F) * EU/10
               =(1.0006138 + 10.156766 F ) * EU/10
```

FOR STRESS=13.79 MPa :

VOL CHANGE (%) = (1.0006138 + 10.156766 F)*1.5868597/10

FOR STRESS=20.68 MPa :

VOL CHANGE (%) = (1.0006138 + 10.156766 F)*2.3994199/10

NONLINEAR MODEL:

VOL CHANGE (%) =(1-2*0.3400582)*2.388268 + (1-2*0.2380618)*22.743795*F)*EU/10

FOR STRESS=13.79 MPa :

VOL CHANGE (%) = (0.7639678 + 11.914937 F)*1.5868597/10

FOR STRESS=20.68 MPa :

VOL CHANGE (%) = (0.7639678 + 11.914937 F)*2.3994199/10

Figure 9-24. Computations performed for 900°C experiments to predict volume change.

```
          PREDICTION OF VOLUME CHANGE BASED ON POISSON'S RATIOS
VOL CHANGE (%) = ( (1-2 μ')*INTERCEPT + (1-2 μ")*SLOPE*FLUENCE ) * EU

 LINEAR MODEL:
 ============

VOL CHANGE (%) = (1-2*0.2395293)*3.036806 + (1-2*0.2554676)*9.530063*F) *EU/10
               = (1.581998 + 4.6608184 F) * EU/10

   FOR STRESS=13.79 MPa :
   --------------------

         VOL CHANGE (%) = (1.581998 + 4.6608184 F)*1.5868597/10

   FOR STRESS=20.68 MPa :
   --------------------

         VOL CHANGE (%) = (1.581998 + 4.6608184 F)*2.3994199/10


 NONLINEAR MODEL:
 ===============

 VOL CHANGE (%) =(1-2*0.2393841)*2.906617 +(1-2*0.2549448)*10.433818*F)*EU/10
                =(1.5150212 + 5.1137227 F) * EU

   FOR STRESS=13.79 MPa :
   --------------------

         VOL CHANGE (%) = (1.5150212 + 5.1137227 F)*1.5868597/10

   FOR STRESS=20.68 MPa :
   --------------------


         VOL CHANGE (%) = (1.5150212 + 5.1137227 F)*2.3994199/10
```

Figure 9-25. Computations performed for 600°C experiments to predict volume change.

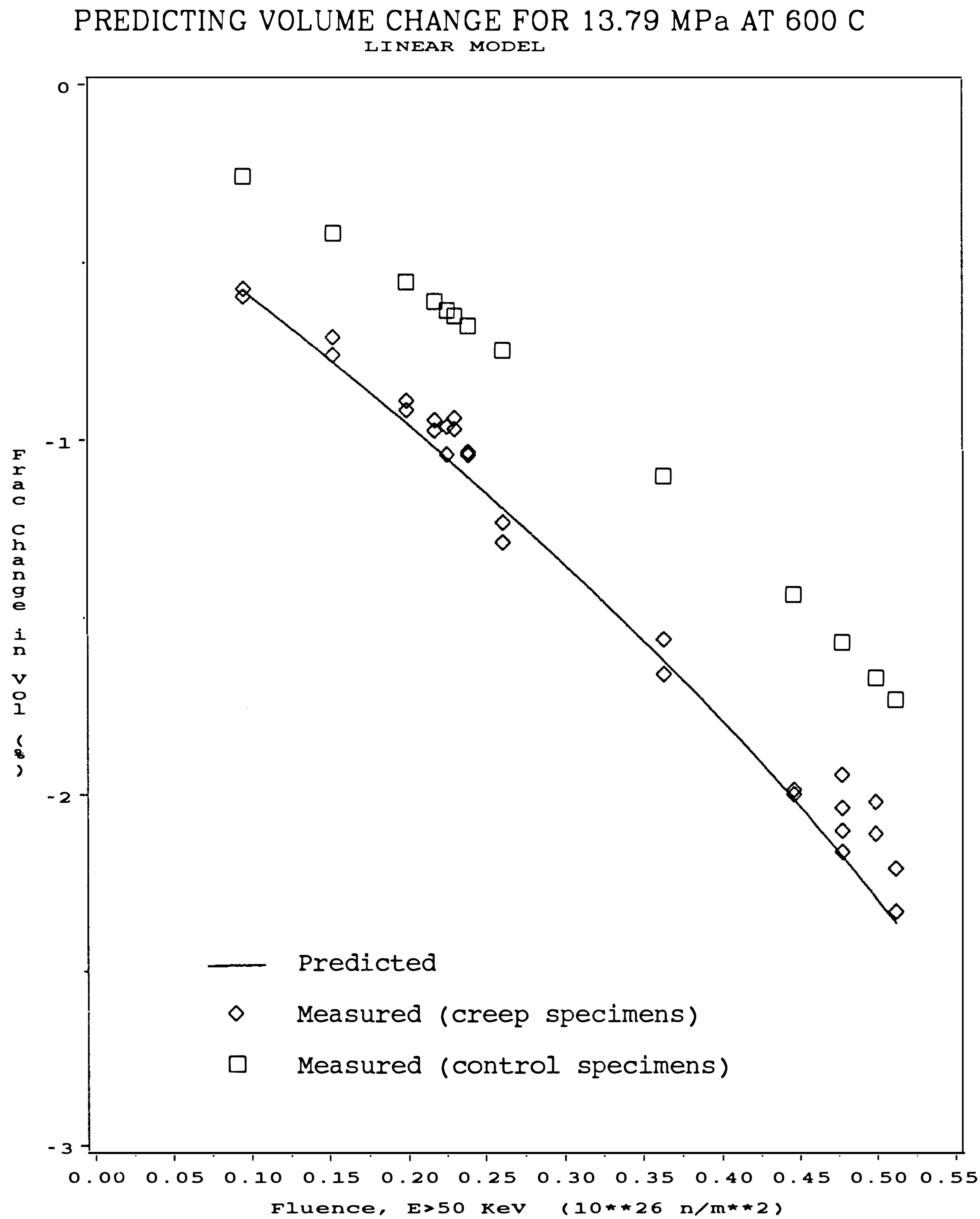


Figure 9-26. Prediction of volume change with neutron fluence for 13.79 MPa at 600°C based on the linear model.

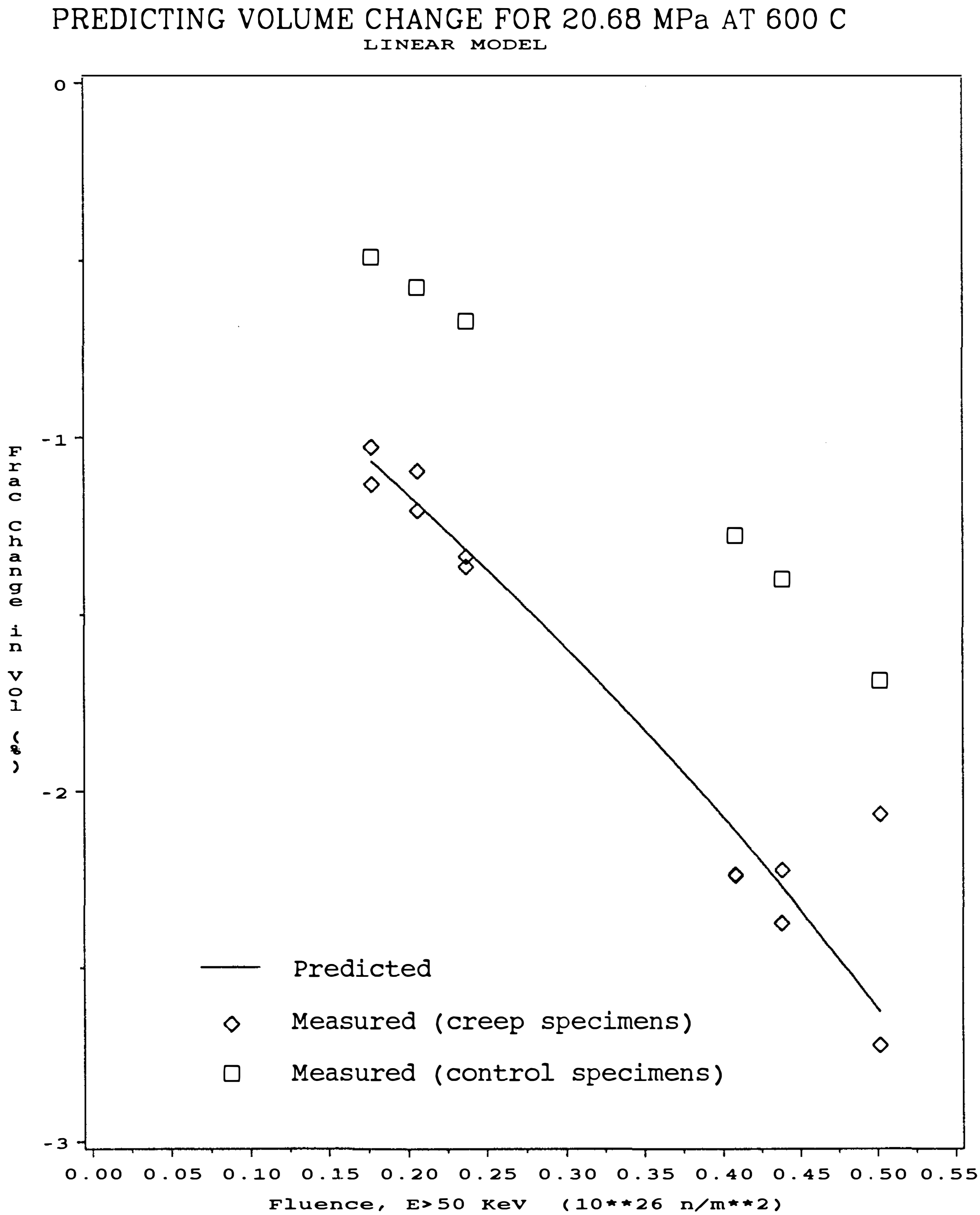


Figure 9-27. Prediction of volume change with neutron fluence for 20.68 MPa at 600°C based on the linear model.

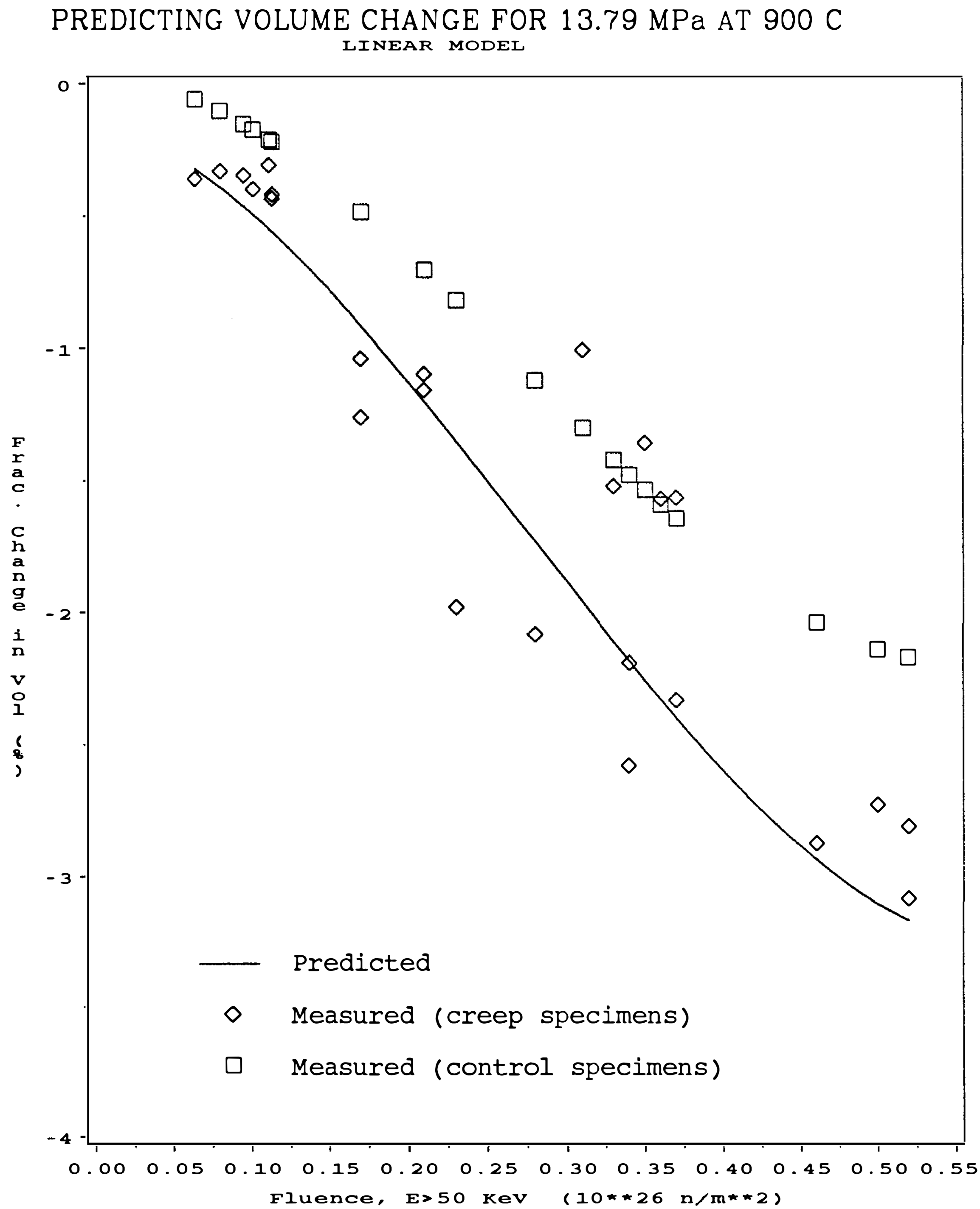


Figure 9-28. Prediction of volume change with neutron fluence for 13.79 MPa at 900°C based on the linear model.

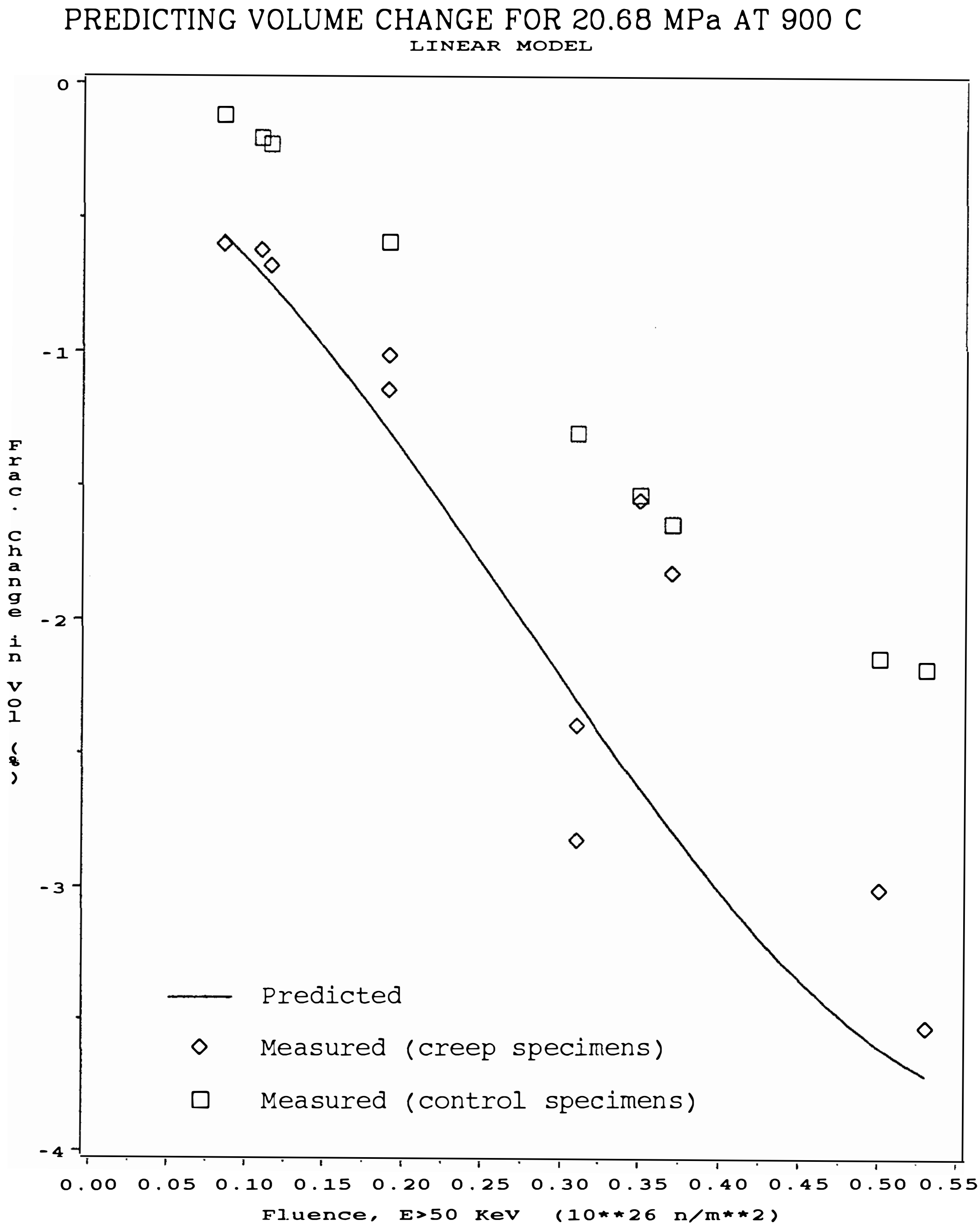


Figure 9-29. Prediction of volume change with neutron fluence for 20.68 MPa at 900°C based on the linear model.

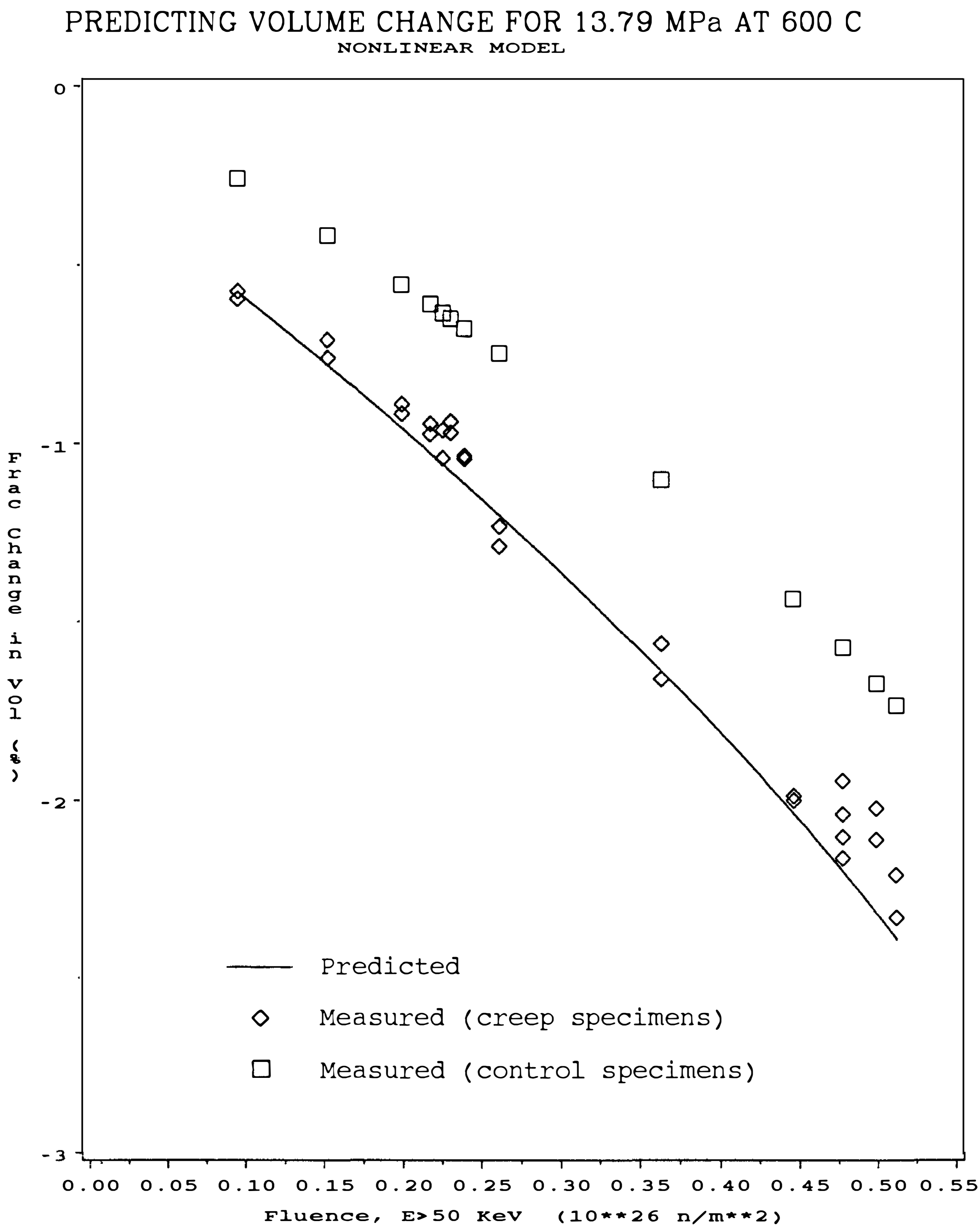


Figure 9-30. Prediction of volume change with neutron fluence for 13.79 MPa at 600°C based on the nonlinear model.

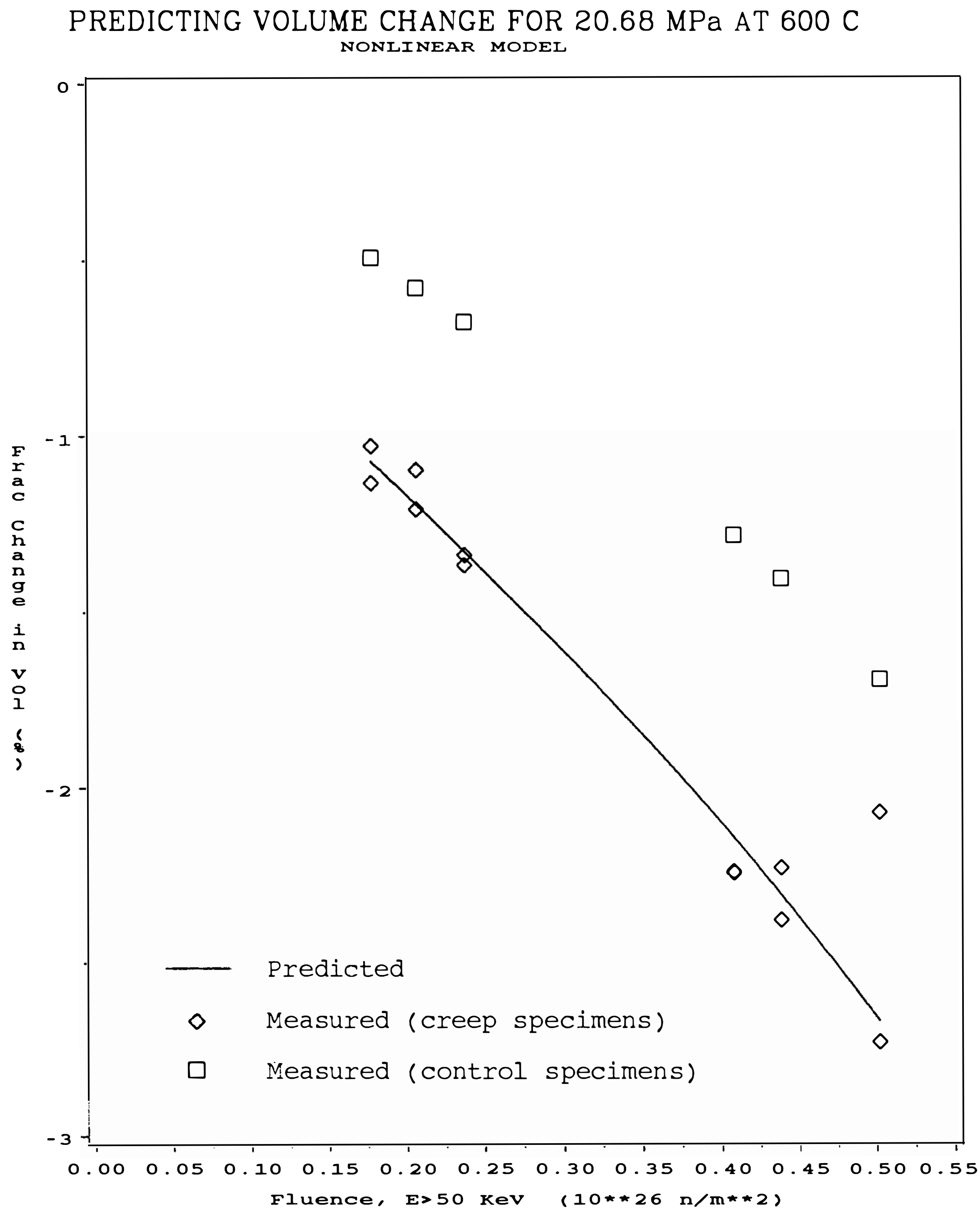


Figure 9-31. Prediction of volume change with neutron fluence for 20.68 MPa at 600°C based on the nonlinear model.

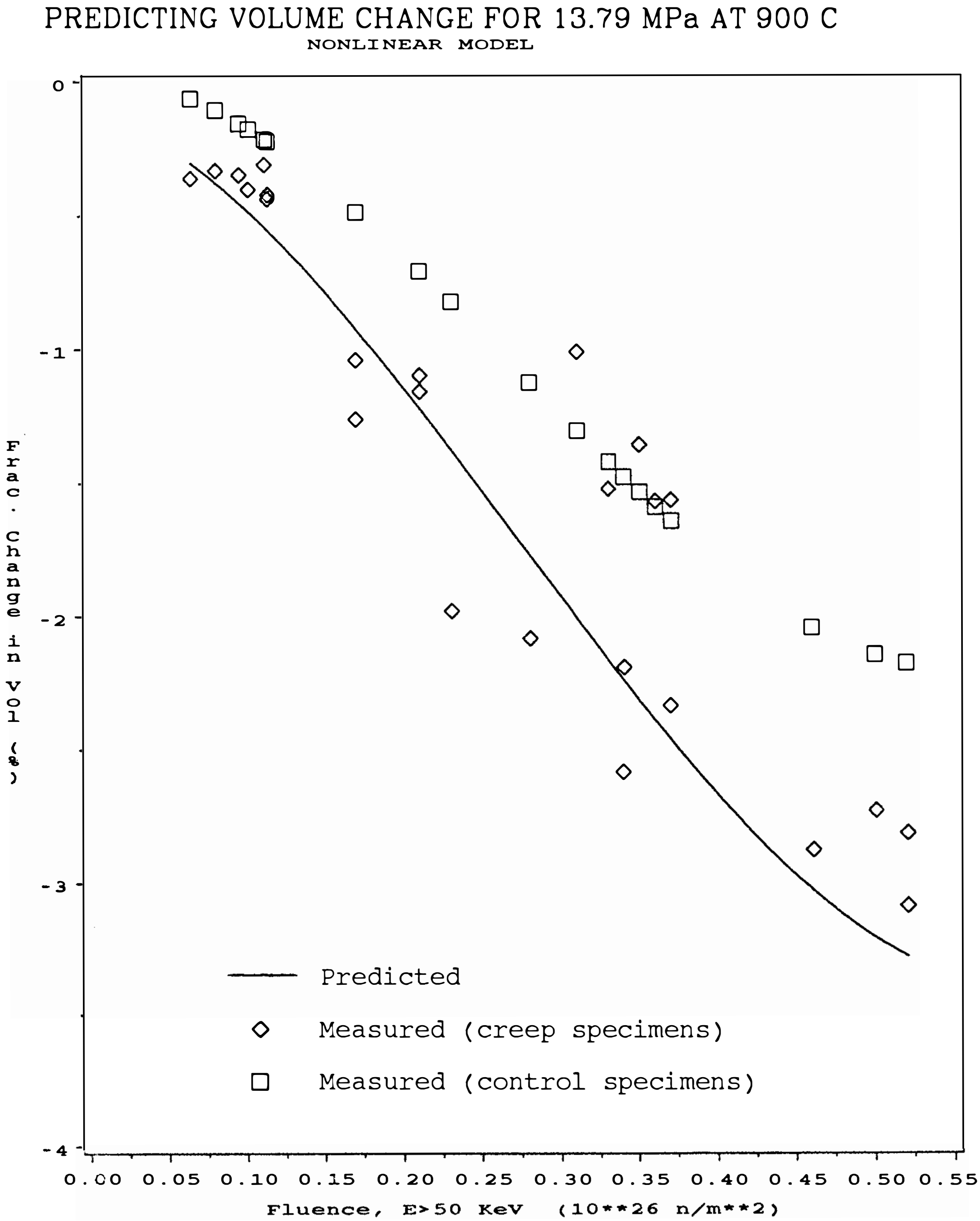


Figure 9-32. Prediction of volume change with neutron fluence for 13.79 MPa at 900°C based on the nonlinear model.

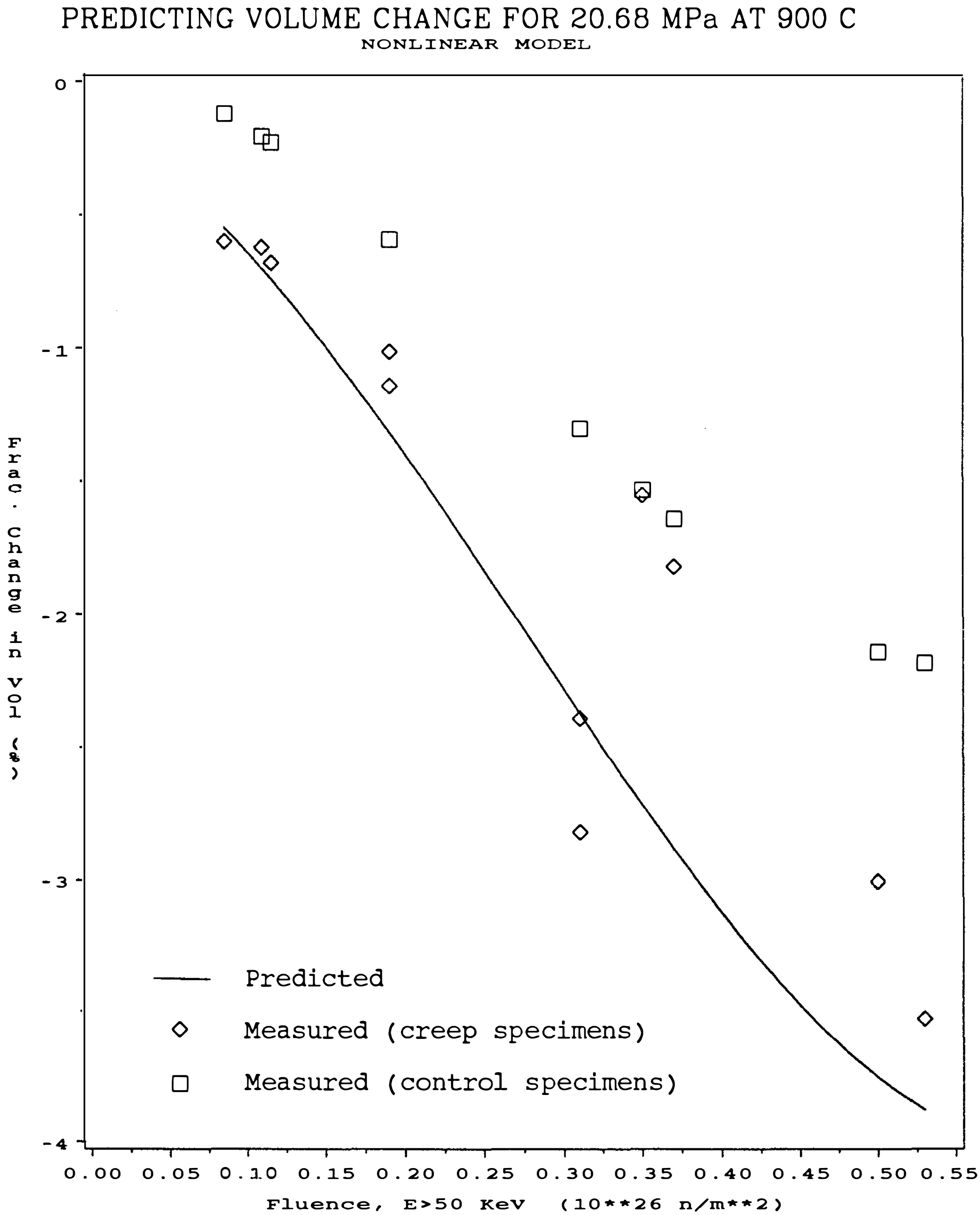


Figure 9-33. Prediction of volume change with neutron fluence for 20.68 MPa at 900°C based on the nonlinear model.

CHAPTER 10

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

10.1 Summary

The available experimental data for the OC-series irradiation-induced creep experiments performed at ORNL were critically examined. The objective of the examination was to establish credibility and confidence levels of the observed behavior of nuclear graphite. The graphite grade H-451 was of main interest in these studies.

The OC-series is composed of five irradiation experiments. The OC-1, OC-3, and OC-5 experiments were conducted at the nominal irradiation temperature of 900°C. The other two experiments, OC-2 and OC-4, were performed at the nominal irradiation temperature of 600°C. The ORR was the source of neutrons for the irradiation experiments. The irradiation temperatures were maintained by gamma heating, mainly, and by Ohmic heating for "fine tuning".

The reactor data for OC-3 and OC-4 experiments were provided by ORNL for analysis. The best estimates for the actual irradiation temperatures were determined by analyzing the temperature and reactor power data, using the SAS system. It was determined according to thermocouple readouts that the best estimate values for the irradiation temperatures were well within ±10°C of the design temperatures of 900°C and 600°C.

Pre- and postirradiation measurement data on graphite were also provided for creep studies. These data were the measurement and fluence data obtained for the five OC-experiments described in Chapter 4.

Linear and nonlinear models for irradiation-induced creep in graphite were examined to determine the extent to which the variations of creep strain with neutron fluence (at the two irradiation temperatures of 900°C and 600°C) can be explained by these models. The nonlinear model considers the creep coefficient to vary with neutron fluence due to the densification of graphite with neutron irradiation.

The coefficients for the constitutive equation describing the overall growth of graphite were also studied. In examining the behavior of grade H-451 graphite, the variation of Young's modulus, shear modulus, electrical resistivity, and coefficient of thermal expansion of graphite with fluence/creep were studied. The consistency of calculated Poisson's ratios for primary and secondary creep with volume change, caused by irradiation-induced creep, was also investigated.

10.2 Conclusion

The temperature analyses gave the best estimate values of 899.9 ± 3°C and 601.7 ± 10°C over nine zones (zone one through zone nine) of the specimen columns for OC-3 and OC-4, respectively. The functional relationship between the creep coefficient (K) in linear model and irradiation temperature (close to linear for the temperature range under consideration [30]), was determined to be

$$K = -10.044 + 0.032T \tag{10-1}$$

where

K = secondary creep coefficient for the linear model ((in/in) / (initial elastic strain) / (10^{26} neutron/m^2))

T = temperature (°C)

For the nonlinear model, the functional relationship between K_2 and the irradiation temperature is

$$K_2 = -14.412 + 0.041T \tag{10-2}$$

where

K_2 = the coefficient involved in the secondary creep coefficient for the nonlinear model (essentially the secondary creep coefficient in the linear model for low-fluence data) ((in/in) / (initial elastic strain) / (10^{26} neutron/m^2))

T = temperature (°C)

Based on the above equations it can be determined that an error of less than 2% in K or K_2 is associated with an error of 10°C in the irradiation temperature. Therefore, error in the creep coefficients is mainly due to sources other than temperature such as error in load, fluence, and material variability.

From the fitting of the linear and nonlinear creep models to the available data and examination of the Analysis of Variance (ANOVA), it is concluded that the linear or the nonlinear model explains about 80% and 95% of the variation of creep with fluence at 900°C and 600°C, respectively. The unexplained portion is attributed to errors due to load, fluence, and material variability. Over the temperature and fluence ranges examined, there was no superiority of predictive capability of the nonlinear model over linear model. However, the nonlinear model does not have any serious conflict with the available data. For temperature and fluence ranges considered in the analysis reported here, the linear model would be adequate. Considering the manner that load was applied during the conduction of experiments, the error due to the load is estimated to be about 5%. The errors due to fluence are commonly about 10% and the remaining part would be due to the material variability.

In determining the coefficients of constitutive equation, the examination of the variation of modulus of elasticity and sheer modulus with fluence revealed that these are not affected by creep. However, the electrical resistivity seems to be slightly affected by creep. This effect was revealed to be less than 5%. It was determined that the CTE increases with creep strain. Finally, it was concluded that the calculated Poisson's ratios (for primary and secondary creep) were consistent with the volume change caused by irradiation-induced creep at 600°C and 900°C.

10.3 Recommendations

It should be noted that the temperature analyses were performed on the available temperature data for one out of three experiments for 900°C and on one out of two experiments for 600°C. Because the other three experiments were done in the same way, it was assumed that the temperature control was the same. The variation of the creep coefficients with temperature determined here should be viewed in the light of the assumption that the best estimate values for the irradiation temperatures involved in the unanalyzed OC-experiments are the same as the ones obtained here. It is recommended that further studies be conducted to gain more confidence in temperature variation.

It is also recommended that analyses similar to the ones performed here be conducted for higher fluence data to establish whether the nonlinear model is superior to the linear model.

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LIST OF REFERENCES

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APPENDICES

APPENDIX A

CREEP PROPERTIES OF SOLID MATERIALS

CREEP PROPERTIES OF SOLID MATERIALS

This appendix provides some general information on long-term properties of solid materials and includes the associated definitions and nomenclatures.

As the name implies, long-term properties of materials are those which manifest as time passes by. In other words, factor of time is involved in the study of these properties. Generally speaking, these properties are associated with two phenomena: creep (explained in this appendix) and fatigue.

Creep Strain

Creep is defined as time-dependent slow plastic deformation of a solid under a constant stress and at a constant temperature. For metals and ionic solids, extensive creep occurs at temperatures greater than approximately 0.4 of their absolute melting temperatures [35]. A solid material can experience creep strain even for stresses below its yield strength. This is in contrast to the slip phenomenon which can only occur, as a time-independent plastic deformation, at stresses higher than the yield strength.

Creep-Time Analysis

A typical variation of creep strain with time is depicted, schematically and as an isothermal and isostress curve, in Figure A-1 (curve a). As indicated in this figure, the total strain is made up of elastic strain and plastic

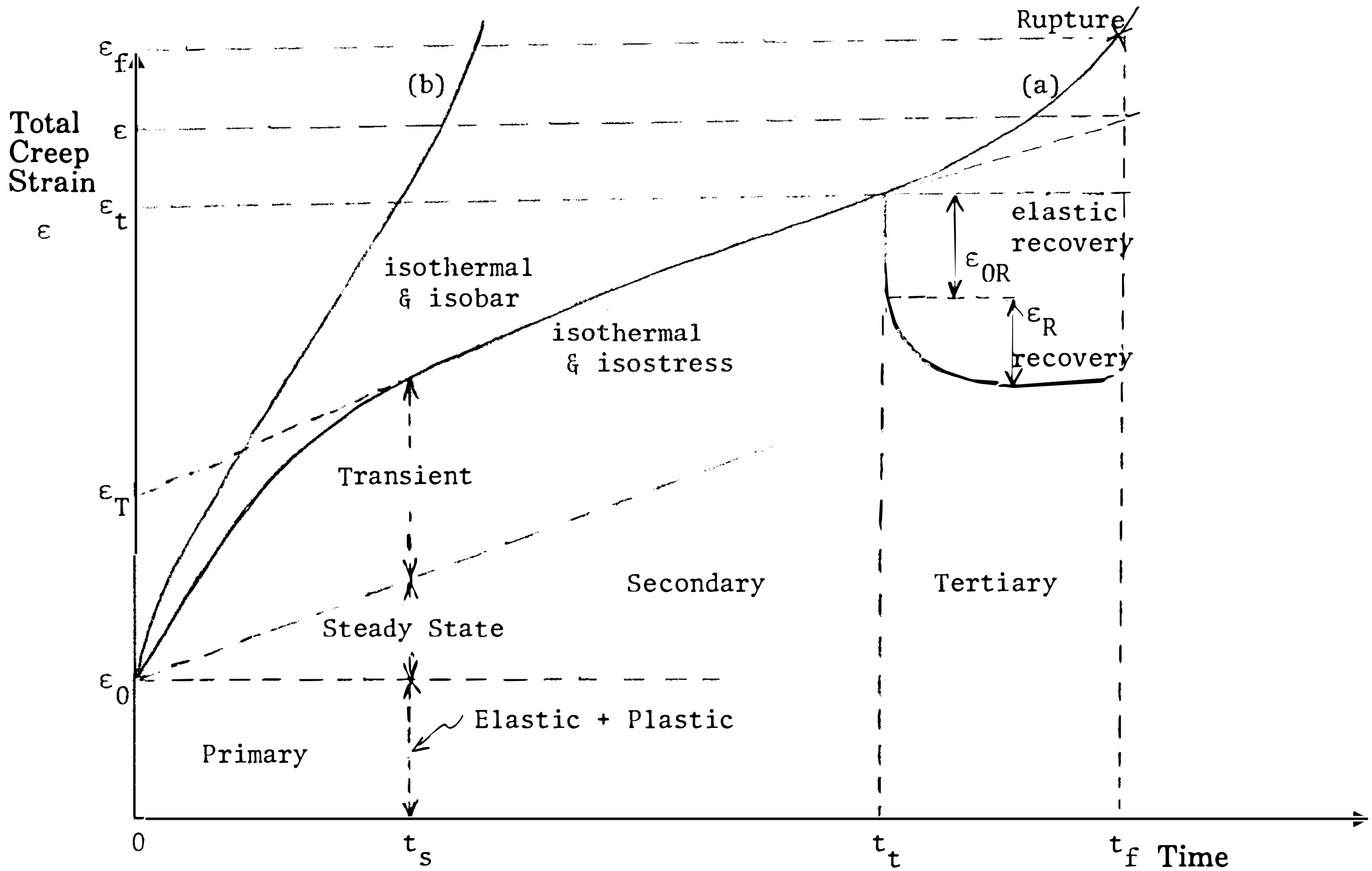

Figure A-1. Schematic creep curves: (a) constant tensile stress, (b) constant tensile load.

strain that results from slip, creep, or both. The elastic portion of the strain is recovered when the load is removed, but the plastic part (slip and creep) remains as permanent set. In some cases, this plastic deformation may be reduced after a period of time. This phenomenon is called recovery [36]. Figure A-1 (curve b) shows a typical creep behavior for constant tensile load.

Considering the trend of creep rate, typically, three stages are distinguished. The first stage or primary creep is identified by the decrease in the rate of creep; it is also called transient creep. During the second stage or secondary creep, the creep rate remains constant; this is also called "steady-state creep." This stage begins when strain hardening and thermal softening balance each other. The final stage, which usually precedes fracture, is known as the third stage or tertiary creep. The increase in strain rate in this stage is to a great extent due to the change in the dimension of the cross-section of the specimen and to some extent due to the material deterioration (internal cavitation) affecting the load bearing cross-section [37]. The steady-state creep is more critical than the transient creep due to its continuation to high strain values over long periods of time.

The resistance of a material to failure by creep is indicated by a property which is known as creep limit. This is defined as "the maximum stress for which the plastic strain will not exceed a specified amount during a specified time interval at a specified temperature" [36]. This is an important property for the design of parts which would be subjected to high temperatures and sustained loads.

Creep Rate-Time Analysis

Figure A-2 shows, schematically, the variation of the rate of creep strain with time for the three stages of creep. This indicates that the creep rate is minimum during the second stage of creep.

Effect of Temperature and Stress on Creep

Creep rate increases at higher temperatures or higher stresses. A higher creep rate results in a shorter rupture time. Figure A-3 depicts typical plots of creep strain for 3 levels of temperature and stress.

Graphical Analysis of Creep Strain for Different Situations [37]

To enlighten different situations involving creep, the information obtained from the previous creep curves can be represented in different forms. Considering the five variables of stress, temperature, creep, creep rate, and time, the relationship between any two reasonable choices can be studied graphically provided the remaining ones are kept constant. Some of these graphical representations are illustrated schematically in Figures A-4 through Figure A-9. Figure A-4, obtainable from Figure A-3 by considering some constant values of time, clarifies the relationship between the logarithm of the creep rate and the logarithm of applied stress while considering time as

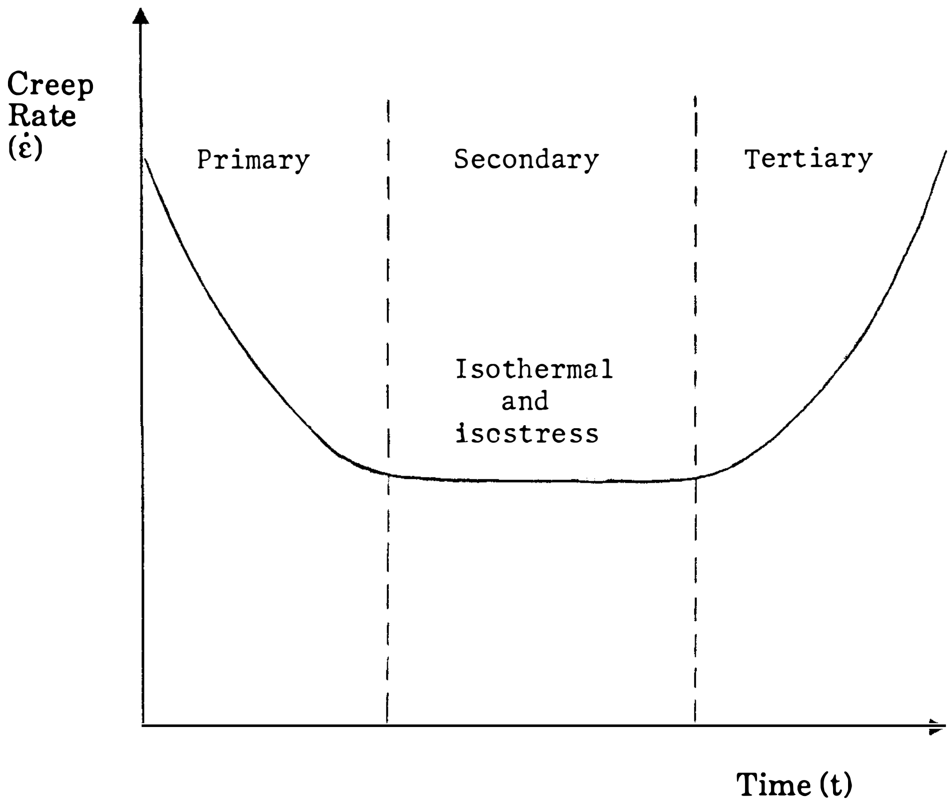

Figure A-2. Typical variation of creep rate with time.

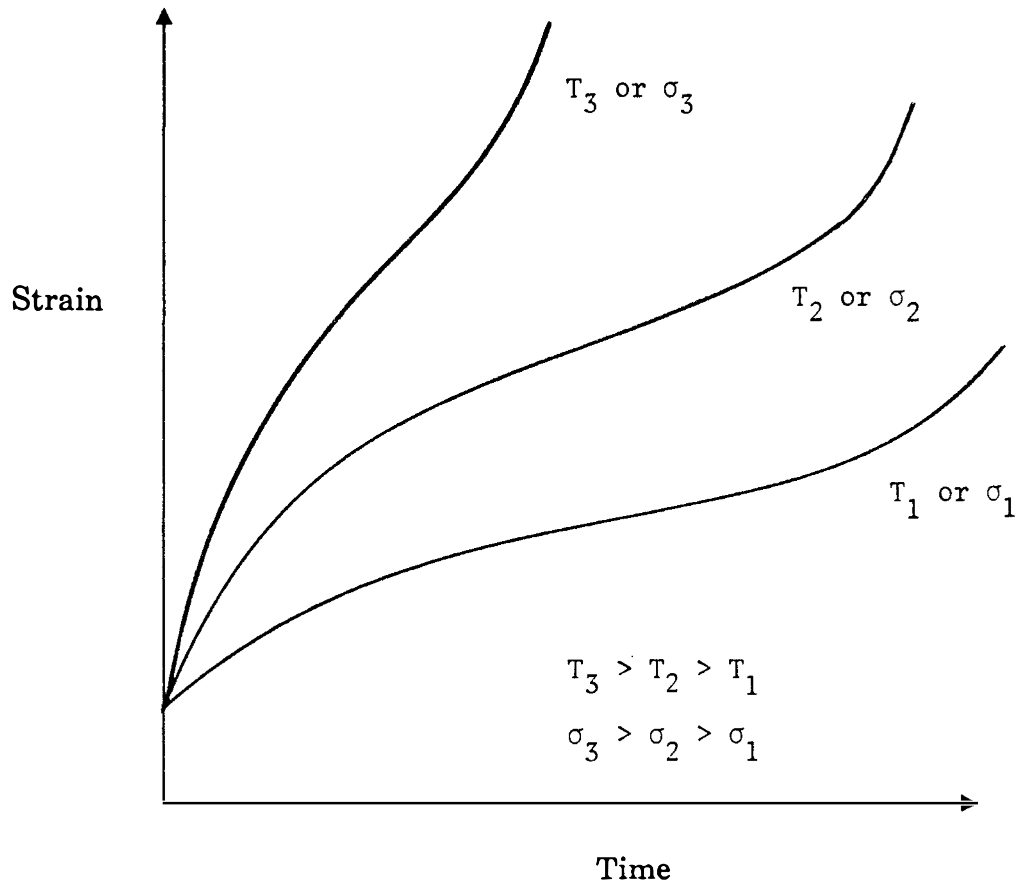

Figure A-3. The effect of temperature or applied stress on the creep curve.

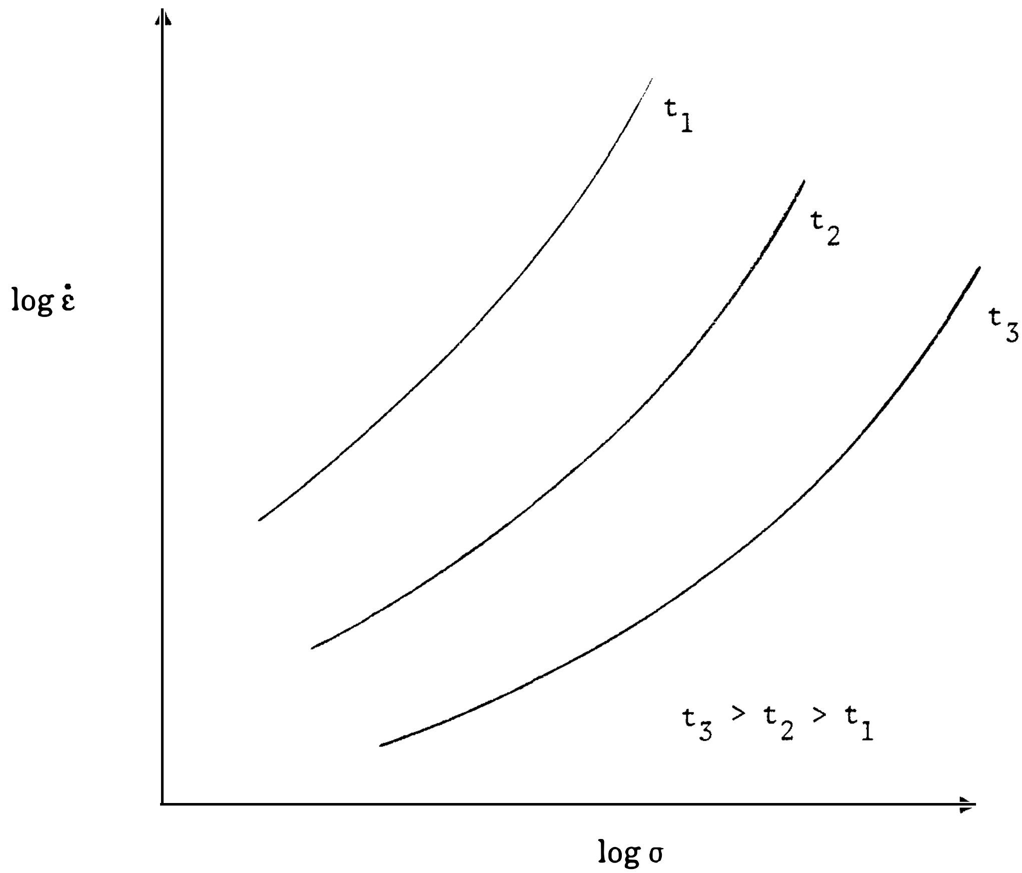

Figure A-4. Schematic isochronous creep curves.

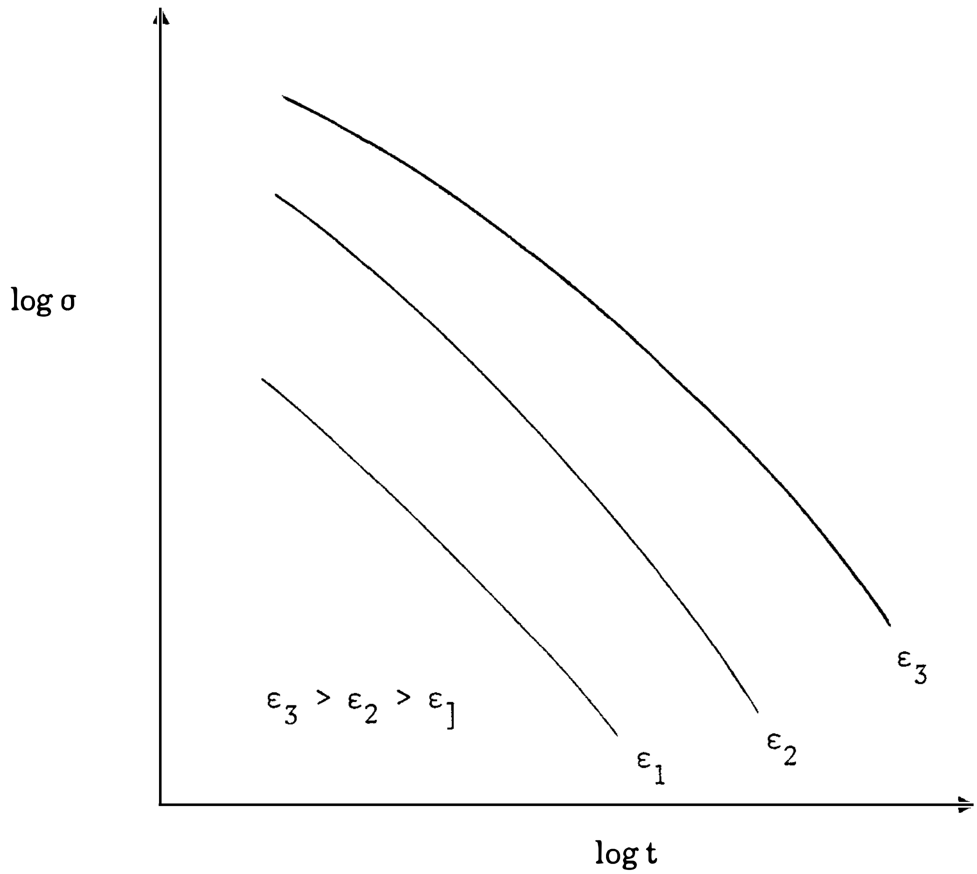

Figure A-5. Schematic isostrain creep curves.

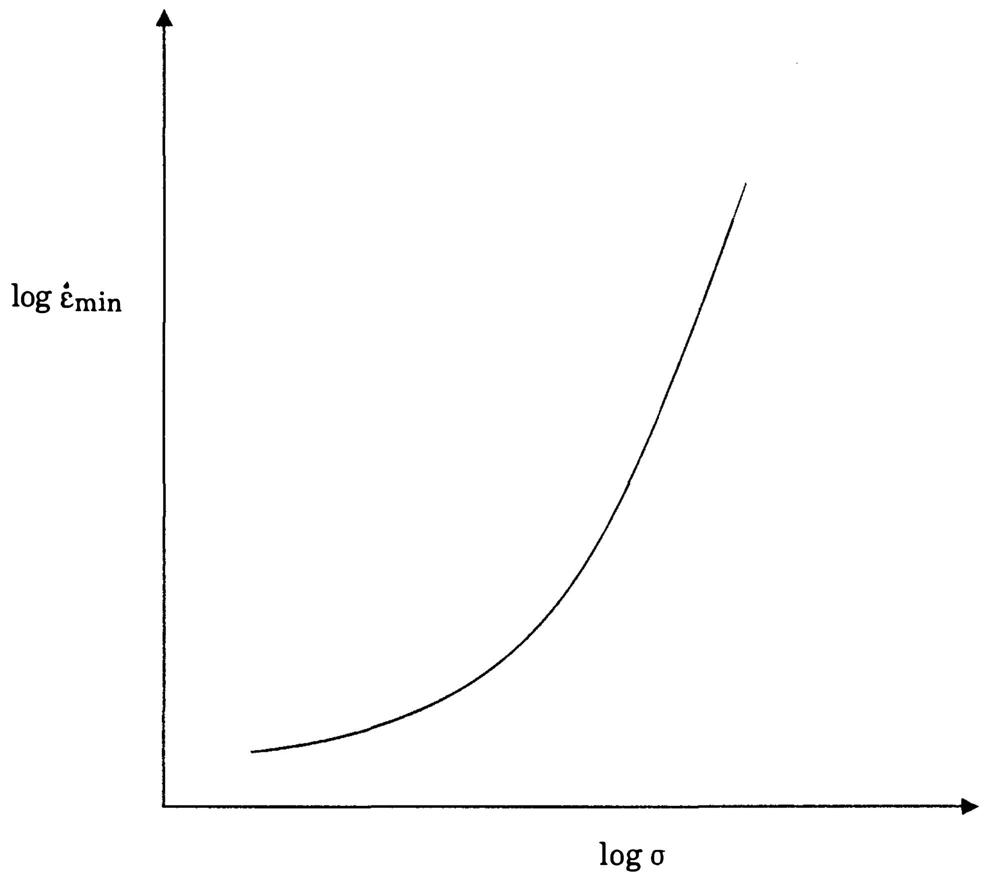

Figure A-6. Schematic plot of logarithm of minimum creep strain rate versus logarithm of stress.

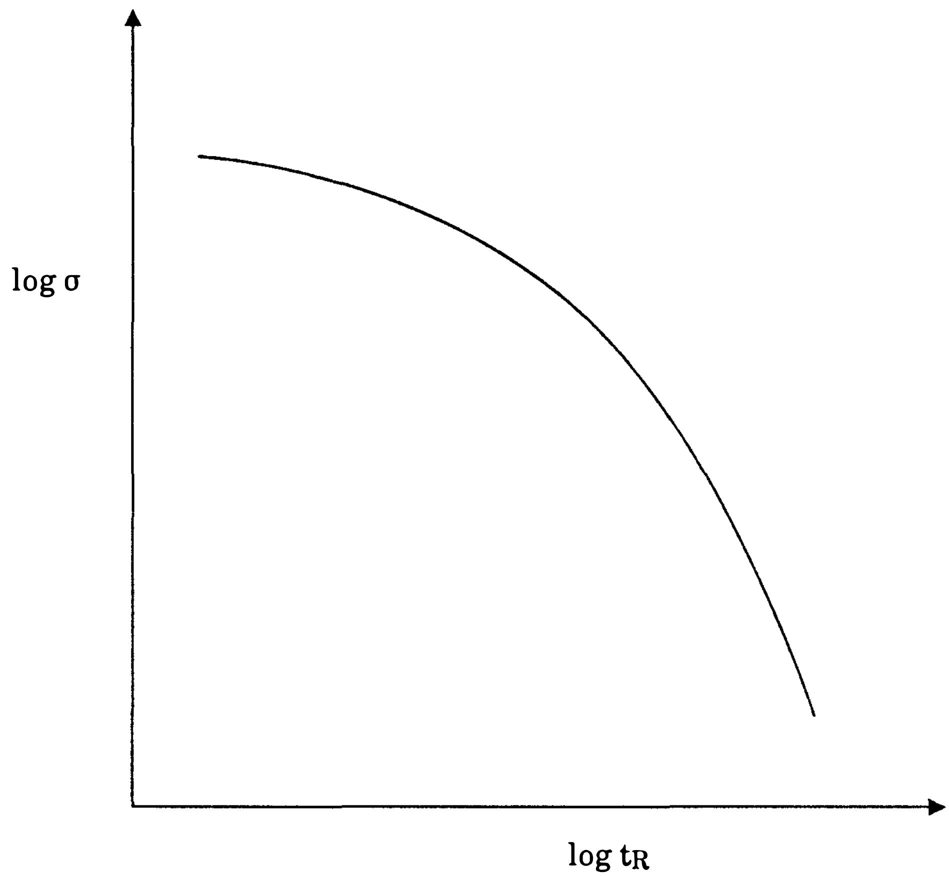

Figure A-7. Schematic plot of logarithm of initial stress versus logarithm of rupture time.

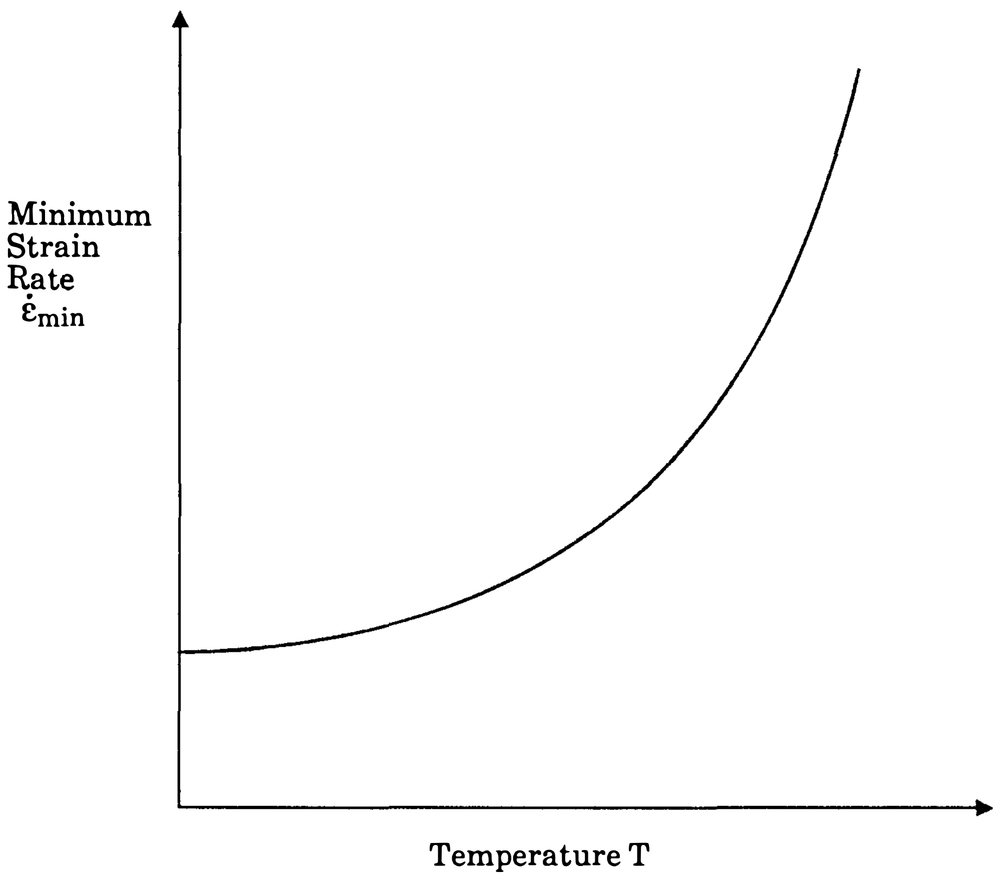

Figure A-8. Variation of minimum (steady-state) creep rate with temperature.

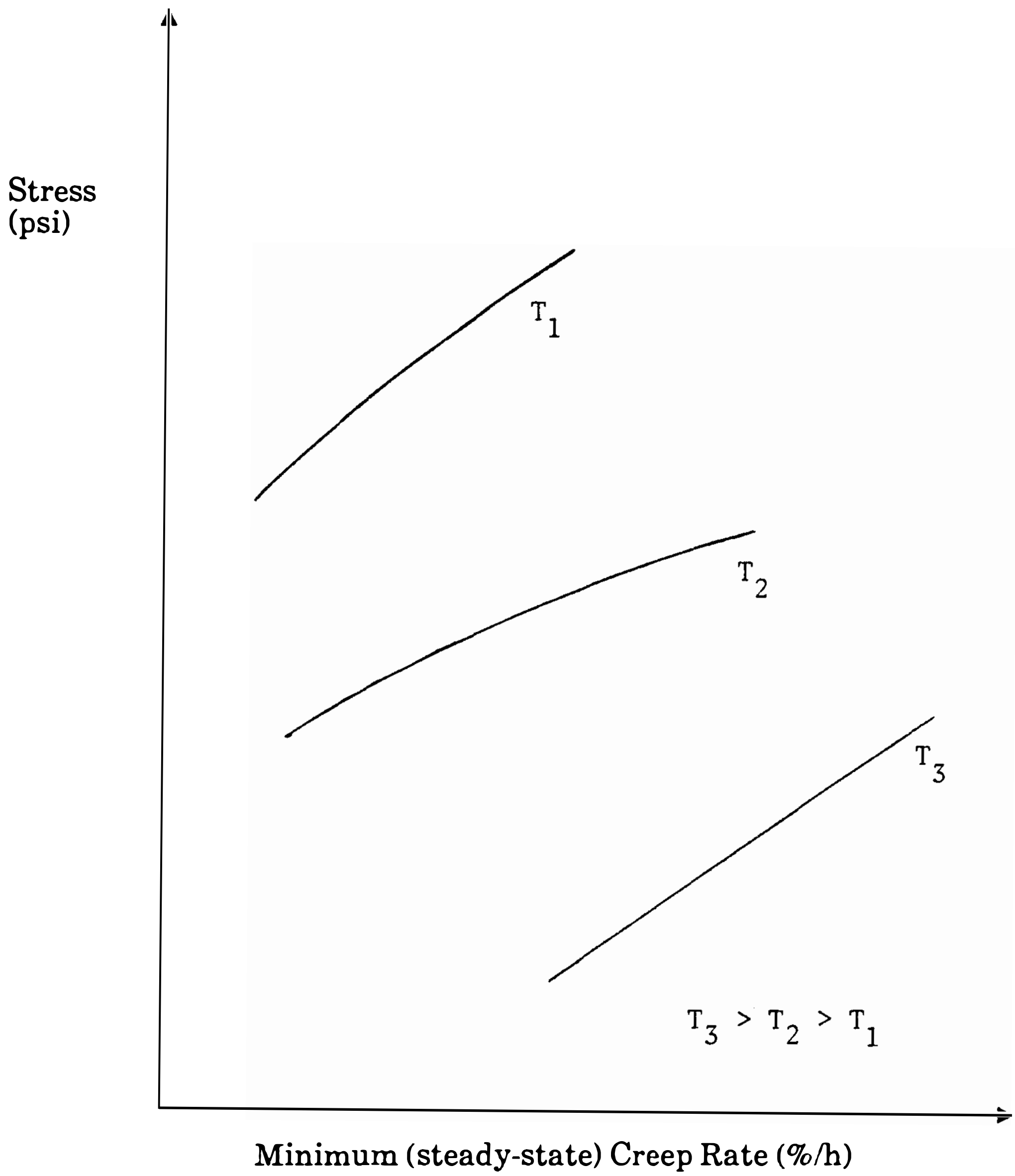

Figure A-9. Schematic isothermal creep curves.

a parameter. Temperature is the same for all curves. The constant time curves are called isochronous creep curves. As indicated, at a constant time (and temperature), on a log-log plot, the creep rate increases with the applied load. This kind of plot helps determine the stress-strain behavior of the material.

Figure A-5, which can also be obtained from Figure A-3, at constant strains, shows the variation of stress with time, for constant strains (isostrain curves), on a log-log plot. This kind of plot indicates the time at which a given strain is reached for a given stress level.

From the isochronous and isostrain creep curves (Figures A-4 and A-5) two plots can be singled out which are particularly useful: the plot of minimum creep rate versus stress and that of initial stress versus rupture time, respectively. Figure A-6 shows, schematically, the first of these two plots. This plot ($\log \dot{e}_{min}$ *vs* $\log \sigma$) generally suggests that the steady-state creep rate, $\dot{\epsilon}_s$, can usually be described by a power-law function of applied stress [35]:

$$\epsilon_s = A\sigma^n$$

where A, the pre-exponential term, is temperature dependent and n, the creep index, has a value typically between 3 and 6 for single-phase materials. As shown in this figure, for tests at lower load, a transition to lower positive slope takes place.

The second plot, Figure A-7, indicates, schematically, the relationship between stress and rupture time. This suggests that the rupture time is inversely proportional to some power of stress but a transition to a higher negative slope occurs for longer-term tests. The high-stress, short-time portion is usually related to ductile type fracture, and the low-stress, long-term section is of a brittle type occurring at low strains [37].

Variable temperatures and loads would add to the complexity of the creep analysis. The variation of steady-state creep rate with temperature is depicted in Figure A-8. This variation is of exponential type and, as such, indicates the sensitivity of the minimum creep rate to even small changes in temperature.

Figure A-9 depicts some schematic isothermal creep curves. For a given stress and temperature, the minimum creep rate can be determined by this sort of plot.

As the simplest example of nonconstant loads, Figure A-10 shows the so-called relaxation curve. The relaxation phenomenon is manifested when, in the creep test, the elongation of a tensile specimen is held constant. This results in a relaxation of the resultant load [37].

Typical creep responses to step loading and unloading are shown in Figures A-11 and A-12. The latter introduces the phenomenon of creep recovery [37].

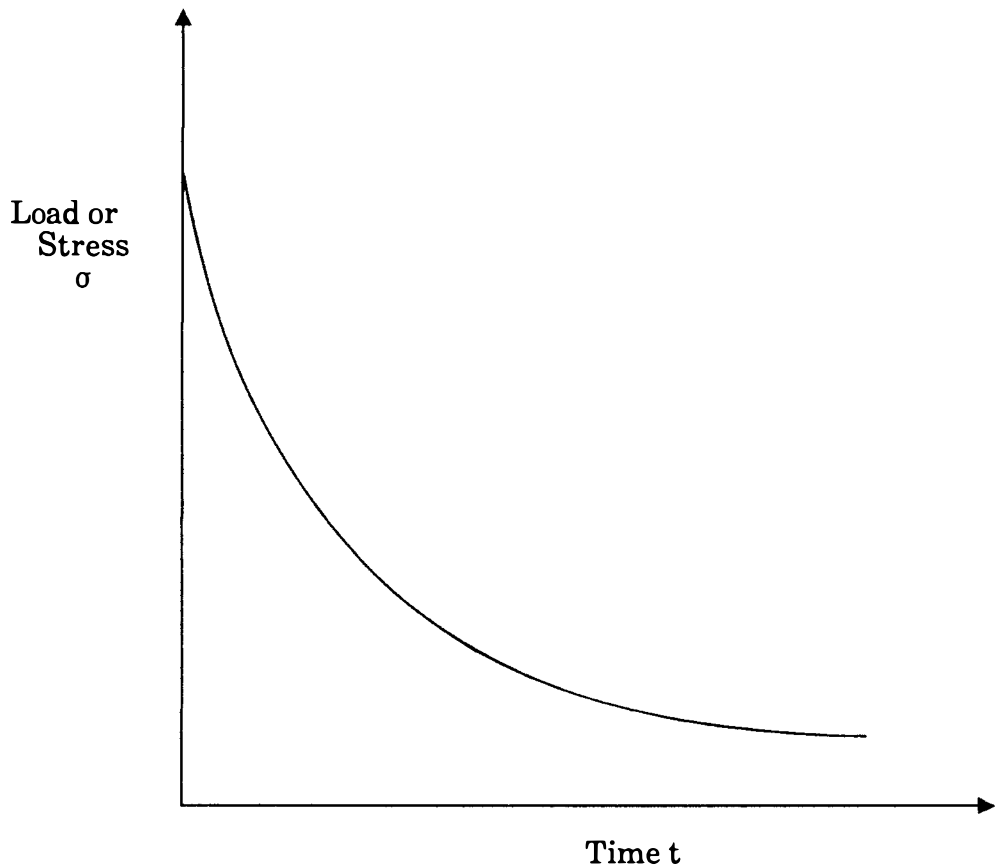

Figure A-10. Typical relaxation curve.

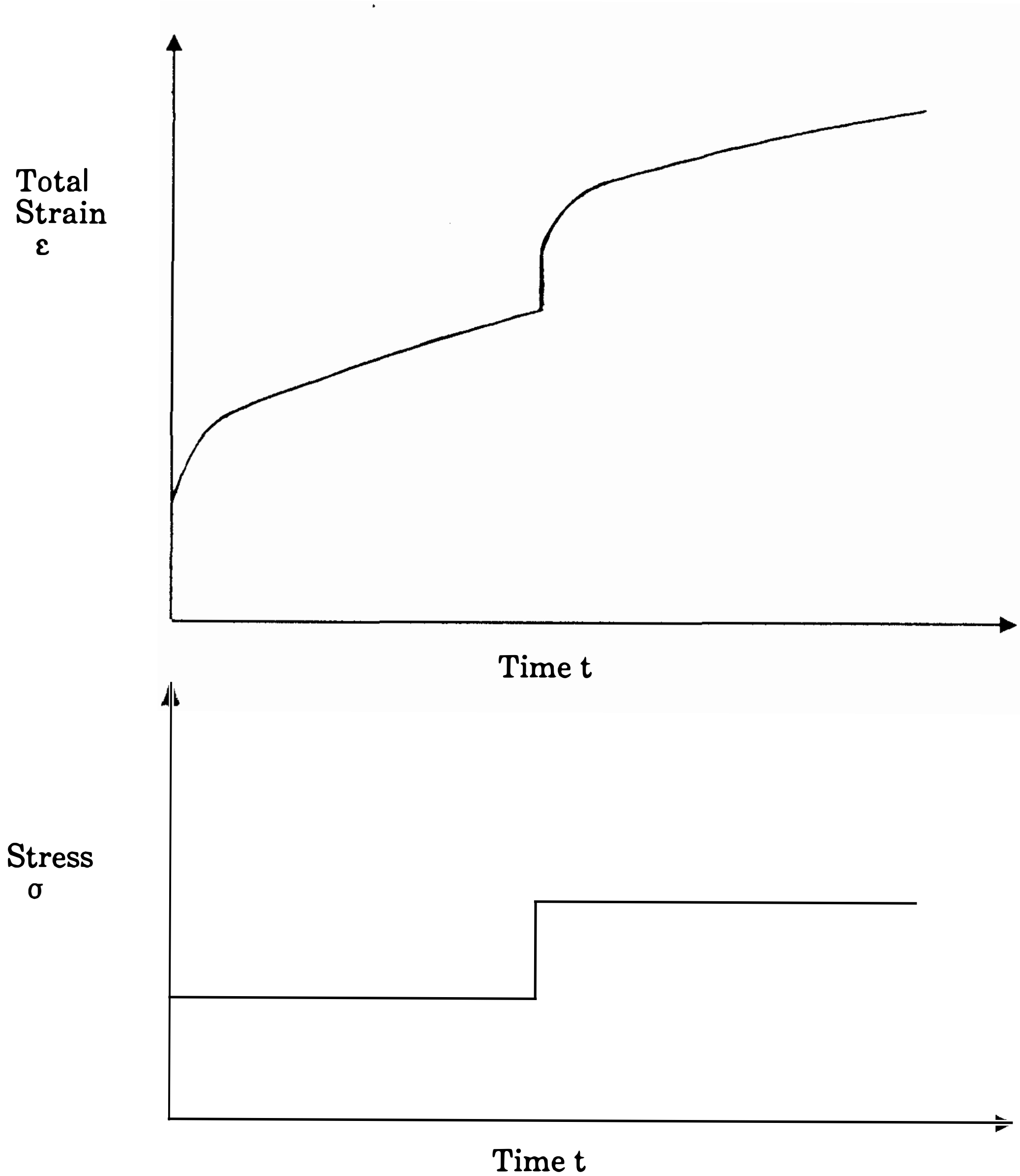

Figure A-11. Typical creep response to step load [37].

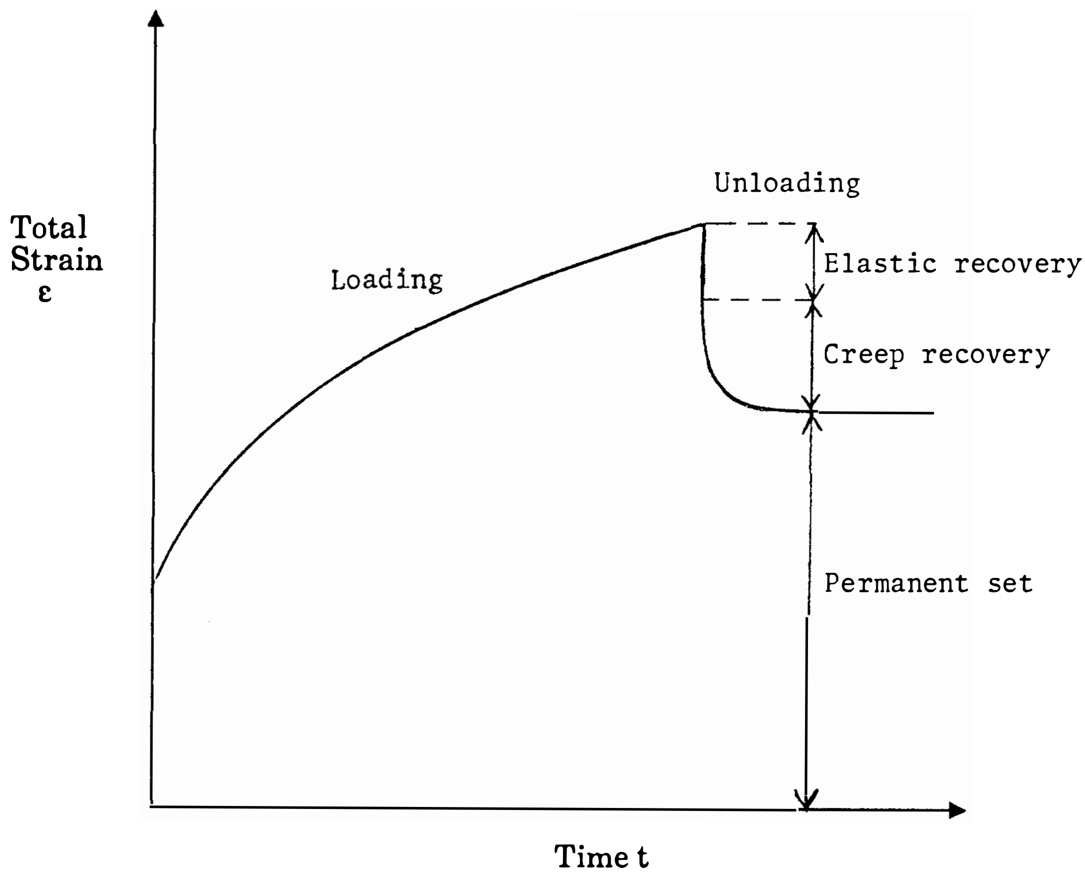

Figure A-12. Effect of unloading on creep [37].

Predicting Creep Properties [38]

Creep strength (creep limit) and creep-rupture strength (stress-rupture strength or simply rupture strength) are the most important properties used directly in design for creep. The deformation allowed is expressed as total strain and the time of interest is the service life.

Creep strength (the highest stress that a material can stand for a specified length of time without excessive deformation) can be determined or predicted by considering the isostrain creep curves (Figure A-5) or the variation of minimum creep rate with stress (Figure A-6). For service lives longer than the test times, extrapolation to longer times must be performed.

Creep-rupture strength (the highest stress that a material can stand for a specified length of time without rupture) can be determined or predicted from the isothermal stress-rupture curves (Figure A-13). The isochronal rupture curves, shown schematically in Figure A-14, can also be used for this purpose. Extrapolation becomes necessary, if the service life is longer than the test time.

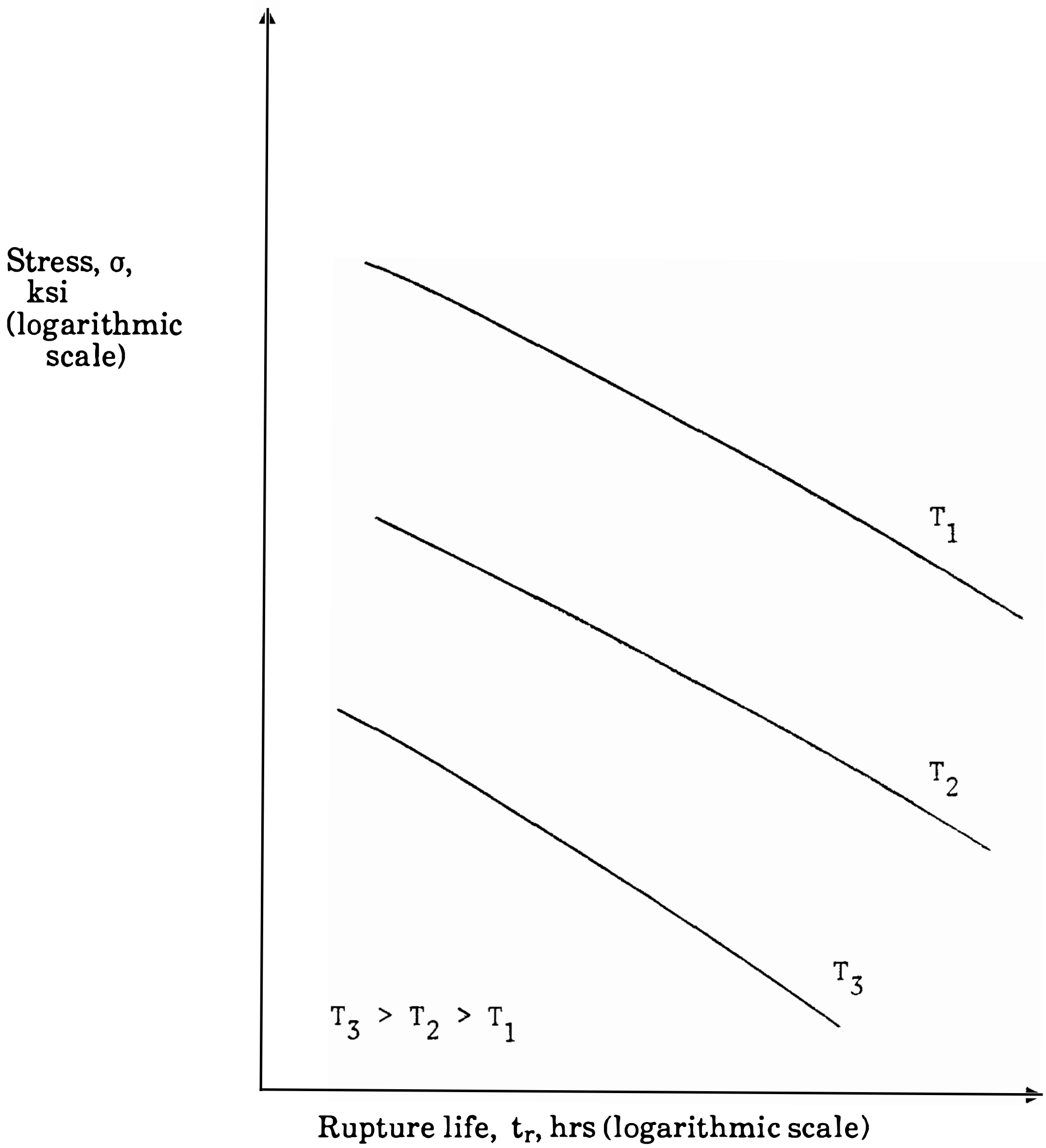

Figure A-13. Schematic typical isothermal stress-rupture curves.

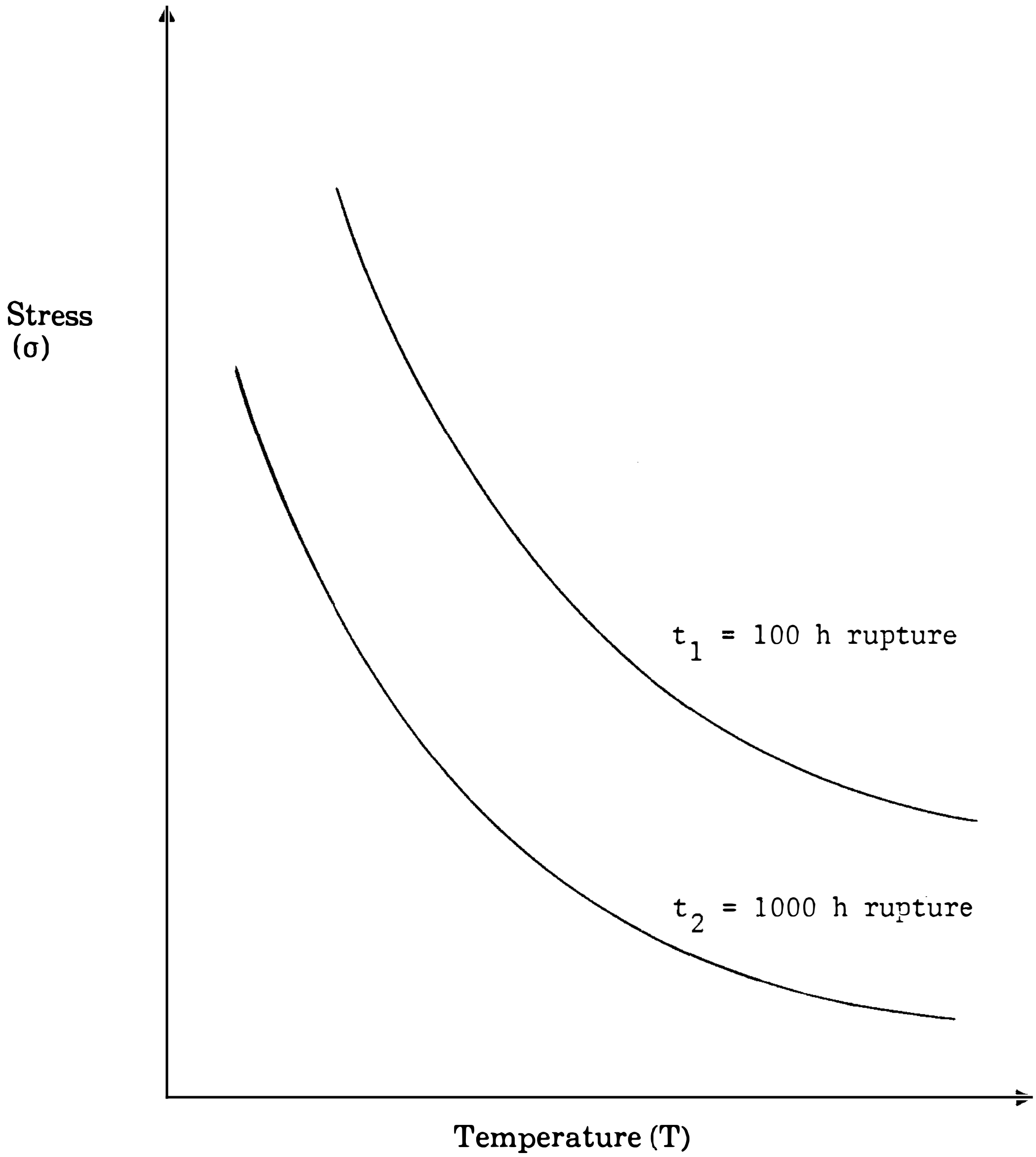

Figure A-14. Schematic typical isochronal rupture curves.

APPENDIX B

DATA READING AND CONVERTING PROGRAM

The list of the modified assembly/FORTRAN code with its required JCL to read and convert the format of the experimental data, is included in this appendix. It should be noted that this code is for 128-point database. For a larger database the dimension of the arrays involved must be changed.

```
//AMMSH2 JOB ,MOBASHERAN,GROUP=J-----,USER=P-----,CLASS=T,
//    MSGLEVEL=(1,1),MSGCLASS=H,TIME=10,PASSWORD=?
/*ROUTE CMSRJO USERID=P-----
/*ROUTE PRINT UTCC
/*JOBPARM ROOM=UTCC,LINES=50
/*NOTIFY UTKVM1.PA----
//S1  EXEC ASMHC,PARM='NODECK,OBJECT'
//SYSGO  DD DSN=&&SYSLIN,UNIT=SYSDA,SPACE=(TRK,(20,10)),
//     DISP=(,PASS),DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200)
//ASM.SYSIN DD *
D113     TITLE 'DEC 11/40 TO 360 FLOATING POINT CONVERSION ROUTINE.'
*
*     THIS SUBROUTINE ACCEPTS AS ITS ARGUMENT A 4-BYTE QUANTITY
*     WHICH IS THE DEC PDP 11/40 REPRESENTATION OF A FLOATING
*     POINT NUMBER AND RETURNS THE NUMBER IN IBM FORM.  IT SHOULD
*     BE CALLED AS A FUNCTION SUBROUTINE, E.G. REAL=D11360(REAL).
*
*     SINCE IBM REPRESENTATIONS OF FLOATING POINT NUMBERS ARE
*     NORMALIZED BASE 16, UP TO THREE BITS OF DATA COULD BE LOST
*     IF STANDARD 32-BIT PRECISION IS USED.  THEREFORE, AT THE OPTION
*     OF THE CALLER, THE RESULT CAN BE SPECIFIED AS A DOUBLE PRECISION
*     NUMBER.
*
      SPACE
D11360 START 0
      SPACE
B     EQU 8
      SPACE
      BC     15,12(15)
      DC     X'7'
      DC     CL7'D11360'
      SPACE
      STM    14,12,12(13)       SAVE THE REGISTERS
      BALR   B,0
      USING  *,B
      SPACE
      L      2,0(1)             GET THE ADDRESS OF THE ARGUMENT
      L      3,0(2)             GET THE ARGUMENT
*     IF THIS IS A "TRUE ZERO", NO CONVERSION IS REQUIRED.
      LTR    3,3
      BC     8,ZERO
      SPACE
      L      2,=X'80000000'     MASK FOR THE SIGN BIT
      NR     2,3                SAVE THE SIGN BIT
      SPACE
      L      4,=X'007FFFFF'     MASK TO GET MANTISSA
      NR     4,3
      SLL    4,8                ONLY SHIFT 8 BECAUSE OF HIDDEN BIT.
      SPACE
      SPACE
      L      5,=X'7F800000'     MASK FOR THE EXPONENT.
```

```
      NR    5,3                 GET THE EXPONENT
      SRL   5,23
      X     5,=XL4'80'          CONVERT EXCESS 128 TO 2'S COMP.
      SLL   5,24
      SRA   5,24
      L     6,=X'80000000'
      OR    4,6                 RESTORE THE HIDDEN BIT.
      SPACE
      BC    15,LOOP1
LOOP  A     5,=F'1'             EXPONENT = EXPONENT + 1
      SRL   4,1                  MANTISSA = MANTISSA / 2
LOOP1 L     6,=F'3'             MASK FOR 2 LOW ORDER BITS
      NR    6,5                 CHECK FOR ZERO
      BC    8,CHECK             IF YES, IT IS NORMALIZED FOR THE 360
      BC    15,LOOP             KEEP TRYING
      SPACE
      SPACE
CHECK L     6,=XL4'F0000000'    MAKE SURE THE HIGH-ORDER NIBBLE IS > 0
      NR    6,4
      BC    4,DONE              IF NON-ZERO, WE'RE DONE
      SPACE
      SLL   4,4                 IT IS ZERO - SHIFT STUFF UP 4 BITS
      S     5,=F'4'             SUBTRACT 4 (1 BASE 16) FROM EXPONENT
      BC    15,CHECK            GO MAKE SURE IT'S OK NOW
      SPACE
DONE  SRA   5,2                 CHANGE EXP FROM BASE 2 TO BASE 16
      L     6,=XL4'0000005F'    MASK TO ELIMINATE LEFT OVER SIGN BIT.
      NR    5,6
      X     5,=XL4'40'          ADD 40 HEX FOR EXCESS 64 NOTATION
      SLL   5,24                PUT THE EXPONENT INTO THE TOP OF THE WD
      OR    2,5                 COMBINE SIGN AND EXPONENT
      LR    6,4                 PUT THE MANTISSA INTO REG 6
      SRL   4,8                 REG 4 = HIGH THREE BYTES OF MANTISSA
      OR    2,4                 REG 2 = EXP, 3 HIGH BYTES
      ST    2,RESULT            SAVE IT
      SPACE
      N     6,=XL4'F0'           MASK FOR REST OF MANTISSA
      SLL   6,24                PUT IT INTO THE TOP OF THE WORD
      ST    6,RESULT+4          SAVE IT IN ITS PROPER POSITION
      BC    15,LOAD
*     INPUT WAS "TRUE ZERO", NO CONVERSION REQUIRED.
ZERO  ST    3,RESULT
      ST    3,RESULT+4
      SPACE
LOAD  LD    0,RESULT            LOAD THE RESULT INTO F.P. REG 0
      SPACE
      LM    2,12,28(13)         RETURN
      MVI   12(13),X'FF'
      BCR   15,14
      SPACE
      DS    0D                  GET ON A DOUBLE WORD BOUNDARY
```

```
RESULT DS    1D                DOUBLE-PRECISON RESULTS STORED HERE
      SPACE
      END
/*
//S3  EXEC FORTVCLG,FORTOPT='TERM,TRMFLG',
//    PARM.GO='EU=-1,EO=-1,DUMP=-G',REGION.GO=1024K
//* EXEC FTN63CLG,PARM.FORT='XREF',PARM.LKED='XREF,MAP',
//*    PARM.GO='EU=-1,EO=-1,DUMP=-G',REGION.GO=384K
//SYSLIN  DD UNIT=SYSDA
//FORT.SYSIN DD *
C**FTN,L,E,M,G.
C     MAIN PROGRAM TO PROCESS MAGTAPE DATA FROM ORR.
C       **************************************************
C       *  MODIFIED BY:   AMIR S. MOBASHERAN              *
C       *                 NUCLEAR ENGR. DEPT.             *
C       *                 UNIV. OF TENN.                  *
C       *                 KNOXVILLE, TN. 37916            *
C       *                 PH.: (615)974-7564              *
C       *  DATE:  SEP. 9, 1984                            *
C       **************************************************
      INTEGER*2 PNTNUM,MAXPNT,ICHAN(256),PNTFLG(256)
      INTEGER*2 ALPHSQ(256),SENSOR(256),IDATA(256)
      REAL*4 RDATA(256),PTNAME(256)
      COMMON PNTNUM,MAXPNT,PTNAME,ICHAN,PNTFLG,ALPHSQ,SENSOR,RDATA,IDATA
      CHARACTER*1 ARRAY(1536)
      INTEGER*2 RECID
      CHARACTER*1 TIME(8),DATE(9)
       CHARACTER*6 PARRAY(256)/256*'
       CHARACTER*8 CTIME
       CHARACTER*9 CDATE
       EQUIVALENCE (ARRAY(1),PARRAY(1)),(TIME(1),CTIME)
       EQUIVALENCE (DATE(1),CDATE)
       MAXPNT = 600
       PNTNUM = 104
       NN = 1
1     CALL GETREC (IERR,RECID,TIME,DATE)
      IF(IERR .EQ. 1) GO TO 100
      IF(IERR .EQ. 4) GO TO 4000
      GO TO 1
100    CONTINUE
C100   PRINT 1000,RECID,TIME,DATE
1000  FORMAT(' ',I2,1X,8A1,1X,9A1)
        IF ((RECID .GT. 12) .OR. (RECID .LT. 1)) GO TO 15
        GO TO (11,12,13,14,15,15,15,15,15,15,21,22), RECID
11     CONTINUE
C11    PRINT 1011,PNTNUM,MAXPNT
1011  FORMAT(' ',2I6)
      GO TO 1
12    NUMCHR=6*PNTNUM
      CALL R50EBC(NUMCHR,PTNAME,ARRAY)
C      PRINT 1012,(ARRAY(L),L=1,NUMCHR)
```

```
1012  FORMAT(' ',10(1X,6A1),/)
      GO TO 1
13     CONTINUE
C13    PRINT 1013,(ICHAN(L),L=1,MAXPNT),(PNTFLG(L),L=1,MAXPNT)
1013  FORMAT(' ',10(1X,I6),/)
      GO TO 1
14     CONTINUE
C14    PRINT 1014,(ALPHSQ(L),L=1,MAXPNT)
1014  FORMAT(' SEQ. ',10(1X,I6),/)
C      PRINT 1016,(SENSOR(L),L=1,MAXPNT)
1016  FORMAT(' SEN. ',40(1X,A2),/)
      GO TO 1
21     CONTINUE
C21    PRINT 1021,(RDATA(L),L=1,MAXPNT)
1021  FORMAT(' RDATA ',8(1X,E14.7),/)
C      WRITE(8) NN,TIME,DATE,PNTNUM,MAXPNT,(RDATA(L),L=1,128)
       NN = NN + 1
C****QUIT AFTER 10 RECORDS
C      IF (NN.GT.10) GO TO 4000
      GO TO 1
22     CONTINUE
C22    PRINT 1015,(IDATA(L),L=1,MAXPNT)
1015  FORMAT(' IDATA ',10(1X,I6),/)
       DO 2200 II=1,MAXPNT
       WRITE(8,2201) II,CDATE,CTIME,PARRAY(II),ICHAN(II),
     1  PNTFLG(II),ALPHSQ(II),SENSOR(II),RDATA(II),IDATA(II)
2201   FORMAT(I3,1X,A9,1X,A8,1X,A6,3I6,1X,A3,E14.7,I6)
2200   CONTINUE
      GO TO 1
15      PRINT 5001, RECID
5001  FORMAT(' ILLEGAL RECORD ID.,= ',I6)
      GO TO 1
4000  PRINT 4001
4001  FORMAT(' END-OF-TAPE')
      STOP 1111
      END
C     -----------------------------------------------------------
      SUBROUTINE GETREC (IERR,IRECID,ATIME,ADATE)
C       ******************************************************
C       *  MODIFIED BY:   AMIR S. MOBASHERAN                 *
C       *  DATE:  SEP. 9, 1984                               *
C       *       SEE THE HEADER BLOCK OF THE MAIN PROGRAM     *
C       ******************************************************
      INTEGER*2 IRECID
      CHARACTER*1 LSENSR(512)
      INTEGER*2 PNTNUM,MAXPNT,ICHAN(256),PNTFLG(256)
      INTEGER*2 ALPHSQ(256),SENSOR(256),IDATA(256)
      REAL*4 RDATA(256),PTNAME(256)
      CHARACTER*1 ATIME(8),ADATE(9)
      COMMON PNTNUM,MAXPNT,PTNAME,ICHAN,PNTFLG,ALPHSQ,SENSOR,RDATA,IDATA
      CHARACTER*1 TIME(8),DATE(9)
```

```
      INTEGER*2 RECID
      CHARACTER*1 LBUFFR(1044)
      INTEGER*2 IBUFFR(522)
      REAL*4 RBUFFR(261)
       CHARACTER*1 EXPNAM(12)
       CHARACTER*1 ARRAY(1536)
      EQUIVALENCE (SENSOR(001),LSENSR(1))
      EQUIVALENCE (LBUFFR(1),IBUFFR(1),RBUFFR(1),RECID)
      EQUIVALENCE (LBUFFR(3),TIME(1))
      EQUIVALENCE (LBUFFR(11),DATE(1))
C
C
C
      IOEOF=0
1     IERR=1
        READ(58,5588,END=5) LBUFFR
5588    FORMAT(200A1,200A1,200A1,200A1,200A1,44A1)
        IFLAG = 0
        LENGTH = 1044
C ***********************************
C THE FOLLOWING TWO CARDS ARE FOR PRINTING THE MAG TAPE RECORD.
C     PRINT 4444,LENGTH,(LBUFFR(LOOP),LOOP=1,LENGTH)
C4444 FORMAT(' REC. ',I6,10(' ',38Z2,/))
      RECID=IBYTSW(RECID)
      IRECID=RECID
      NUMBYT=8
      CALL ASCEBC(NUMBYT,TIME(1),ATIME(1))
      NUMBYT=9
      CALL ASCEBC(NUMBYT,DATE(1),ADATE(1))
C     SEE IF THERE WERE ANY ERRORS.
C      IF(IFLAG)2,2,3
C CHANGE IFLAG MEANING
       IF(IFLAG-1)2,2,3
3     IF(IFLAG - 2)4,5,6
C     RECORD LENGTH ERROR.
4     PRINT 100,RECID,LENGTH
100   FORMAT(' RECORD LENGTH ERROR ',2I6)
      GO TO 3001
5     IF (IOEOF .EQ. 1)GO TO 3002
C END OF FILE, GO TO 3002 TO SET IERR = 4
       GO TO 3002
      PRINT 103
103   FORMAT(' END OF FILE')
      IOEOF=1
      GO TO 1
6     PRINT 102, LENGTH,(LBUFFR(LOOP),LOOP=1,LENGTH)
102   FORMAT(' PARITY ERROR, NO. BYTES= ',I6,7(/,1X,38Z2))
        GO TO 3001
C     RECORD IS GOOD.
2     IOEOF=0
C       PRINT 2626, RECID
```

```
2626    FORMAT('  ******************** RECID = ', I6)
        IF ((RECID .GT. 12) .OR. (RECID .LT. 1)) GO TO 2828
        GO TO (10, 11, 13, 14, 16, 16, 16, 16, 16, 16, 25, 26), RECID
2828    RECID = RECID - 256
        IRECID = RECID
        IF ((RECID .GT. 12) .OR. (RECID .LT. 1)) GO TO 16
        GO TO (10, 11, 13, 14, 16, 16, 16, 16, 16, 16, 25, 26), RECID
10       CONTINUE
C       PRINT 4000,RECID,PNTNUM,MAXPNT
4000  FORMAT('0**',3I6)
      PNTNUM=IBYTSW(IBUFFR(11))
      MAXPNT=IBYTSW(IBUFFR(12))
       CALL ASCEBC (12,LBUFFR(25),EXPNAM(1))
C      WRITE(6,1002) RECID,ADATE,ATIME,PNTNUM,MAXPNT,EXPNAM
1002   FORMAT(1H ,'**',I3,1X,9A1,1X,8A1,2I6,1X,12A1)
      RETURN
11    DO 111 LOOP=1,MAXPNT
111   PTNAME(LOOP)=RBYTSW(RBUFFR(5+LOOP))
       NUMCHR = 6 * PNTNUM
       CALL R50EBC(NUMCHR,PTNAME,ARRAY)
C      WRITE(6,1111) RECID,ADATE,ATIME,(ARRAY(IL),IL=1,60)
1111   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,60A1)
      RETURN
13    DO 113 LOOP=1,MAXPNT
      ICHAN(LOOP)=IBYTSW(IBUFFR(10+LOOP))
113   PNTFLG(LOOP)=IBYTSW(IBUFFR(LOOP+266))
C      WRITE(6,1131) RECID,ADATE,ATIME,(ICHAN(IL),IL=1,12)
1131   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,12I6)
C      WRITE(6,1132) RECID,ADATE,ATIME,(PNTFLG(IL),IL=1,12)
1132   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,12I6)
      RETURN
14    DO 114 LOOP=1,MAXPNT
      ALPHSQ(LOOP)=IBYTSW(IBUFFR(10+LOOP))
C     NO NEED TO SWAP "SENSOR" BECAUSE IT WAS TREATED AS LOGICAL*1
C     IN THE LOGGING TASK ON THE PDP 11/40.
114   CONTINUE
      CALL ASCEBC (512,LBUFFR(533),LSENSR(1))
C      WRITE(6,1141) RECID,ADATE,ATIME,(ALPHSQ(IL),IL=1,12)
1141   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,12I6)
C      WRITE(6,1142) RECID,ADATE,ATIME,(SENSOR(IL),IL=1,12)
1142   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,12A3)
      RETURN
25    DO 125 LOOP=1,MAXPNT
C     MOVE DATA AND CONVERT TO IBM 360 FLOATING POINT.
125   RDATA(LOOP)=D11360(RBYTSW(RBUFFR(5+LOOP)))
C      WRITE(6,1251) RECID,ADATE,ATIME,(RDATA(IL),IL=1,10)
1251   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,5E14.7/24X,5E14.7)
      RETURN
26    DO 126 LOOP=1,MAXPNT
      IDATA(LOOP)=IBYTSW(IBUFFR(10+LOOP))
126   PNTFLG(LOOP)=IBYTSW(IBUFFR(266+LOOP))
```

```
C      WRITE(6,1261) RECID,ADATE,ATIME,(IDATA(IL),IL=1,12)
1261   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,12I6)
C      WRITE(6,1262) RECID,ADATE,ATIME,(PNTFLG(IL),IL=1,12)
1262   FORMAT(1H ,I3,1X,9A1,1X,8A1,1X,12I6)
      RETURN
16      PRINT 2000,RECID
2000  FORMAT(' ILLEGAL RECORD NO., ',I6)
        IERR = 2
      RETURN
3001  IERR=3
      RETURN
3002  IERR=4
      RETURN
      END
      SUBROUTINE R50EBC (NUMCHR,IDATA,IOUT)
      CHARACTER*1 IOUT(1),ILCHAR(2)
      INTEGER*2 IDATA(1),I(2),IPOWR(3),ICHAR,LOOP,INDEX,KOUNT,ICONV
      INTEGER*4 J
      DATA IPOWR/1600,40,1/
      EQUIVALENCE (I(1),J),(ILCHAR(1),ICHAR)
      IF(NUMCHR .EQ. 0)RETURN
      KOUNT=0
      ICONV=0
1     KOUNT=KOUNT+1
      I(1)=0
      I(2)=IDATA(KOUNT)
C     TEST FOR MAXIMUM VALUE, IF GREATER, SET TO UNUSED CHARACTERS
C     TO CAUSE FILLING WITH QUESTION MARKS.
      IF(J .GT. 63999)J=47589
      DO 2 LOOP=1,3
      INDEX=J/IPOWR(LOOP)
      J=J-INDEX*IPOWR(LOOP)
      IF(INDEX .NE. 0)GO TO 3
C     CHARACTER IS A SPACE.
      ICHAR=64
      GO TO 20
C     (A-I)?
3     IF(INDEX .GT. 9)GO TO 4
      ICHAR=192+INDEX
      GO TO 20
C     (J-R)?
4     IF(INDEX .GT. 18)GO TO 5
      ICHAR=199+INDEX
      GO TO 20
C     (S-Z)?
5     IF(INDEX .GT. 26)GO TO 6
      ICHAR=207+INDEX
      GO TO 20
C     ($)?
6     IF(INDEX .GT. 27)GO TO 7
      ICHAR=91
```

```
      GO TO 20
C     (.)?
7     IF(INDEX .GT. 28)GO TO 8
      ICHAR=75
      GO TO 20
C     (UNUSED CHARACTER)?
8     IF(INDEX .GT. 29)GO TO 9
10     ICHAR=111
      GO TO 20
C     (0-9)?
9     IF(INDEX .GT. 39)GO TO 10
      ICHAR=210+INDEX
      GO TO 20
20     ICONV=ICONV+1
      IOUT(ICONV)=ILCHAR(2)
C     HAVE ALL CHARACTERS BEEN CONVERTED?
      IF(ICONV .EQ. NUMCHR)RETURN
2     CONTINUE
      GO TO 1
      END
      SUBROUTINE ASCEBC(NUMBYT,INPUT,OUTPUT)
      CHARACTER*1 INPUT(1),OUTPUT(1),EBCDIC(128),TEMP(2)
      CHARACTER*4 XEBCDI(32)

      INTEGER*2 ITEMP
      EQUIVALENCE (TEMP(1),ITEMP),(EBCDIC(1),XEBCDI(1))
      DATA XEBCDI/
     1Z00010203,Z372D2E2F,Z1605250B,Z0C0D0E0F,
     2Z10111200,Z3C3D3226,Z18193F27,Z22003500,
     3Z405A7F7B,Z5B6C507D,Z4D5D5C4E,Z6B604B61,
     4ZF0F1F2F3,ZF4F5F6F7,ZF8F97A5E,Z4C7E6E6F,
     5Z7CC1C2C3,ZC4C5C6C7,ZC8C9D1D2,ZD3D4D5D6,
     6ZD7D8D9E2,ZE3E4E5E6,ZE7E8E9AD,Z00BD006D,
     7Z00818283,Z84858687,Z88899192,Z93949596,
     8Z979899A2,ZA3A4A5A6,ZA7A8A900,Z4F000000/
      IF(NUMBYT .LE. 0)RETURN
      DO 101 LOOP=1,NUMBYT
       ITEMP = 1
       TEMP(2) = INPUT(LOOP)
       INDEX = ITEMP + 1
      OUTPUT(LOOP)=EBCDIC(INDEX)
101   CONTINUE
      RETURN
      END
      FUNCTION IBYTSW(ARG)
      INTEGER*2 ARG,HOLD
      CHARACTER*1 L(2),SAVE
      EQUIVALENCE (HOLD,L(1))
      HOLD=ARG
      SAVE=L(1)
      L(1)=L(2)
```

```
      L(2)=SAVE
      IBYTSW=HOLD
      RETURN
      END
      FUNCTION RBYTSW(ARG)
      REAL*4 HOLD,ARG
      CHARACTER*1 L(4),SAVE
      EQUIVALENCE (HOLD,L(1))
      HOLD=ARG
      SAVE=L(1)
      L(1)=L(2)
      L(2)=SAVE
      SAVE=L(3)
      L(3)=L(4)
      L(4)=SAVE
      RBYTSW=HOLD
      RETURN
      END
//*FT55F001 DD DSN=&&SYSUT2,DISP=(,PASS),UNIT=SYSDA,
//*      DCB=(RECFM=FB,LRECL=20,BLKSIZE=320),
//*      SPACE=(320,(0,2560),RLSE)
//*LKED.SYSLMOD DD DSN=&&GOSET(NAMEX)
//*LKED.SYSLIB DD DSN=&&LOGLIB,DISP=(OLD,DELETE)
//LKED.SYSIN  DD *
 ENTRY MAIN
//GO.DUMP   DD SYSOUT=*,DCB=(RECFM=FA,BLKSIZE=133)
//*GO.FT53F001 DD DSN=&&GOSET(NAMEX),DISP=(OLD,DELETE),
//*     LABEL=(,,,IN),DCB=(RECFM=U,BLKSIZE=256)
//*FT55F001 DD DSN=&&SYSUT2,DISP=(OLD,DELETE)
//*GO.BU58F001 DD UNIT=TAPE800,LABEL=(1,NL,,IN),VOL=SER=U30542,
//*GO.FT58F001 DD UNIT=TAPE6250,LABEL=(2,SL,,IN),VOL=SER=U22200,
//*  DISP=(OLD,KEEP),DSN=AMM126,DCB=(RECFM=F,LRECL=1044,BLKSIZE=1044)
//GO.FT58F001 DD UNIT=TAPE,LABEL=(,NL,,IN),VOL=SER=U25995,
//  DISP=(OLD,KEEP),DSN=ANY,DCB=(RECFM=F,LRECL=1044,BLKSIZE=1044)
//GO.FT08F001 DD DSN=OC3.FEB2879,DISP=(,KEEP),UNIT=TAPE,
//  LABEL=EXPDT=94365,DCB=(RECFM=FB,LRECL=71,BLKSIZE=14200)
/*  NO DATA IS INPUT TO THIS PROGRAM
//
```

APPENDIX C

VARIATION OF SETPOINTS AND MEAN TEMPERATURE

WITH TIME FOR OC-3

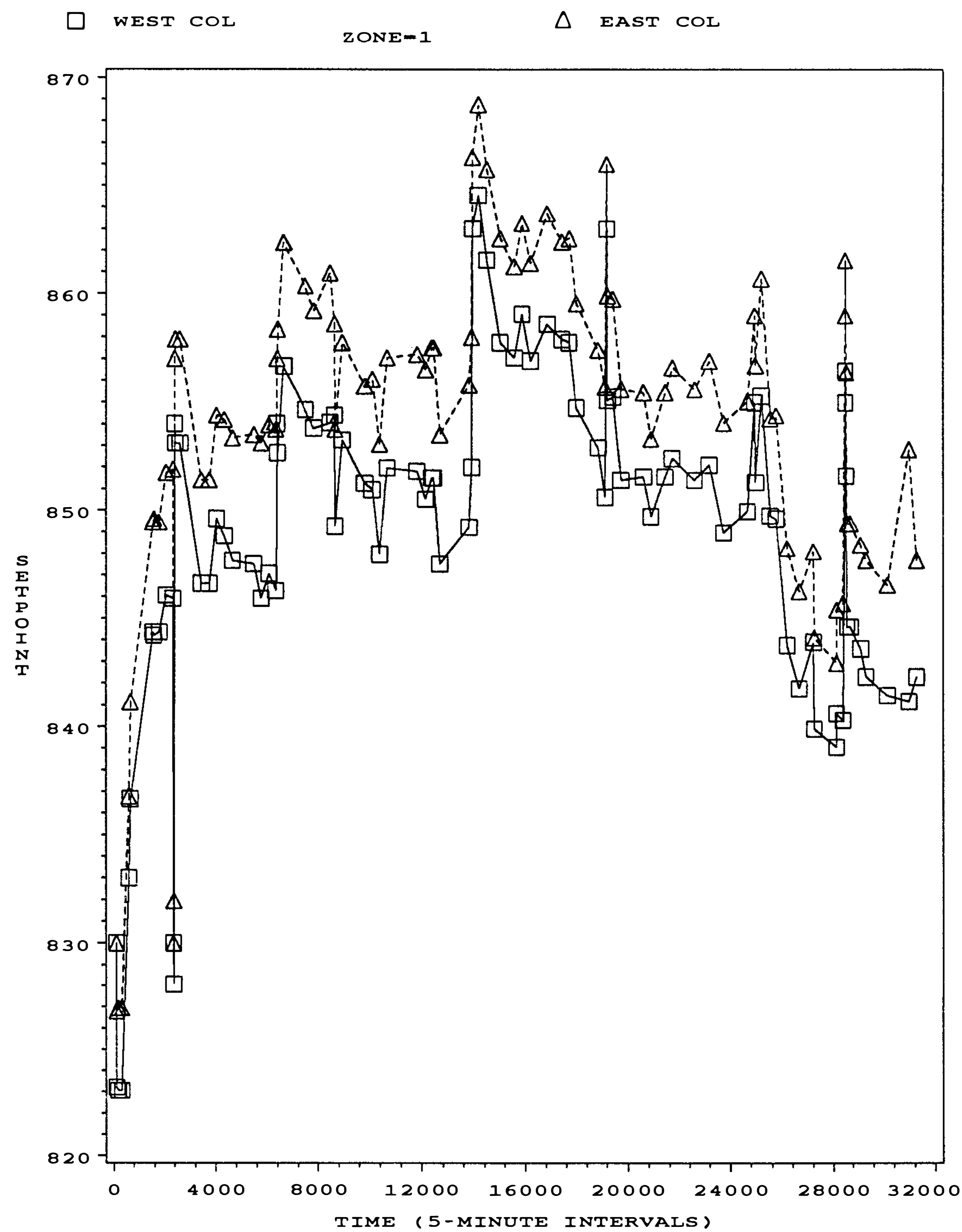

Figure C-1. Variation of setpoint values with time for zone 1 of the west and east columns of OC-3.

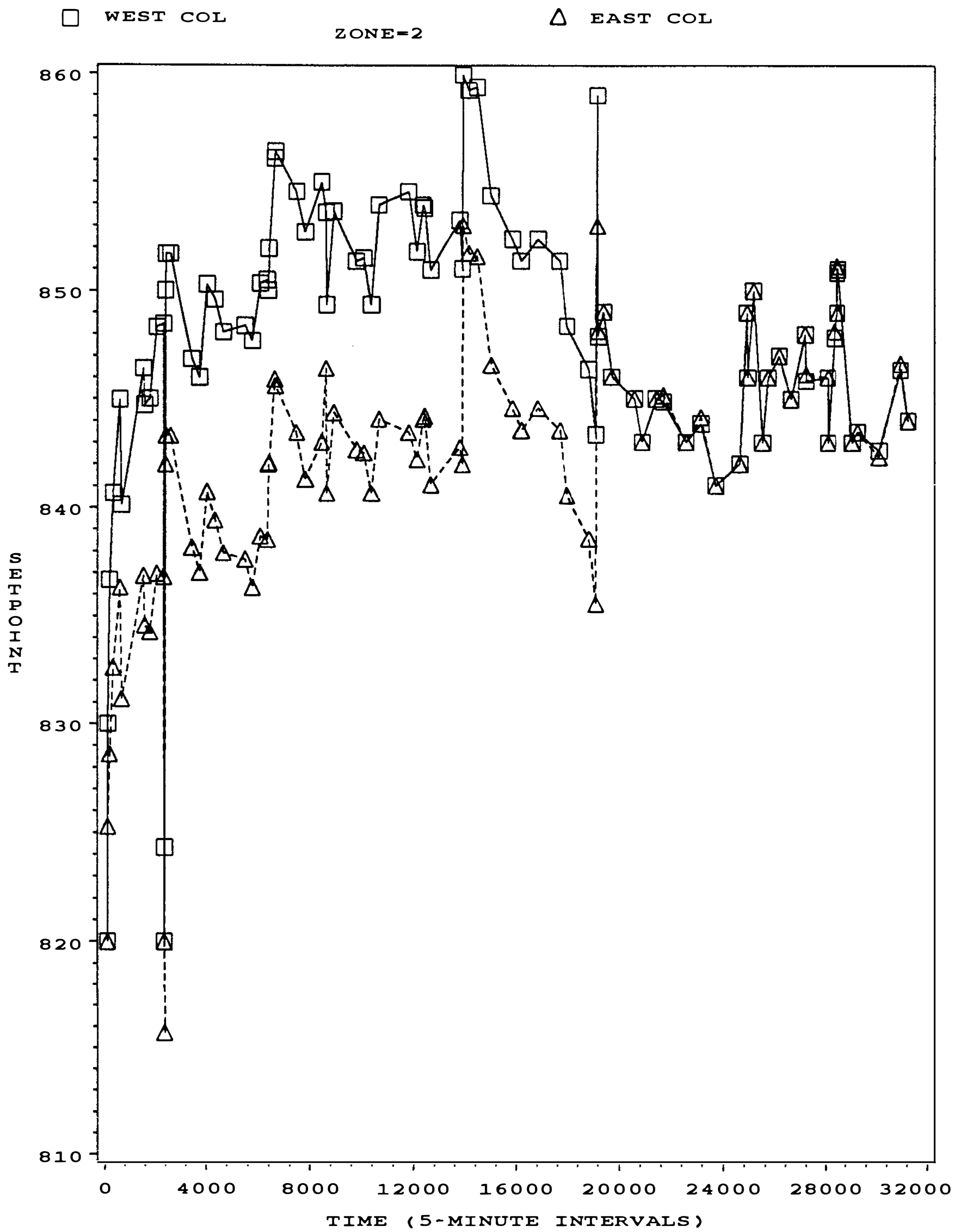

Figure C-2. Variation of setpoint values with time for zone 2 of the west and east columns of OC-3.

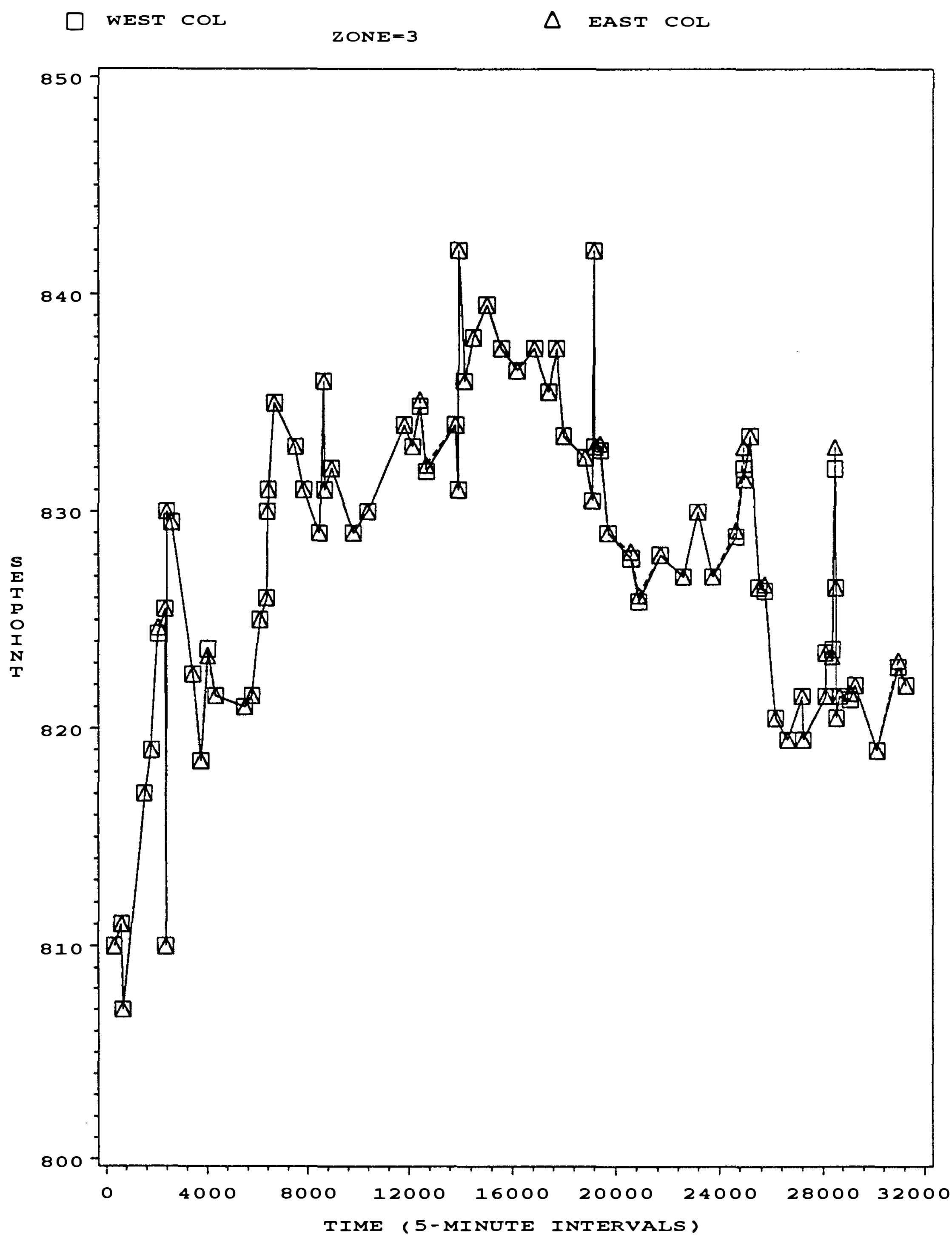

Figure C-3. Variation of setpoint values with time for zone 3 of the west and east columns of OC-3.

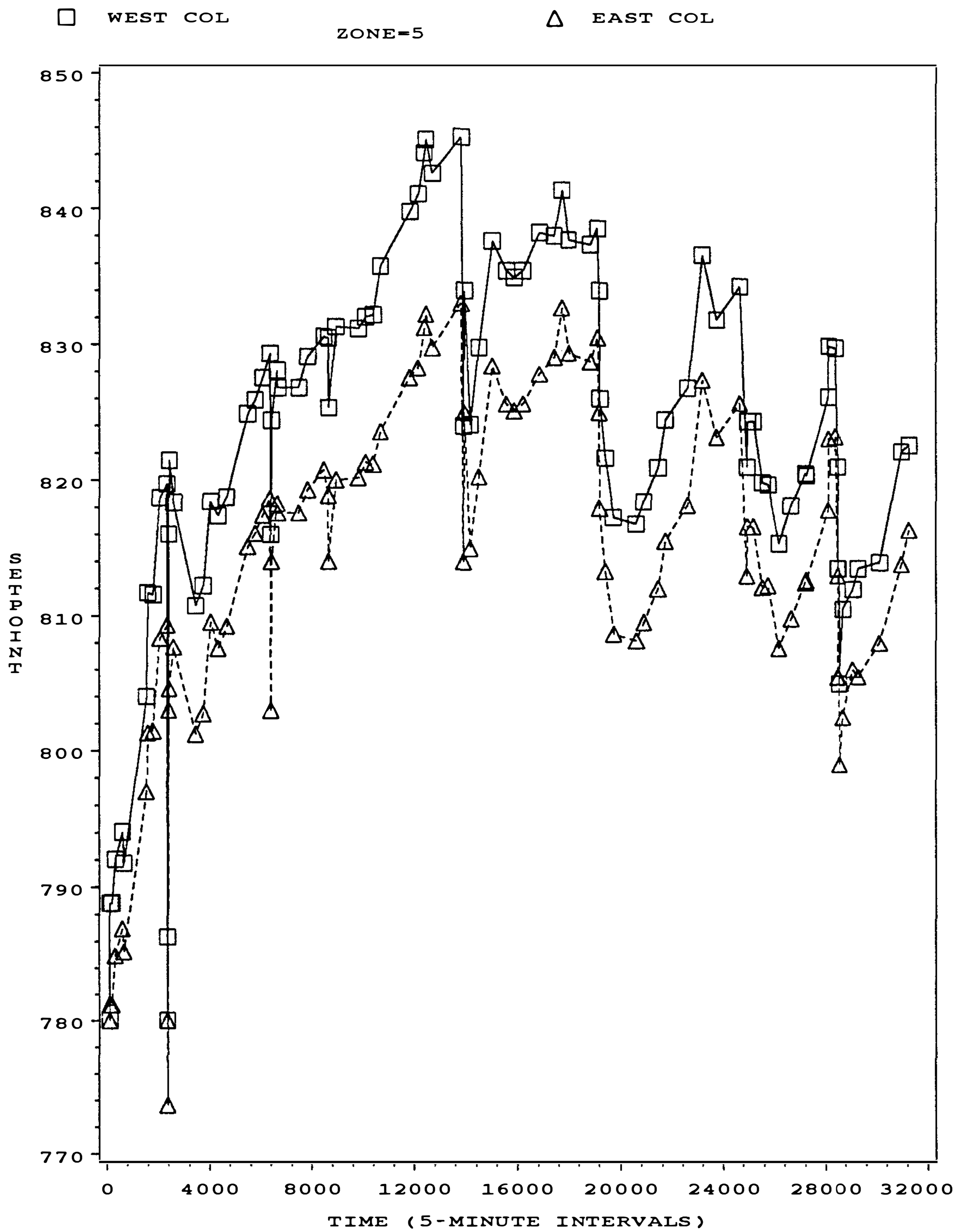

Figure C-4. Variation of setpoint values with time for zone 5 of the west and east columns of OC-3.

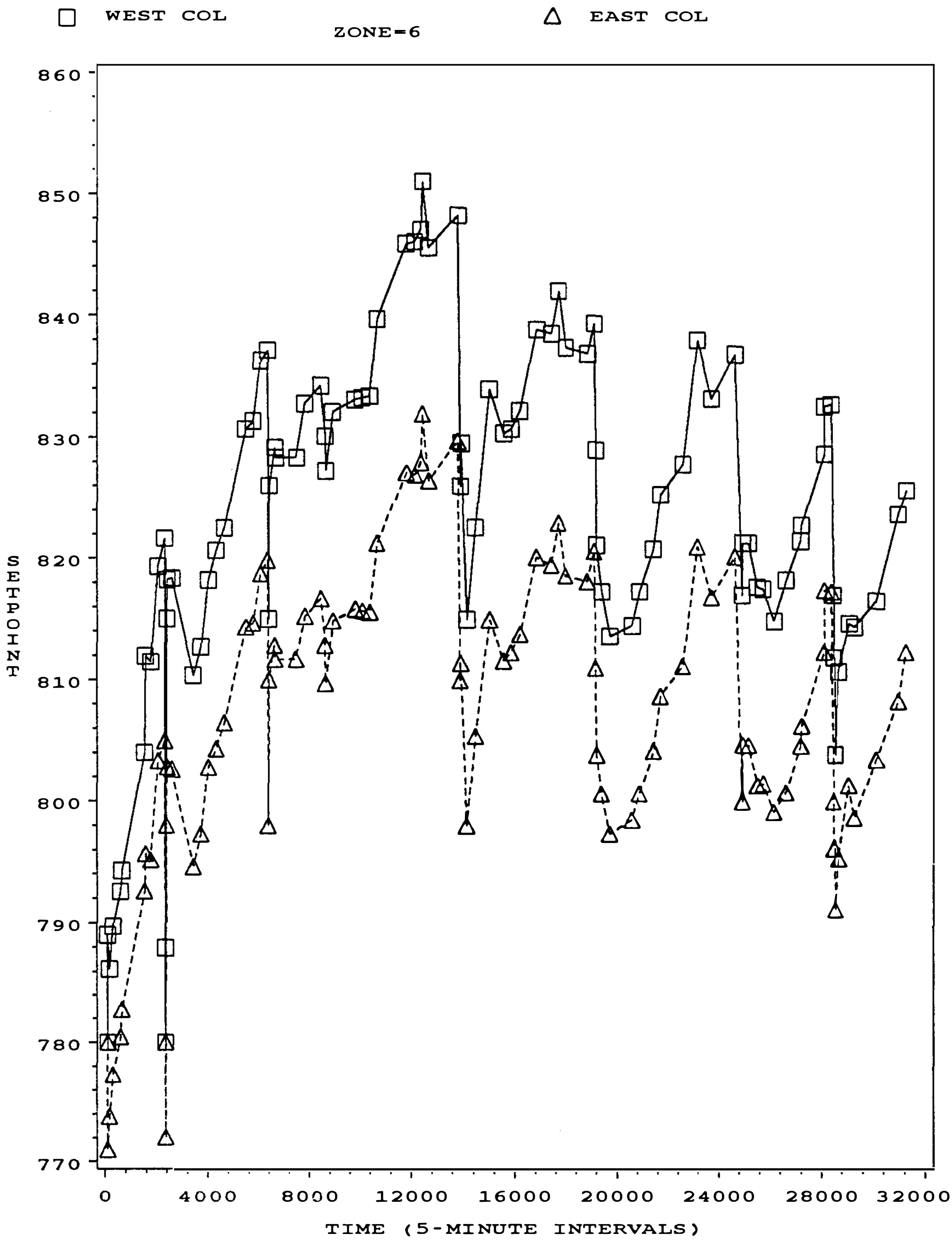

Figure C-5. Variation of setpoint values with time for zone 6 of the west and east columns of OC-3.

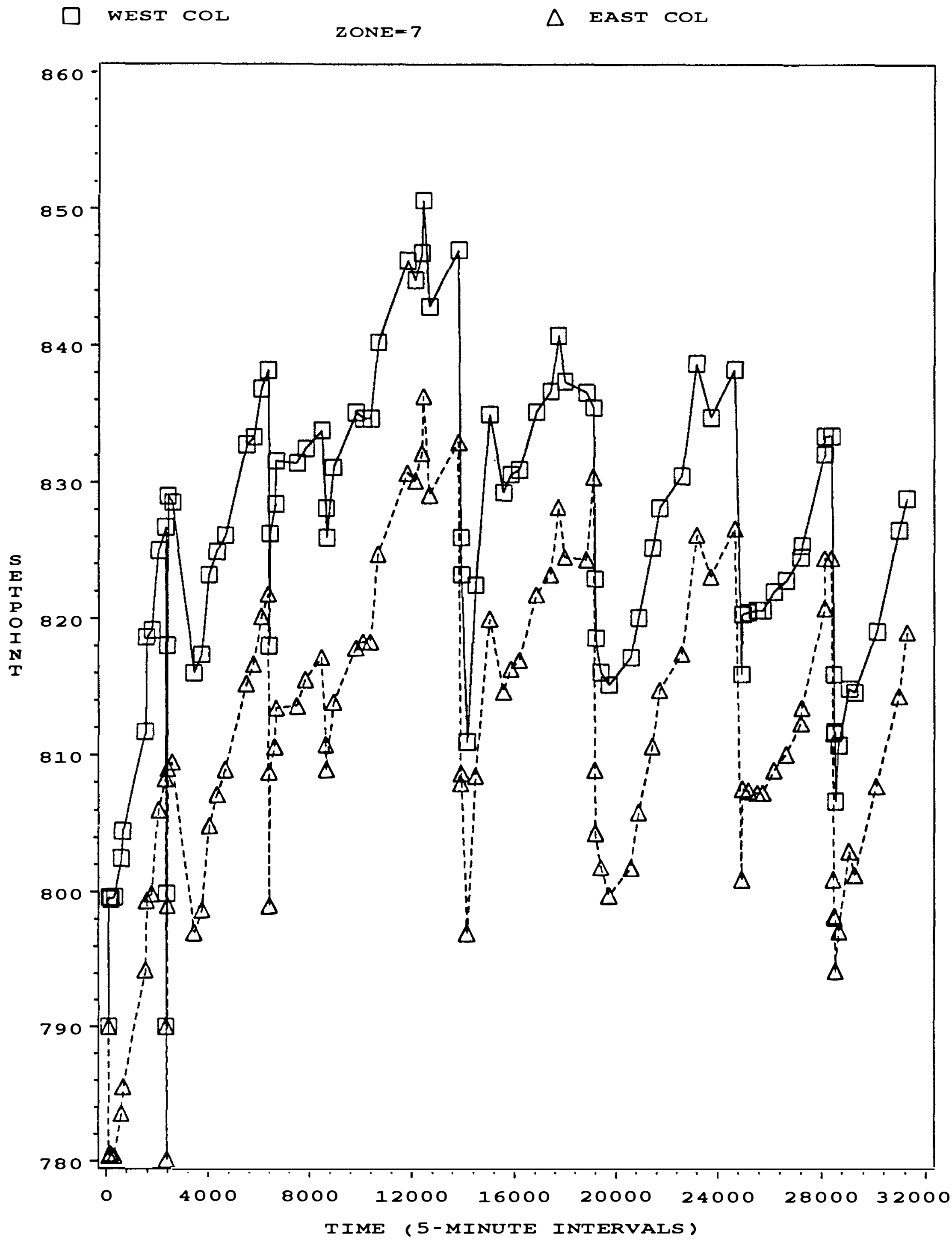

Figure C-6. Variation of setpoint values with time for zone 7 of the west and east columns of OC-3.

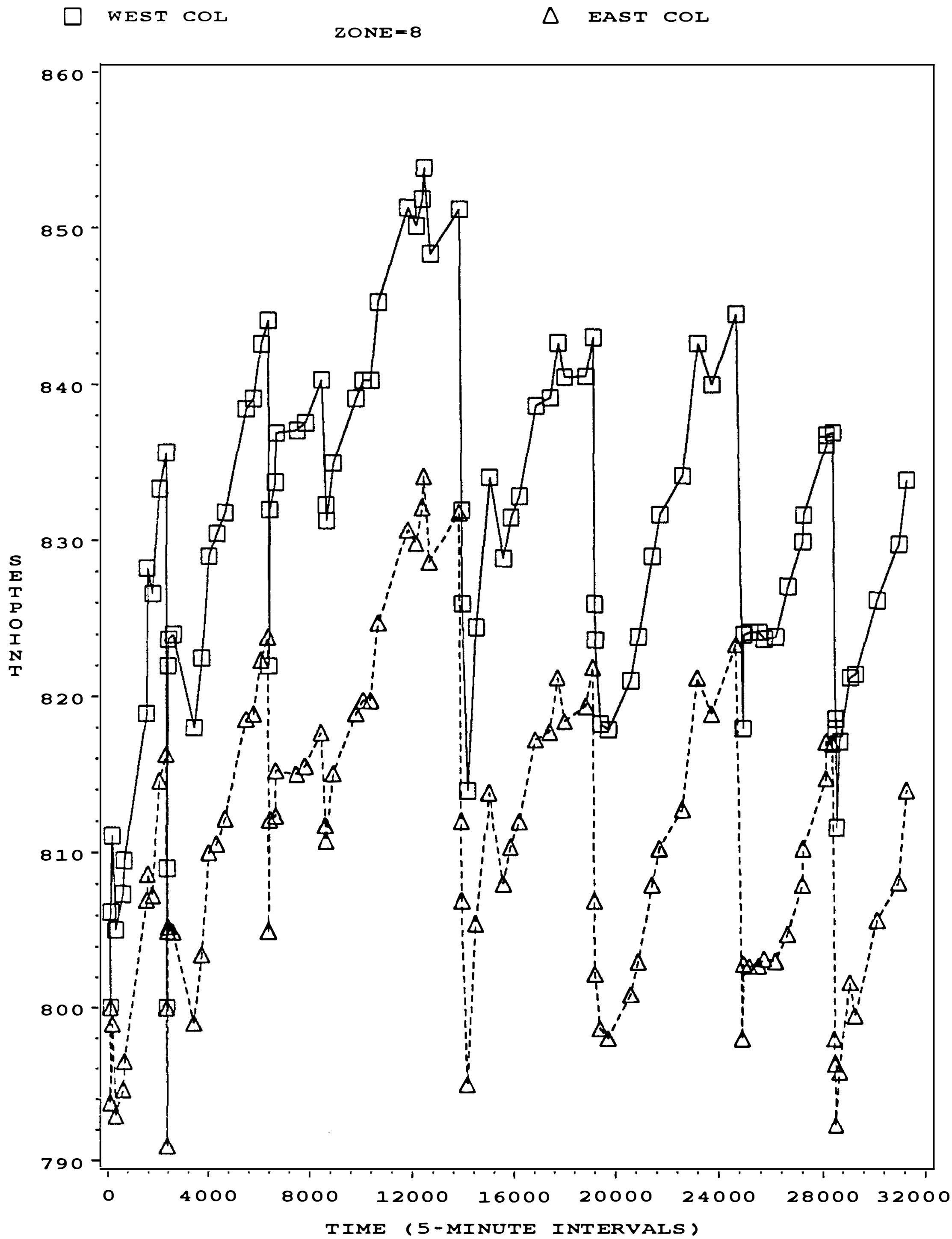

Figure C-7. Variation of setpoint values with time for zone 8 of the west and east columns of OC-3.

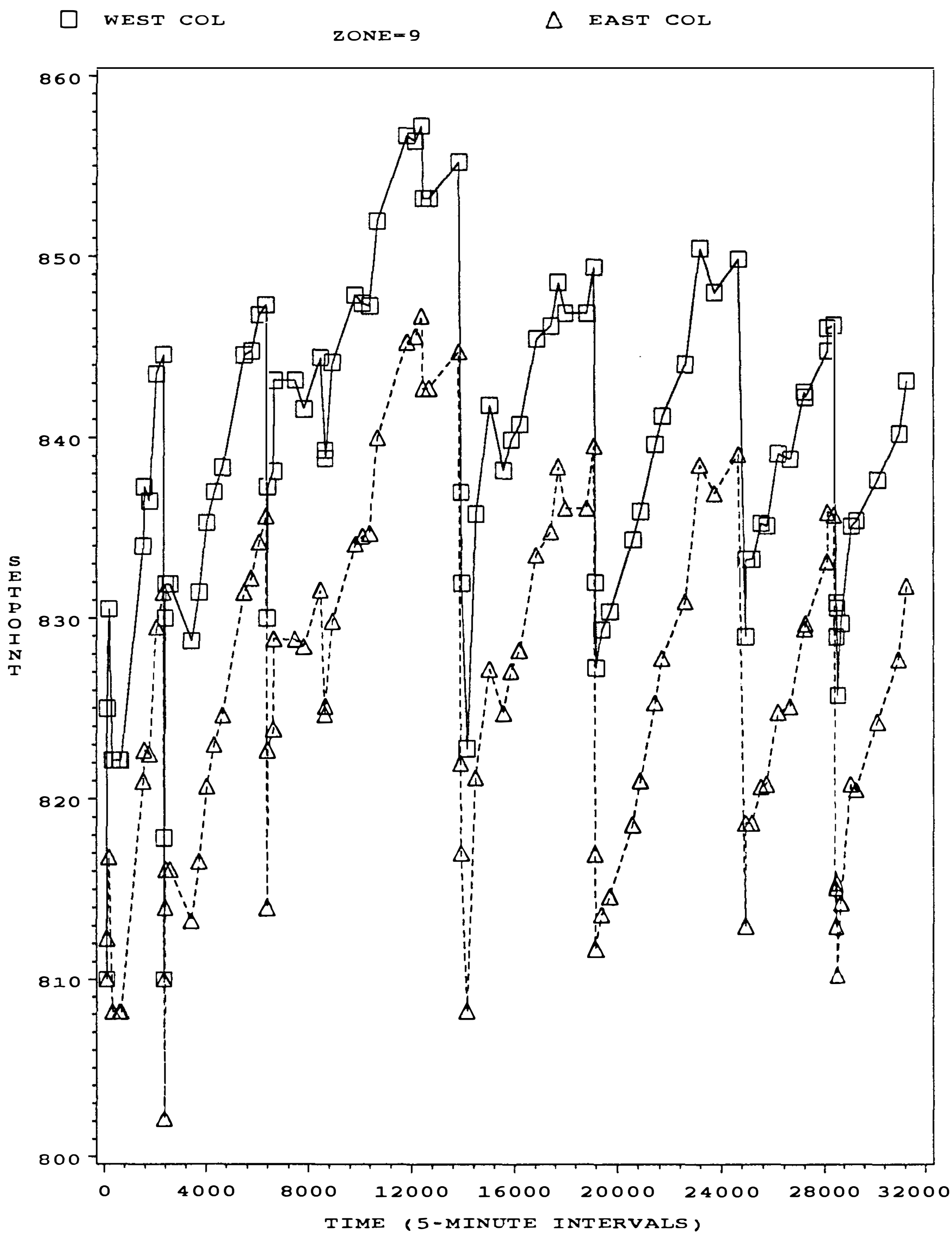

Figure C-8. Variation of setpoint values with time for zone 9 of the west and east columns of OC-3.

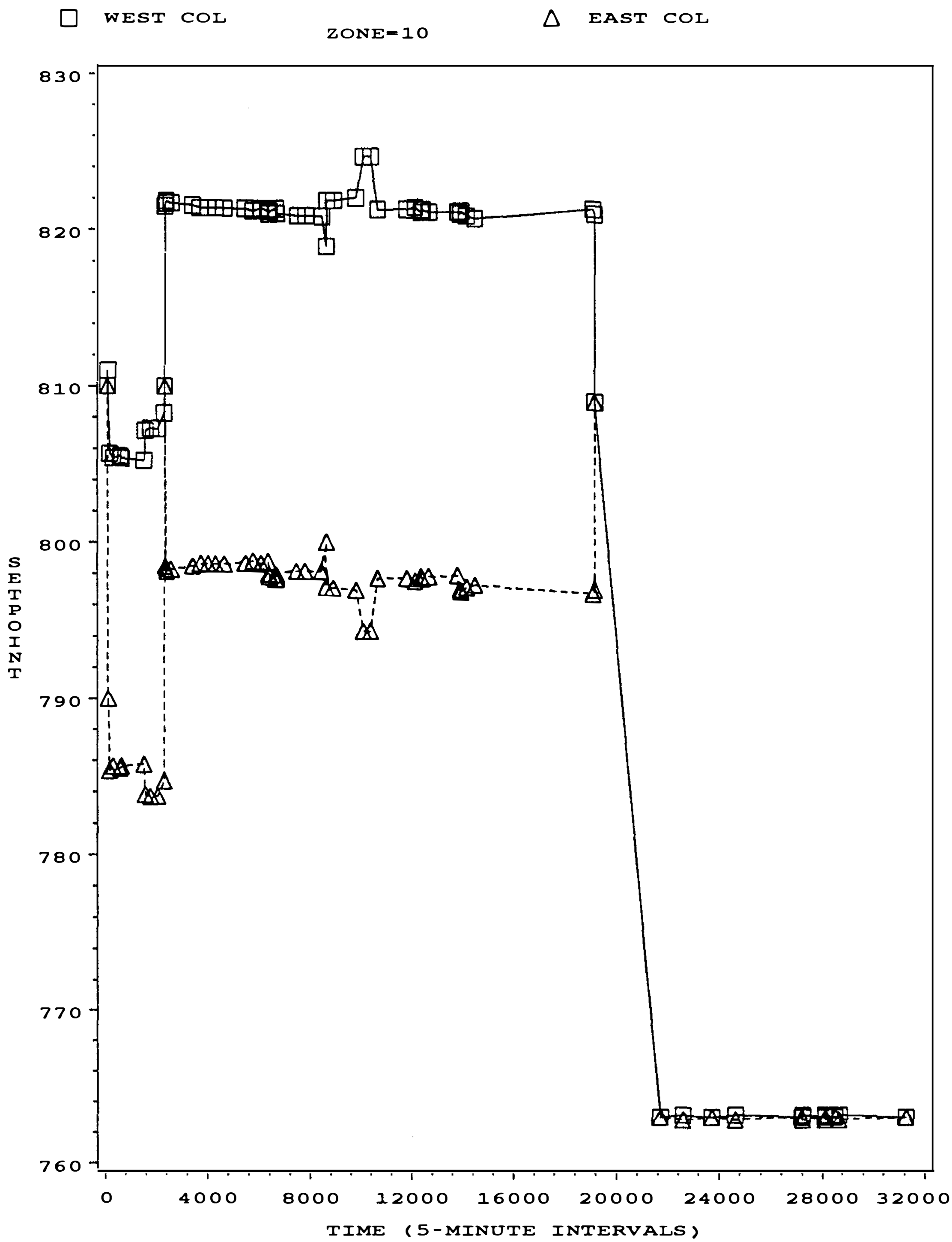

Figure C-9. Variation of setpoint values with time for zone 10 of the west and east columns of OC-3.

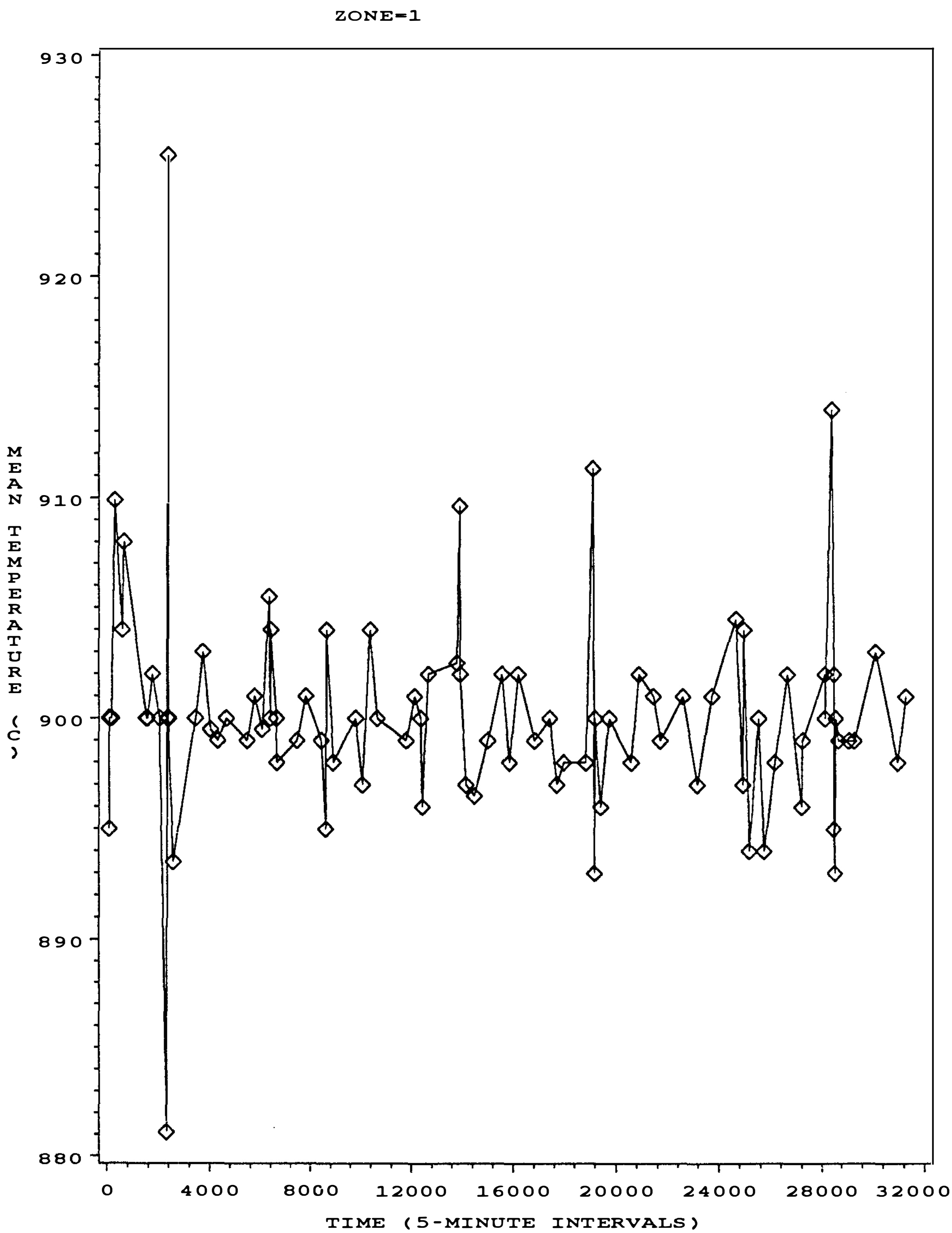

Figure C-10. Variation of the mean temperature (at z-trace time) for zone 1 of the specimen columns of OC-3.

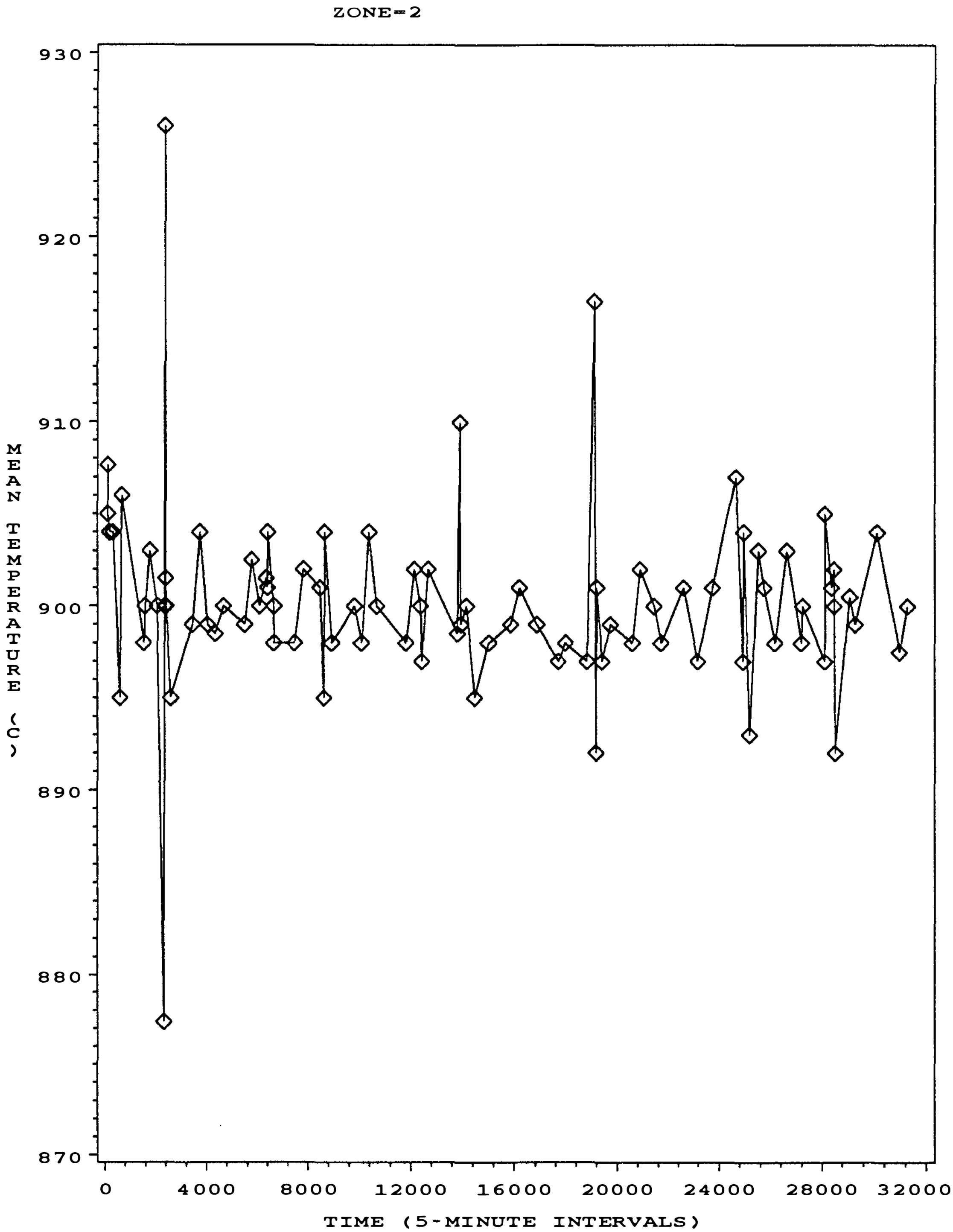

Figure C-11. Variation of the mean temperature (at z-trace time) for zone 2 of the specimen columns of OC-3.

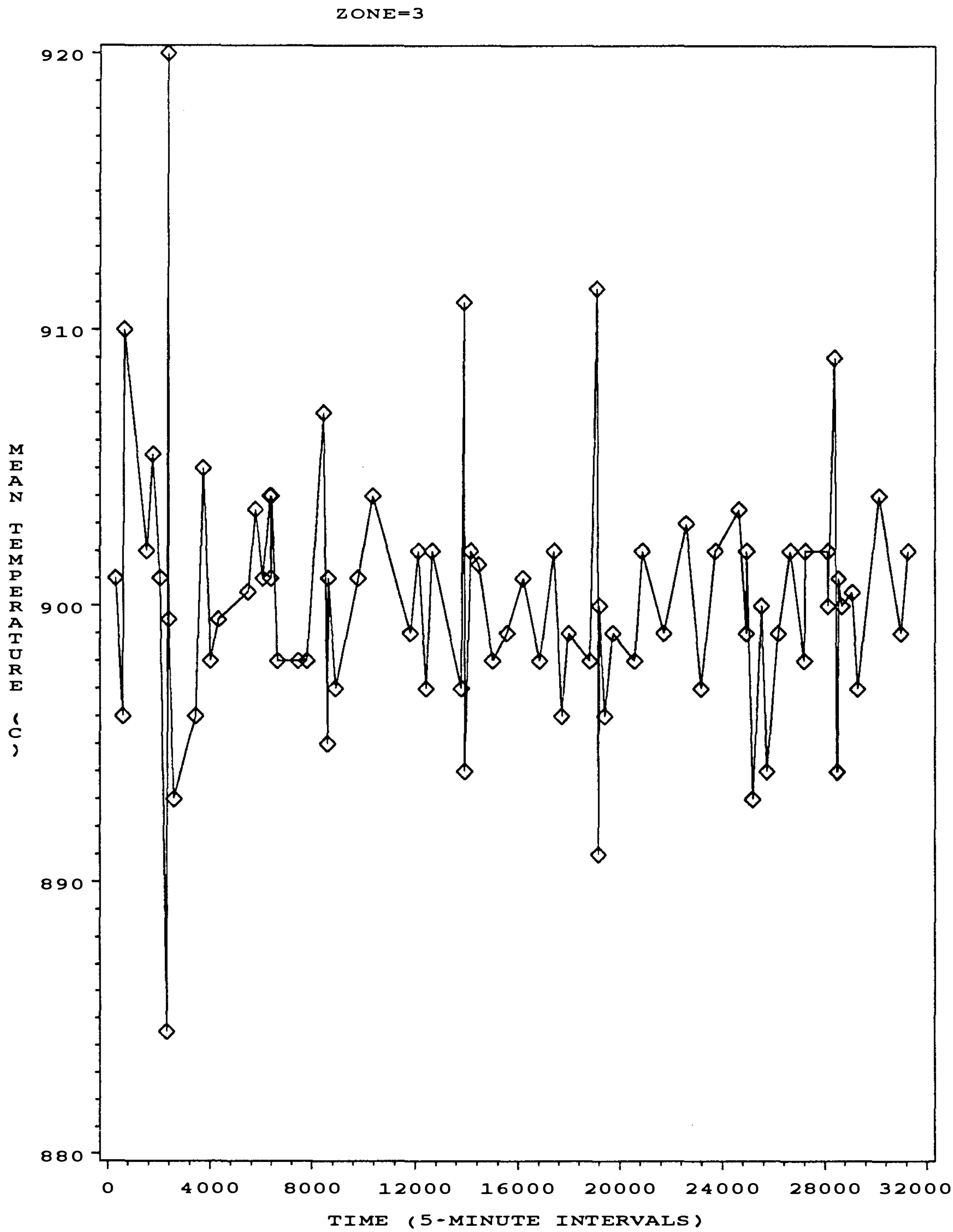

Figure C-12. Variation of the mean temperature (at z-trace time) for zone 3 of the specimen columns of OC-3.

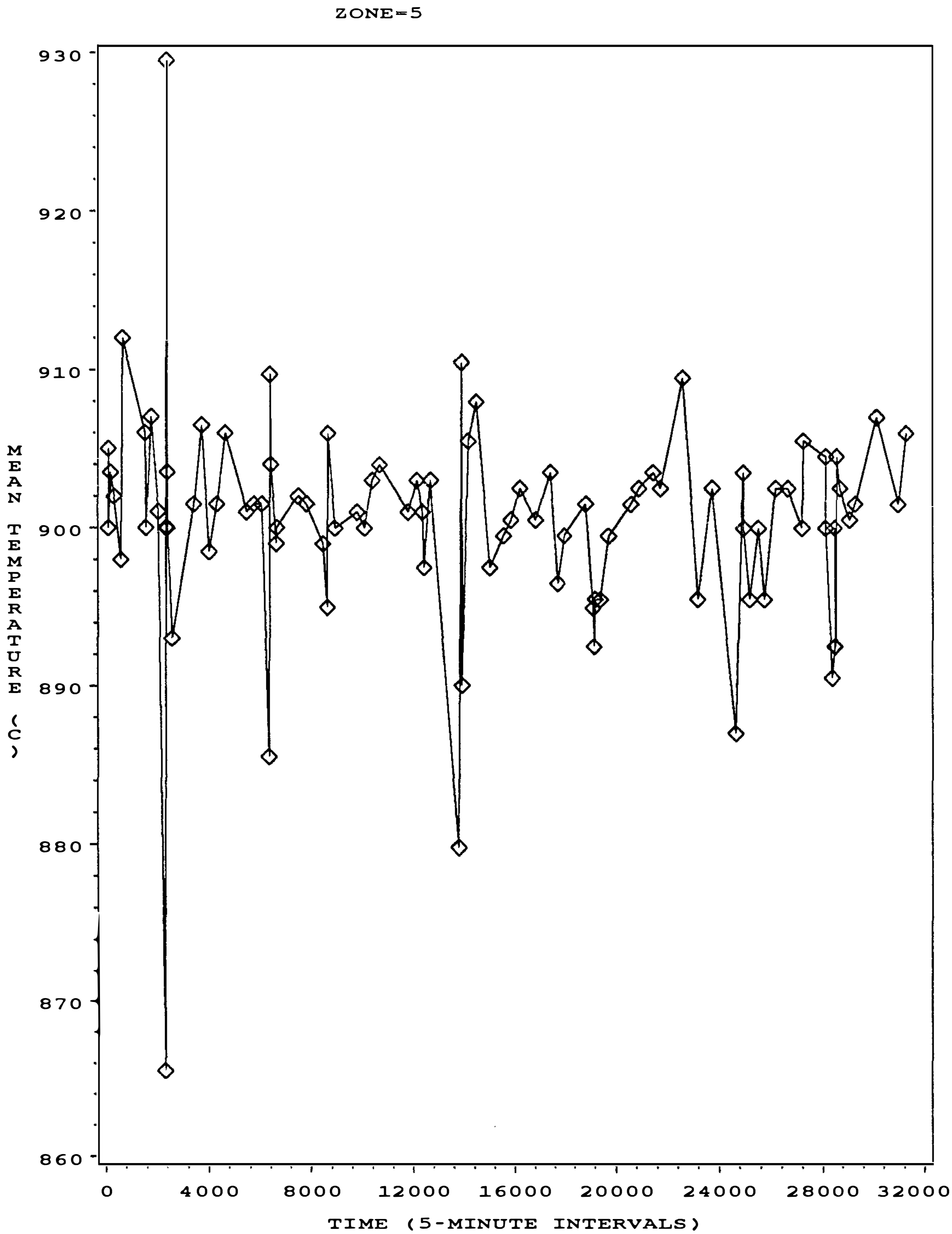

Figure C-13. Variation of the mean temperature (at z-trace time) for zone 5 of the specimen columns of OC-3.

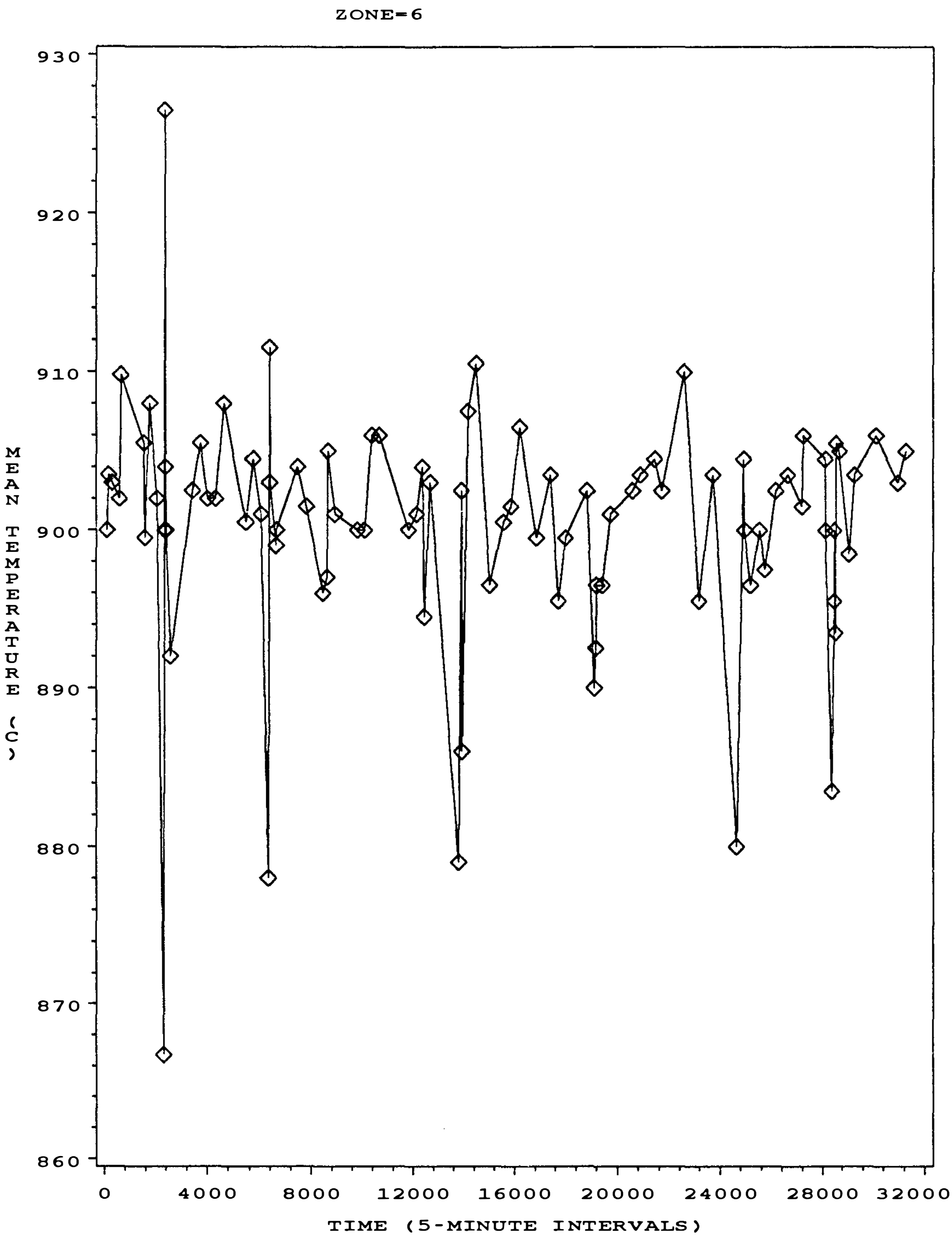

Figure C-14. Variation of the mean temperature (at z-trace time) for zone 6 of the specimen columns of OC-3.

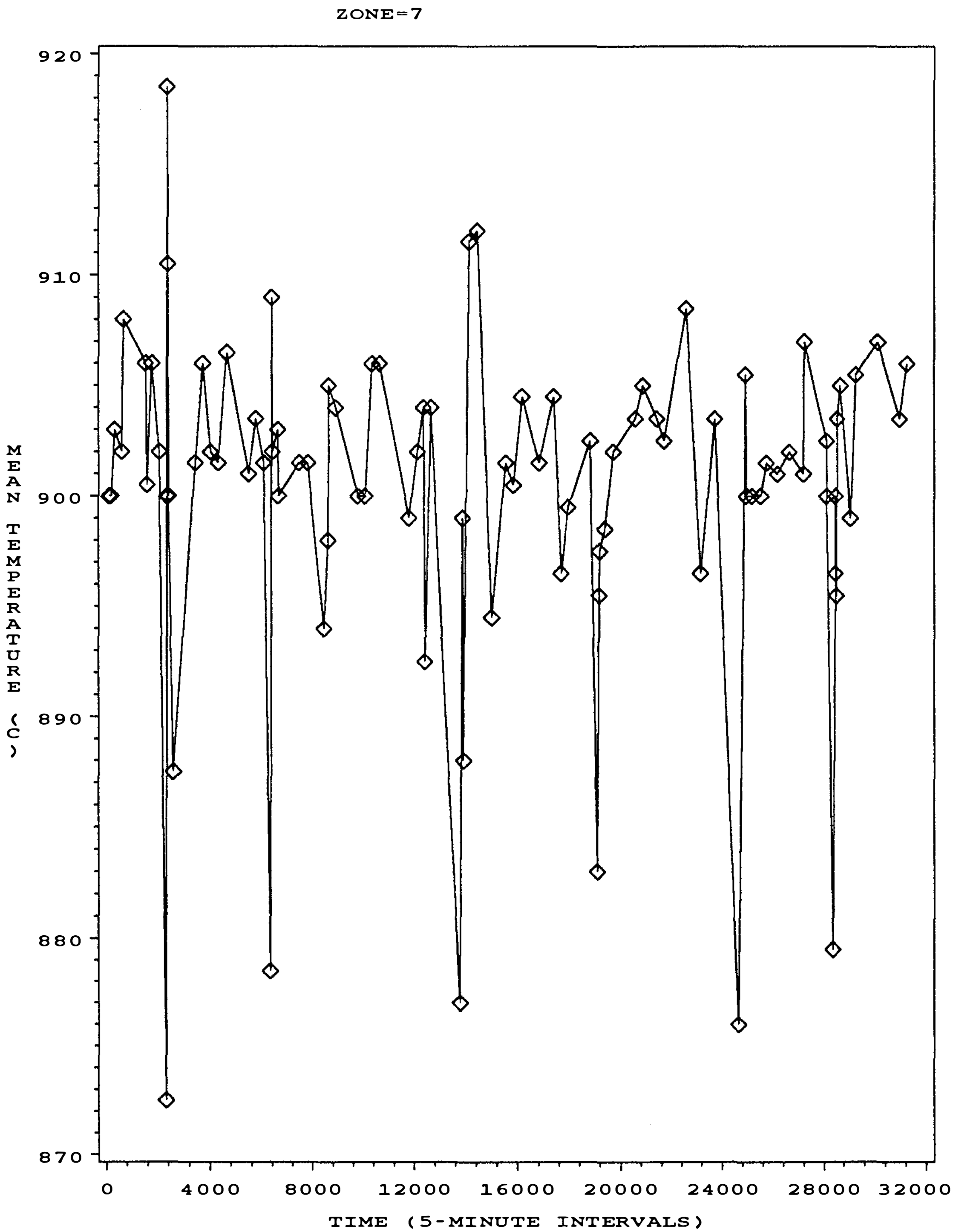

Figure C-15. Variation of the mean temperature (at z-trace time) for zone 7 of the specimen columns of OC-3.

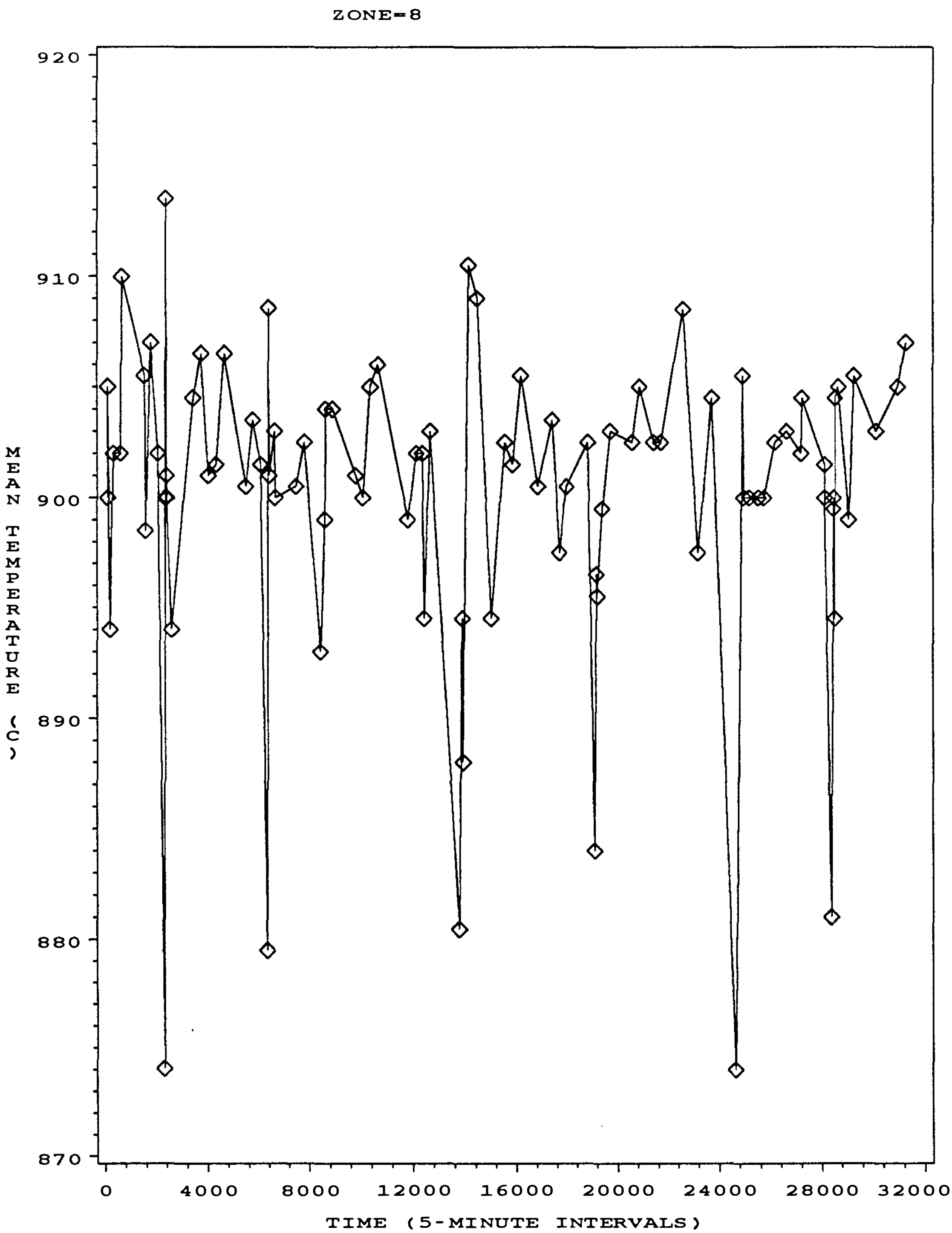

Figure C-16. Variation of the mean temperature (at z-trace time) for zone 8 of the specimen columns of OC-3.

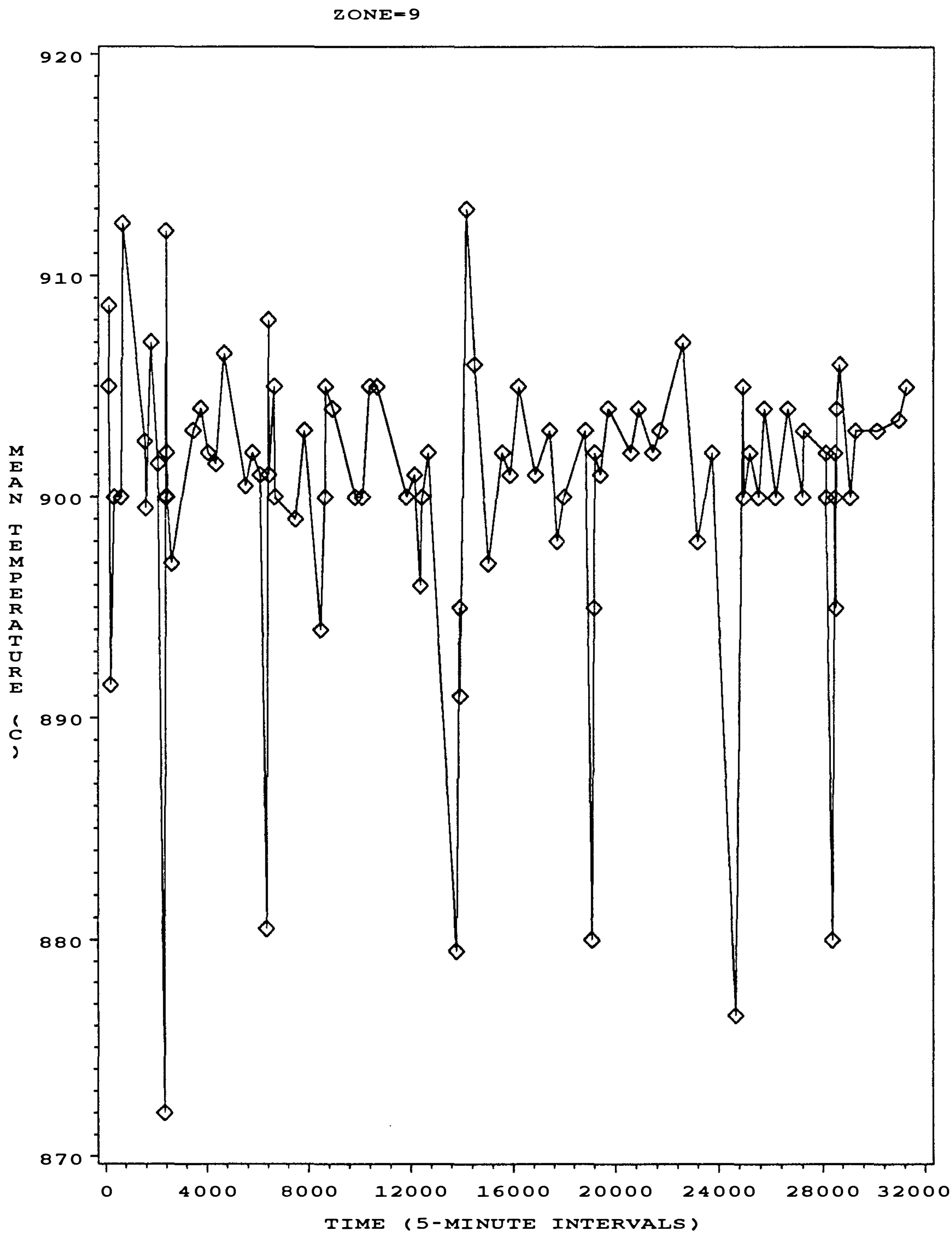

Figure C-17. Variation of the mean temperature (at z-trace time) for zone 9 of the specimen columns of OC-3.

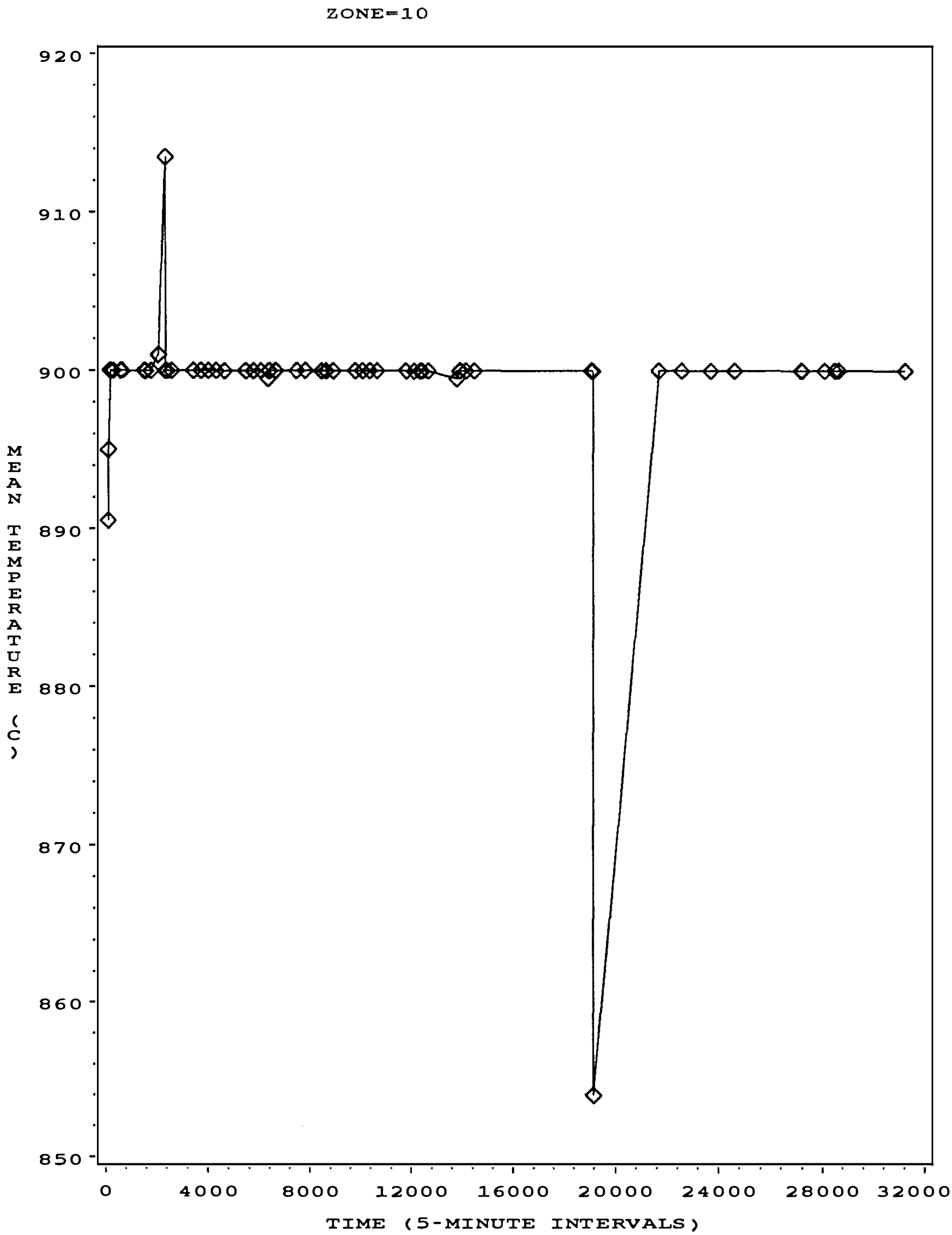

Figure C-18. Variation of the mean temperature (at z-trace time) for zone 10 of the specimen columns of OC-3.

APPENDIX D

VARIATION OF SETPOINTS AND MEAN TEMPERATURE WITH TIME FOR OC-4

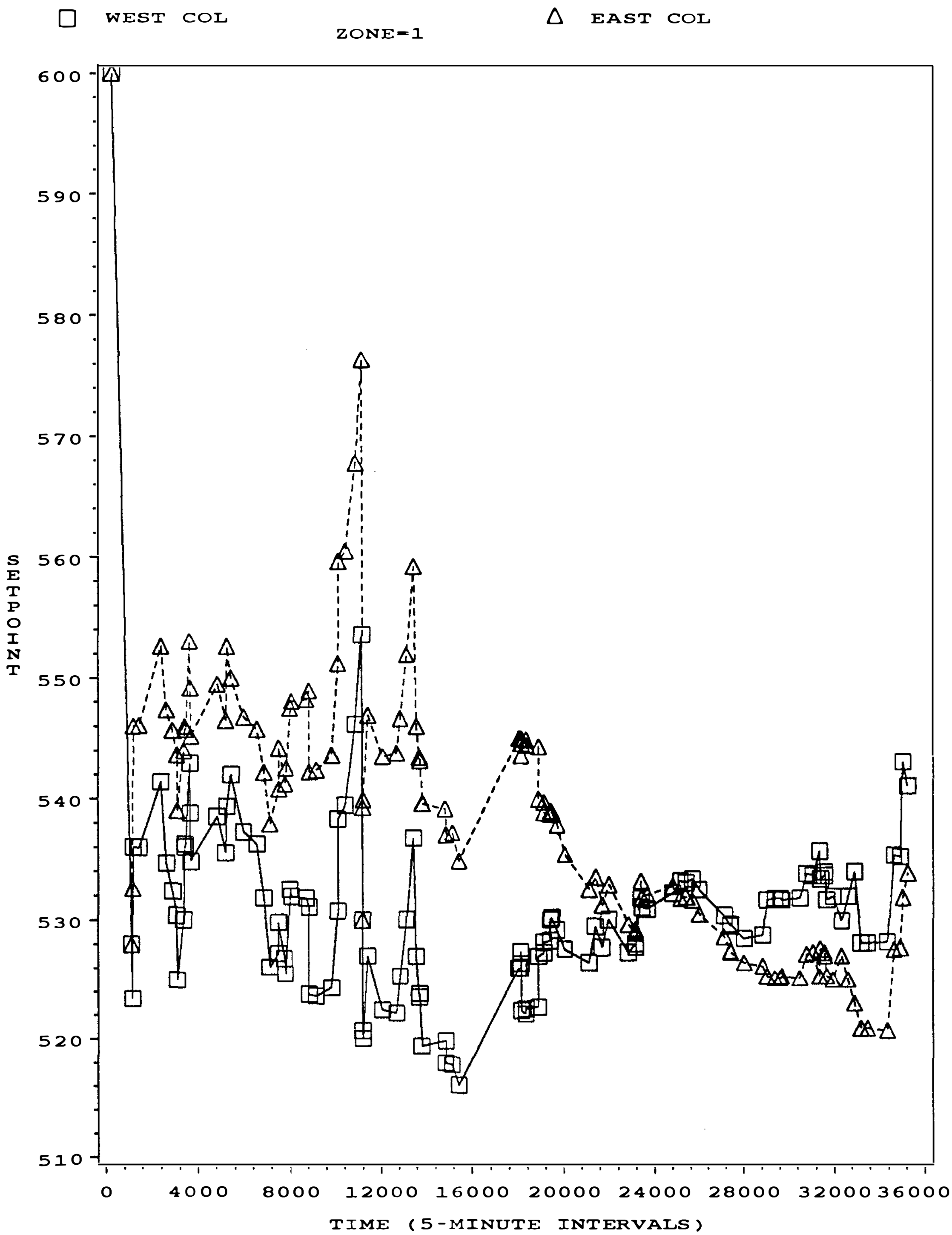

Figure D-1. Variation of setpoint values with time for zone 1 of the west and east columns of OC-4.

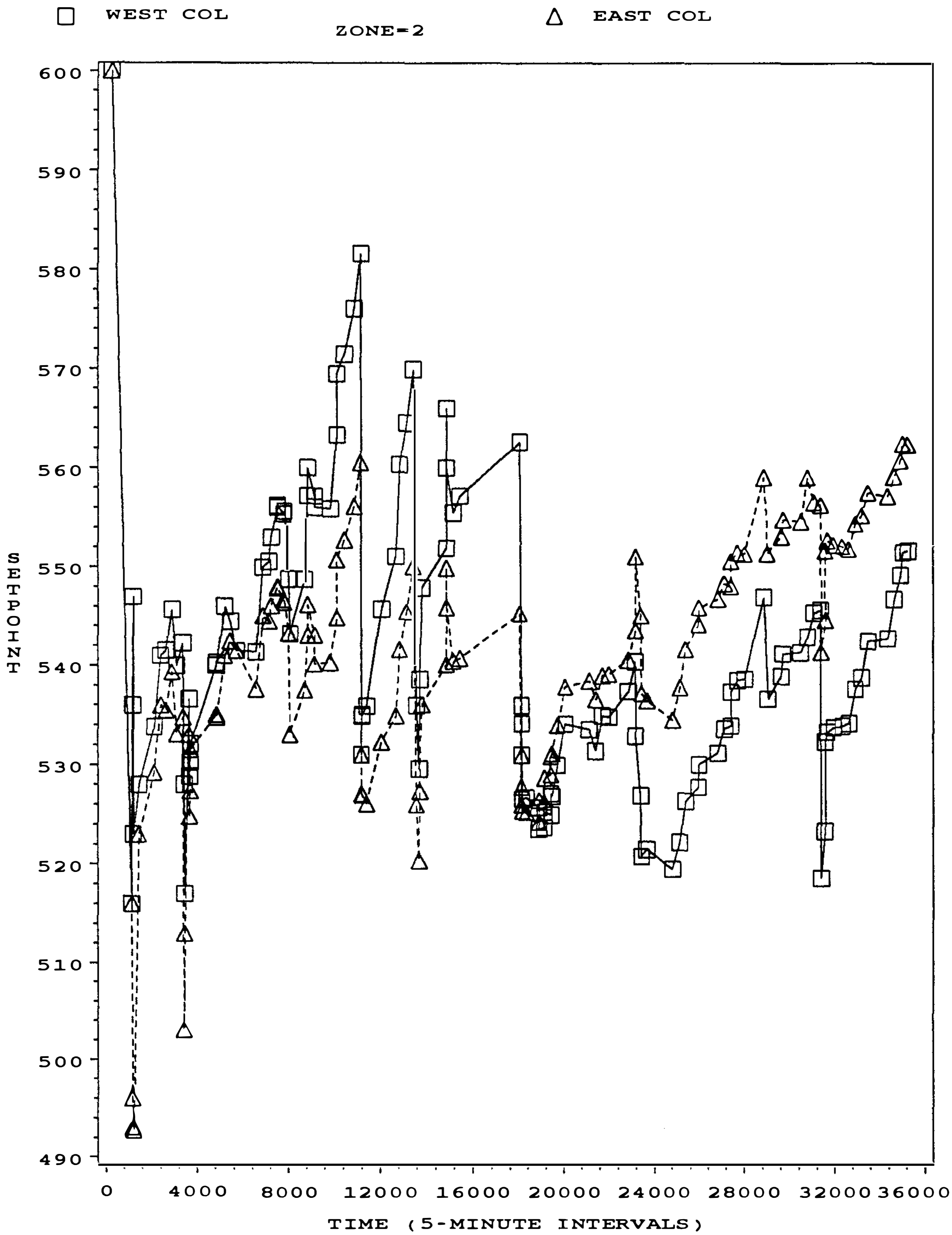

Figure D-2. Variation of setpoint values with time for zone 2 of the west and east columns of OC-4.

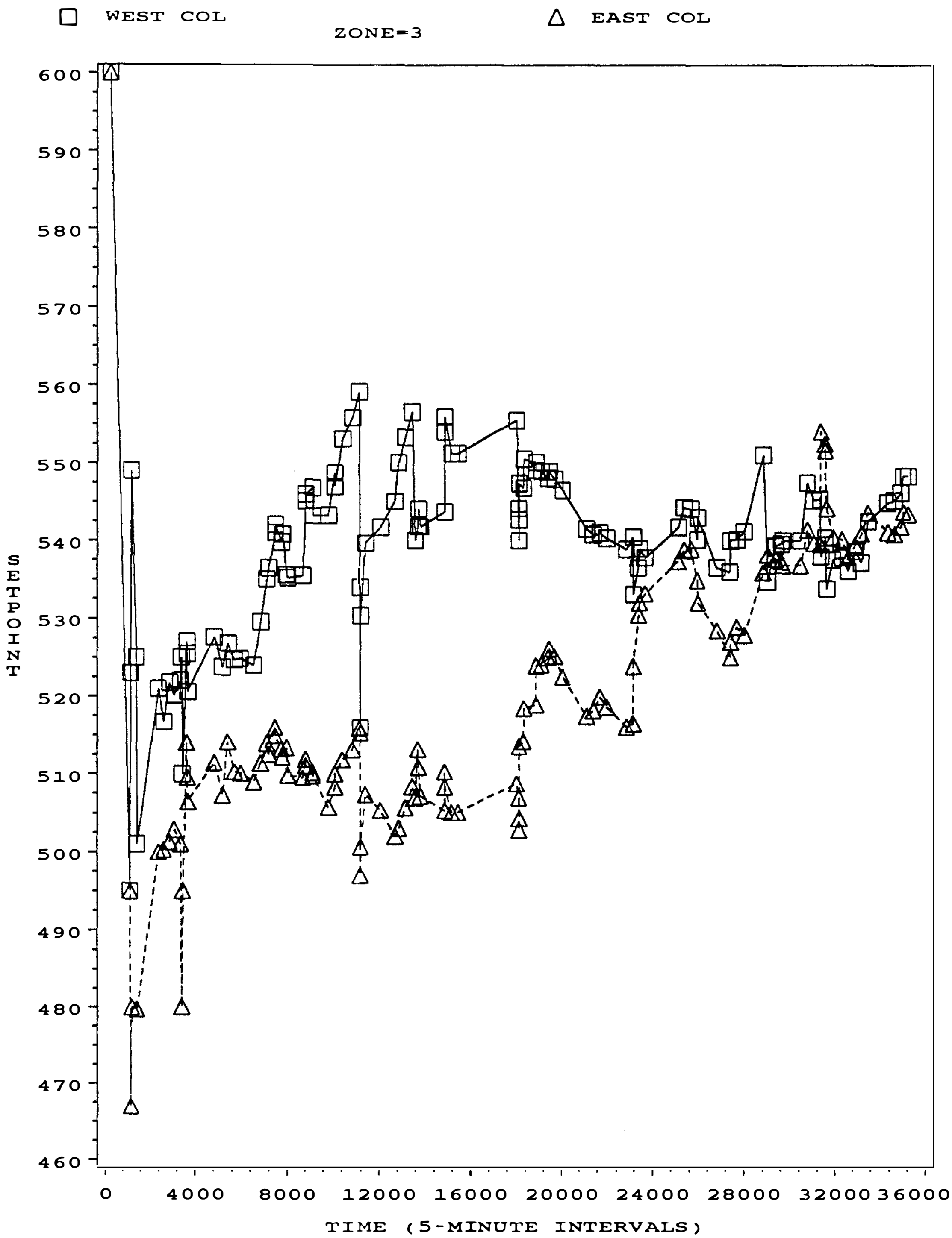

Figure D-3. Variation of setpoint values with time for zone 3 of the west and east columns of OC-4.

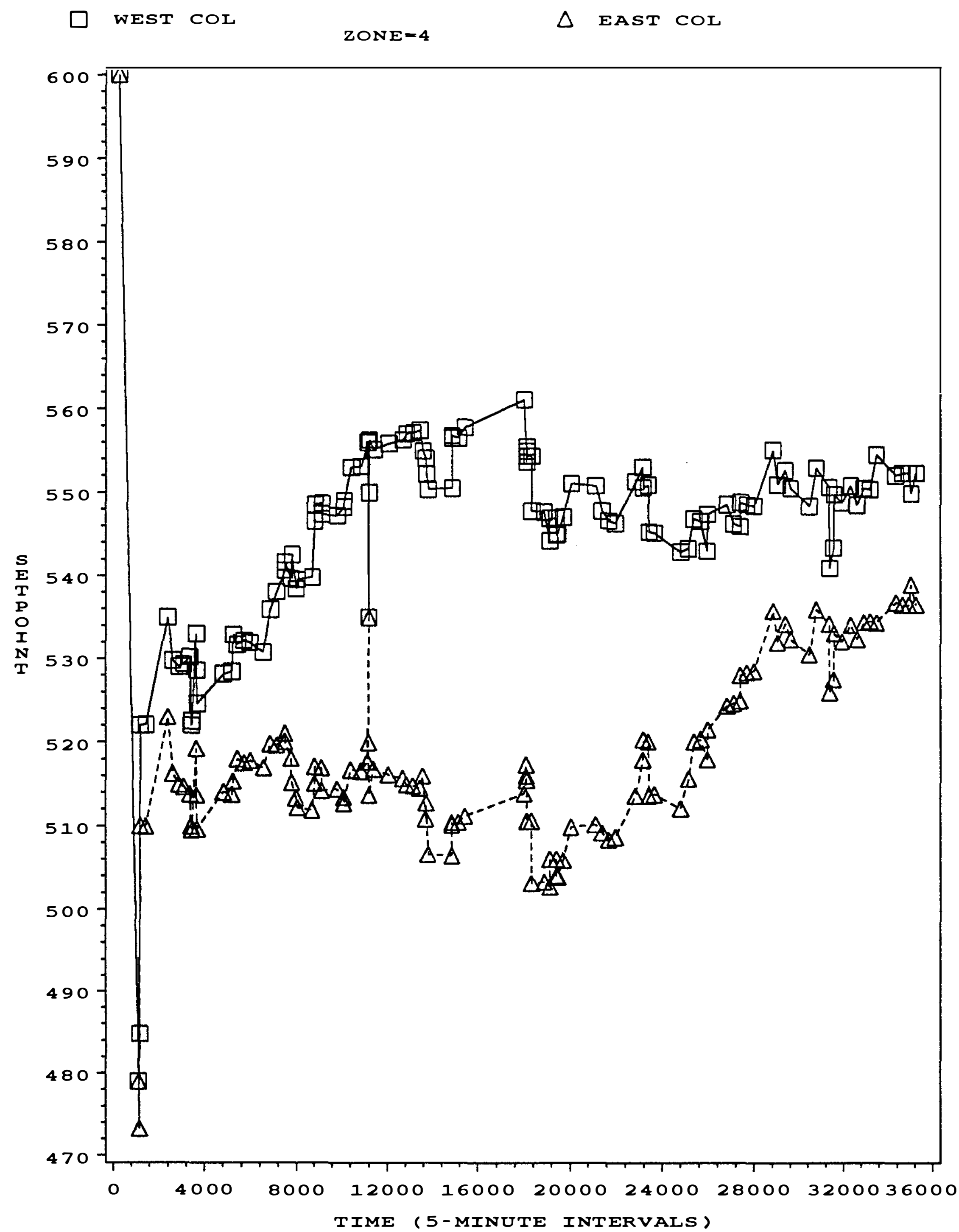

Figure D-4. Variation of setpoint values with time for zone 4 of the west and east columns of OC-4.

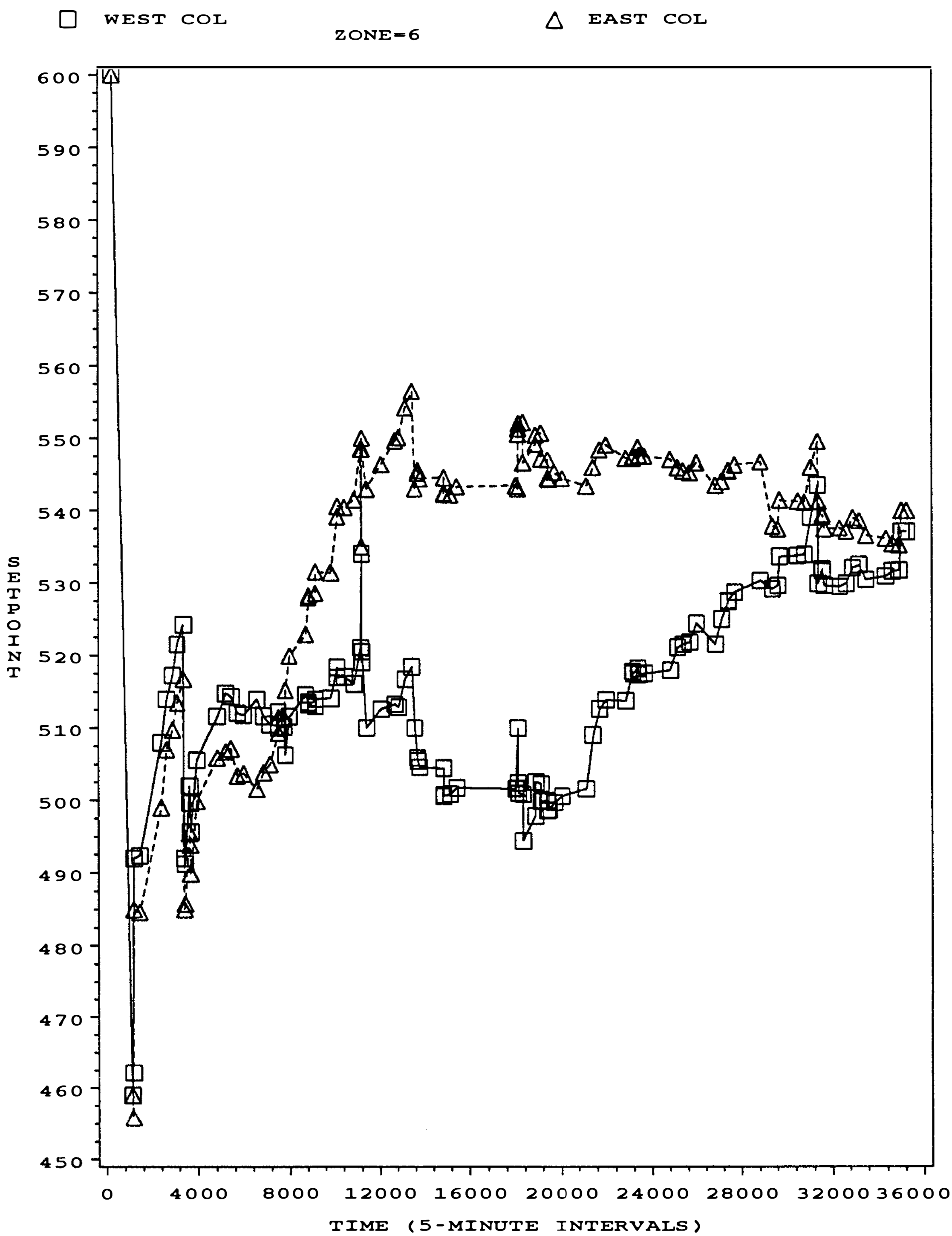

Figure D-5. Variation of setpoint values with time for zone 6 of the west and east columns of OC-4.

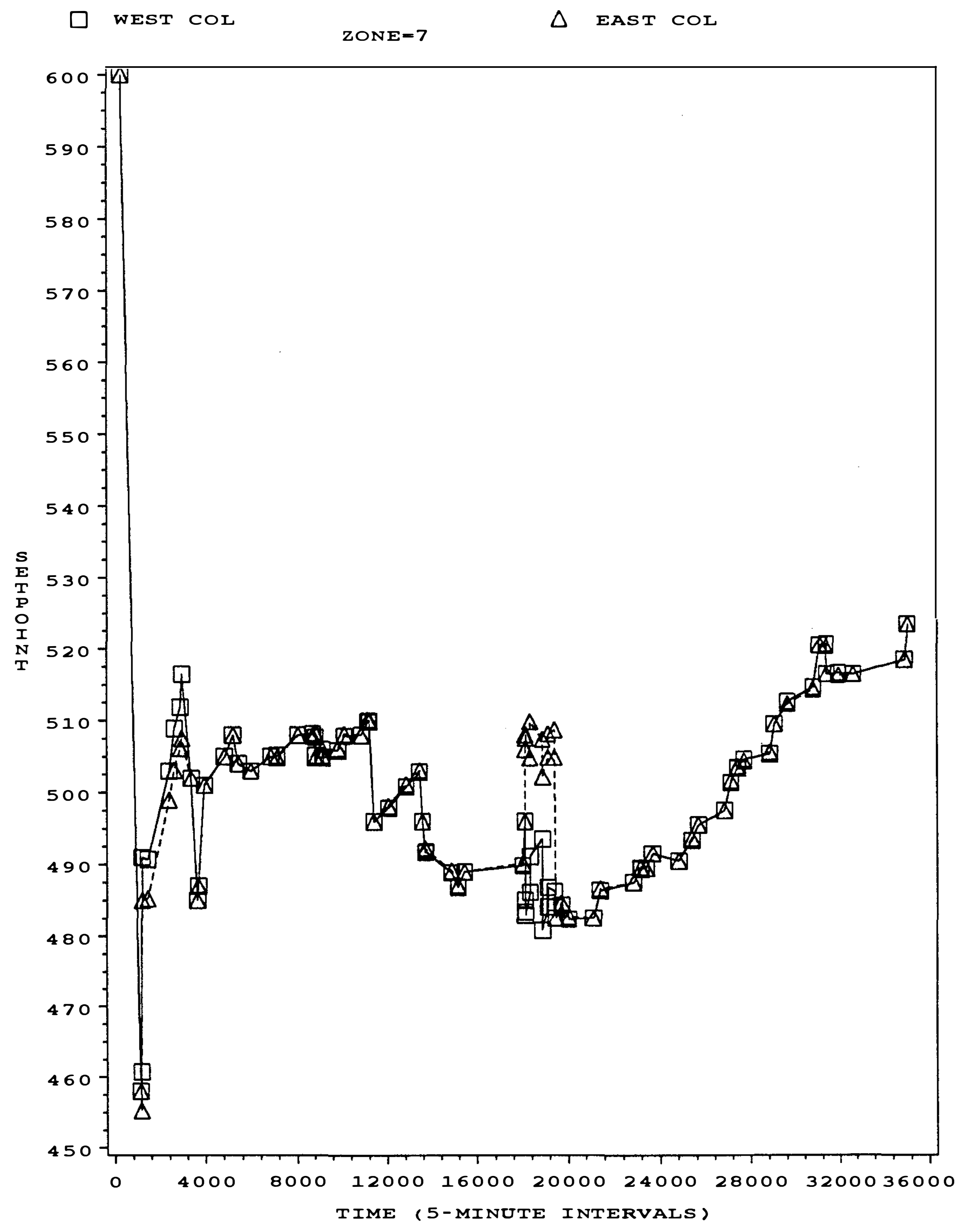

Figure D-6. Variation of setpoint values with time for zone 7 of the west and east columns of OC-4.

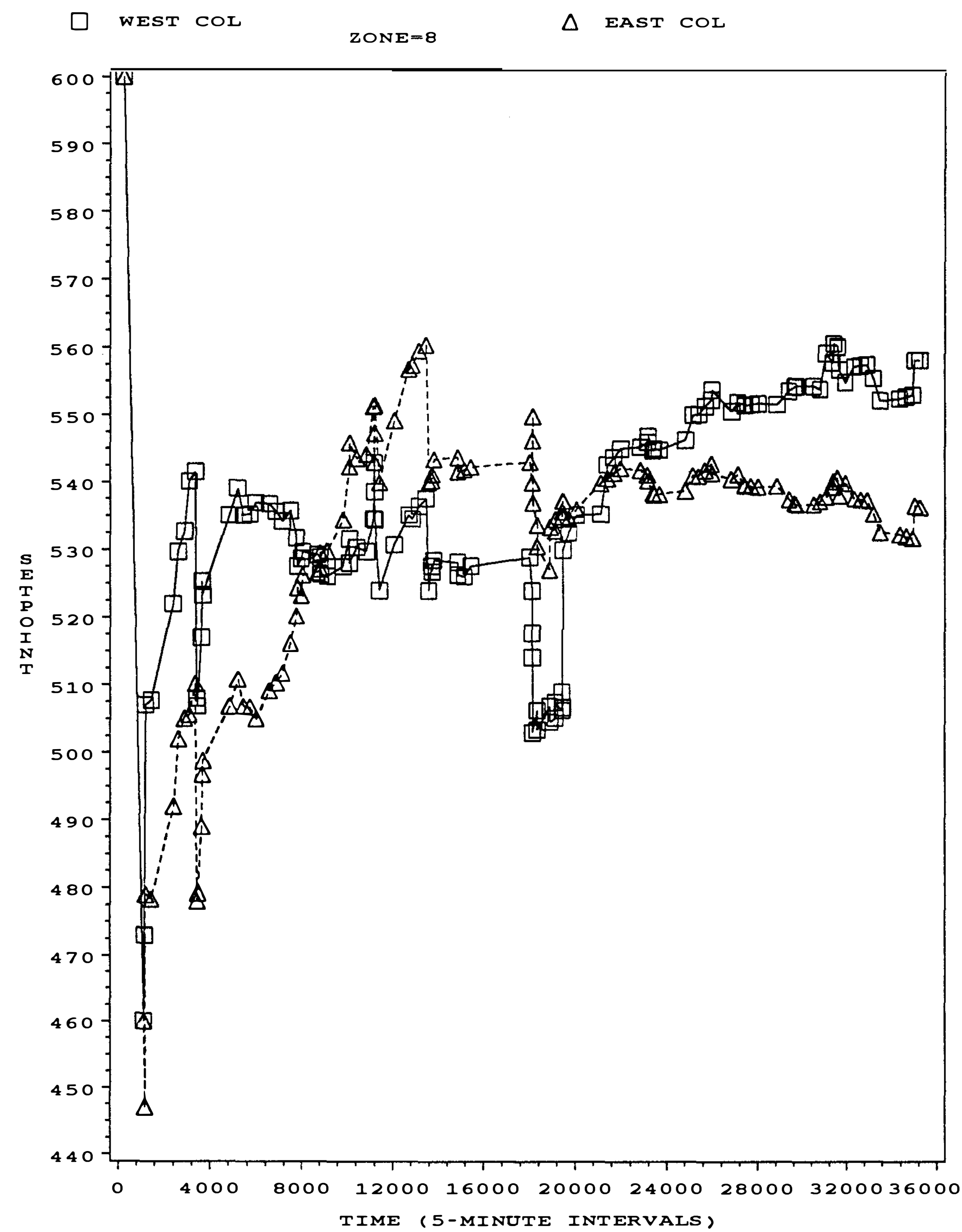

Figure D-7. Variation of setpoint values with time for zone 8 of the west and east columns of OC-4.

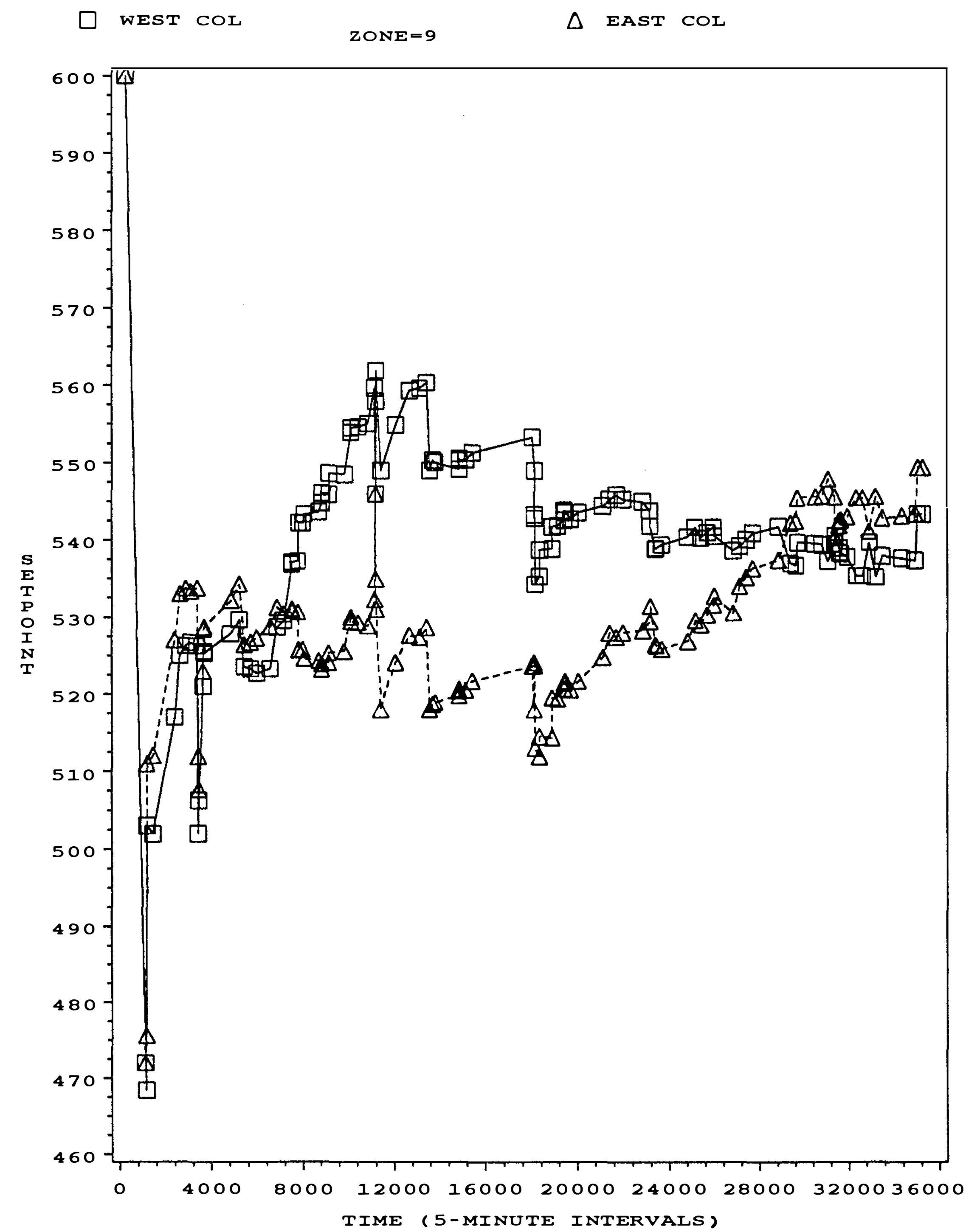

Figure D-8. Variation of setpoint values with time for zone 9 of the west and east columns of OC-4.

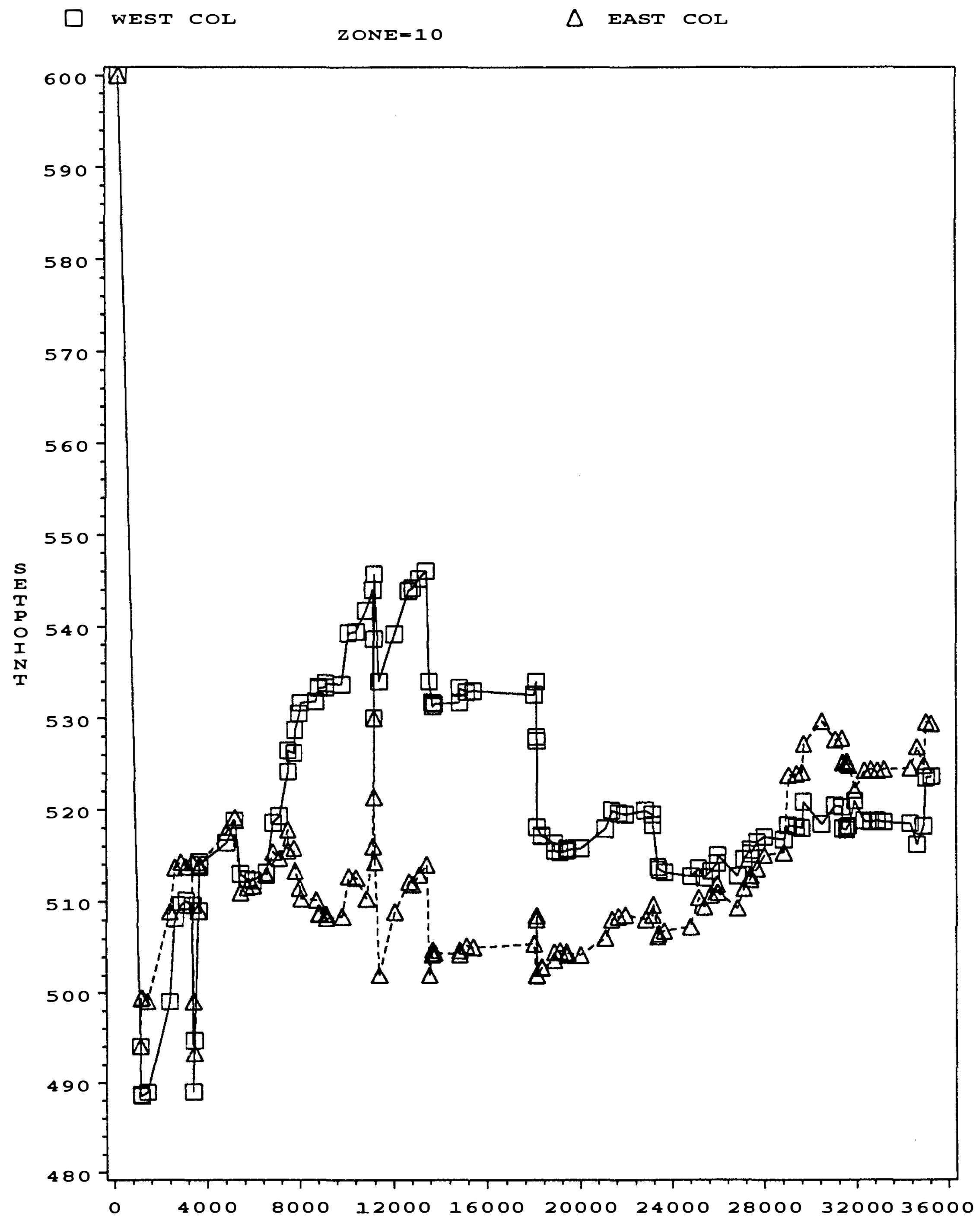

Figure D-9. Variation of setpoint values with time for zone 10 of the west and east columns of OC-4.

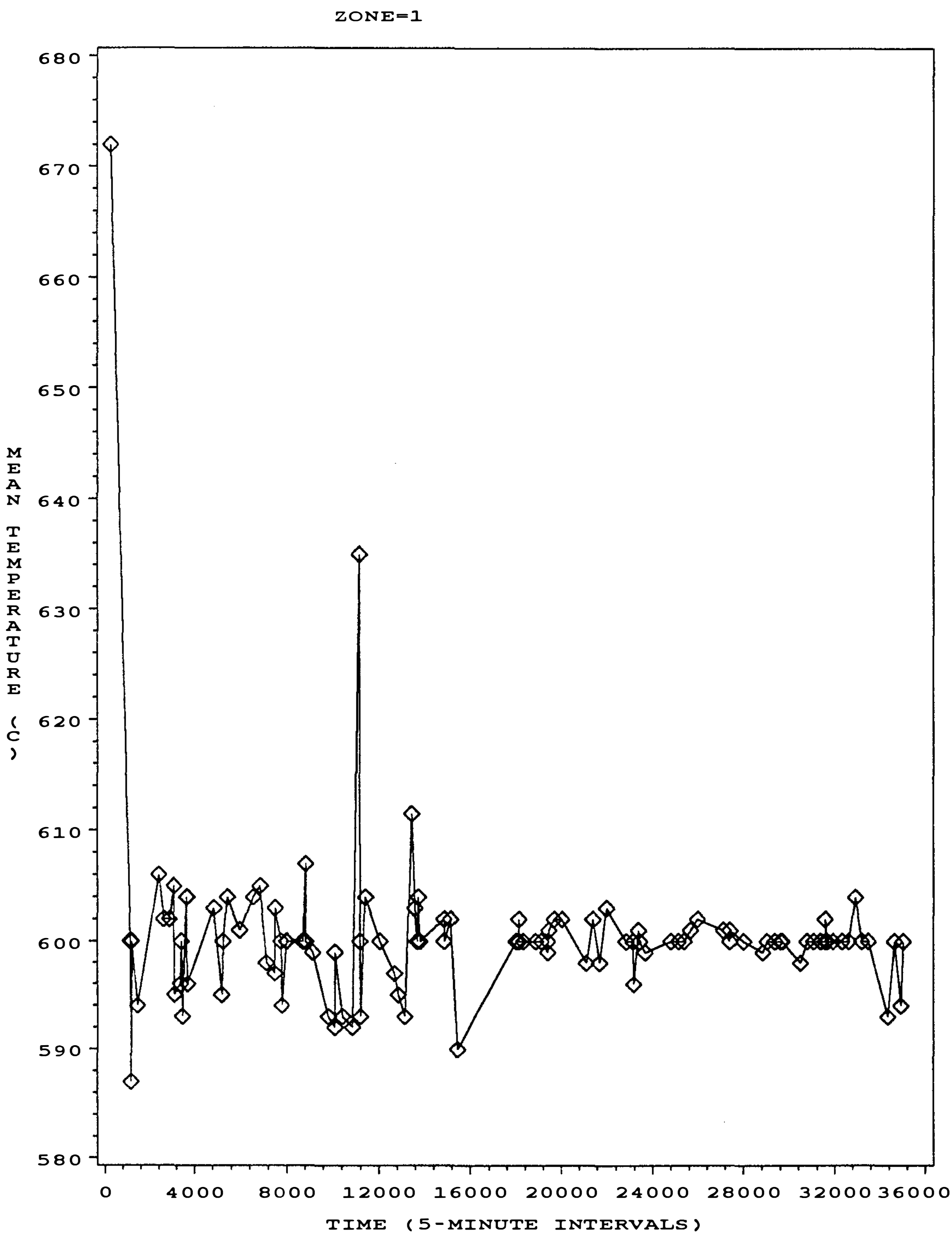

Figure D-10. Variation of the mean temperature (at z-trace time) for zone 1 of the specimen columns of OC-4.

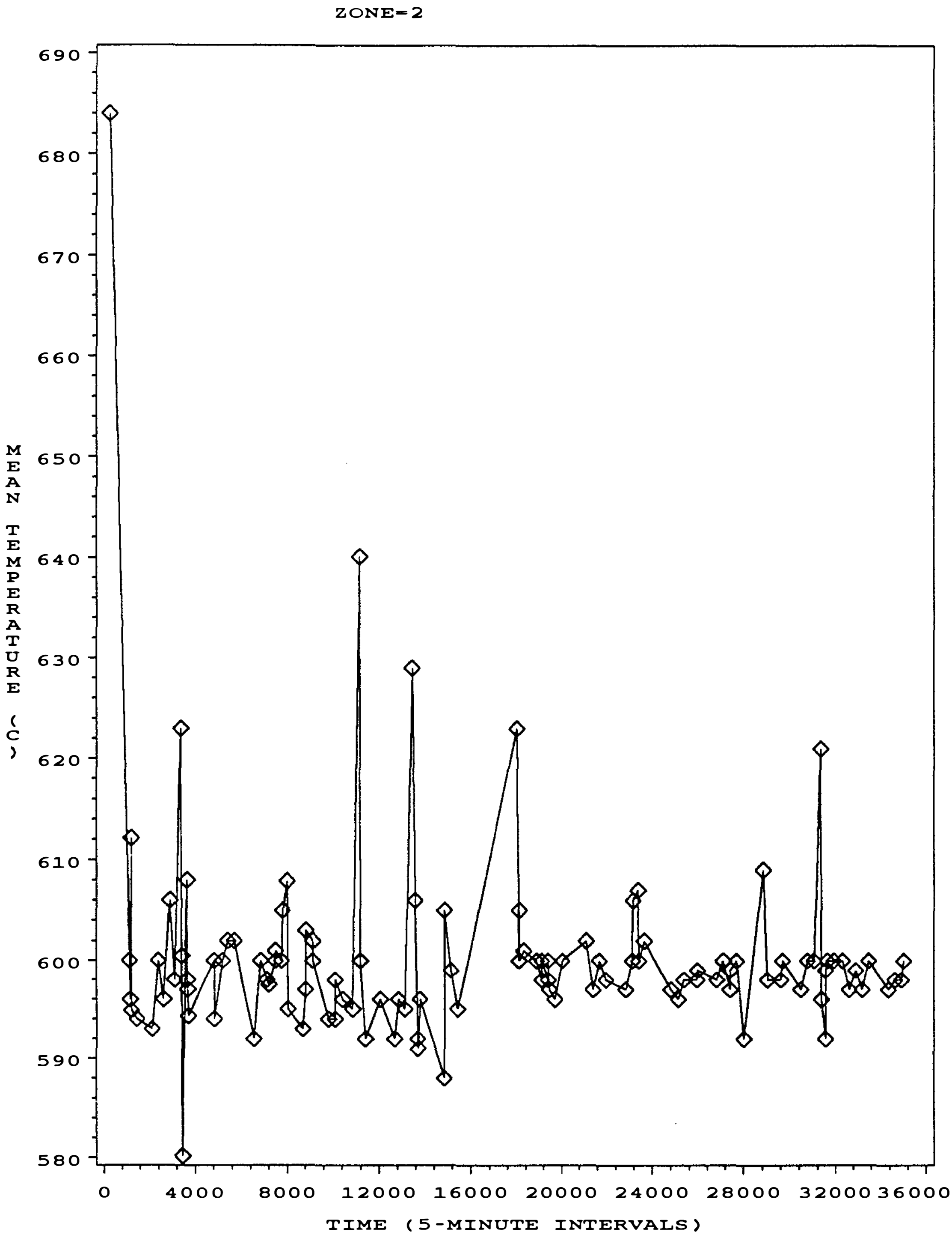

Figure D-11. Variation of the mean temperature (at z-trace time) for zone 2 of the specimen columns of OC-4.

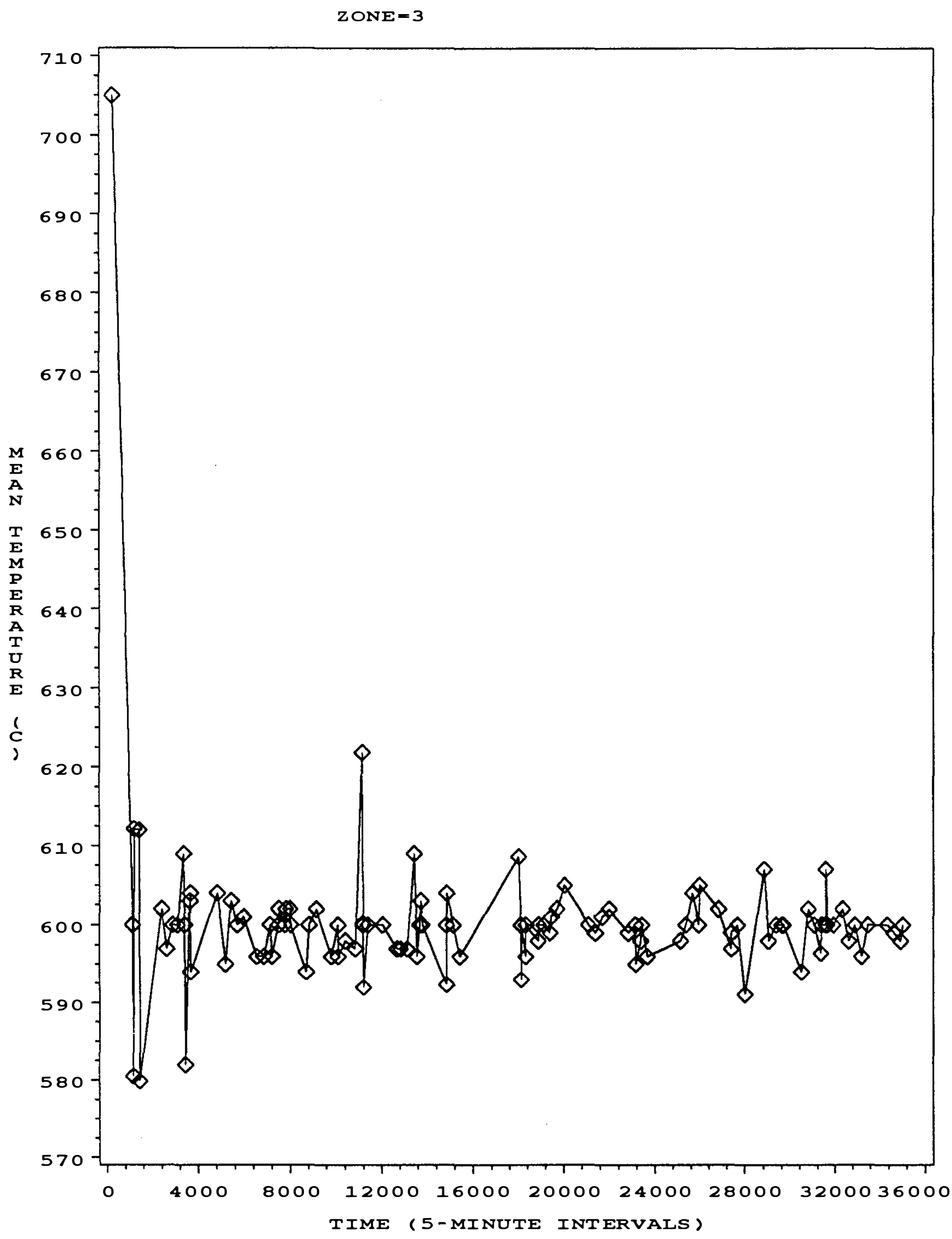

Figure D-12. Variation of the mean temperature (at z-trace time) for zone 3 of the specimen columns of OC-4.

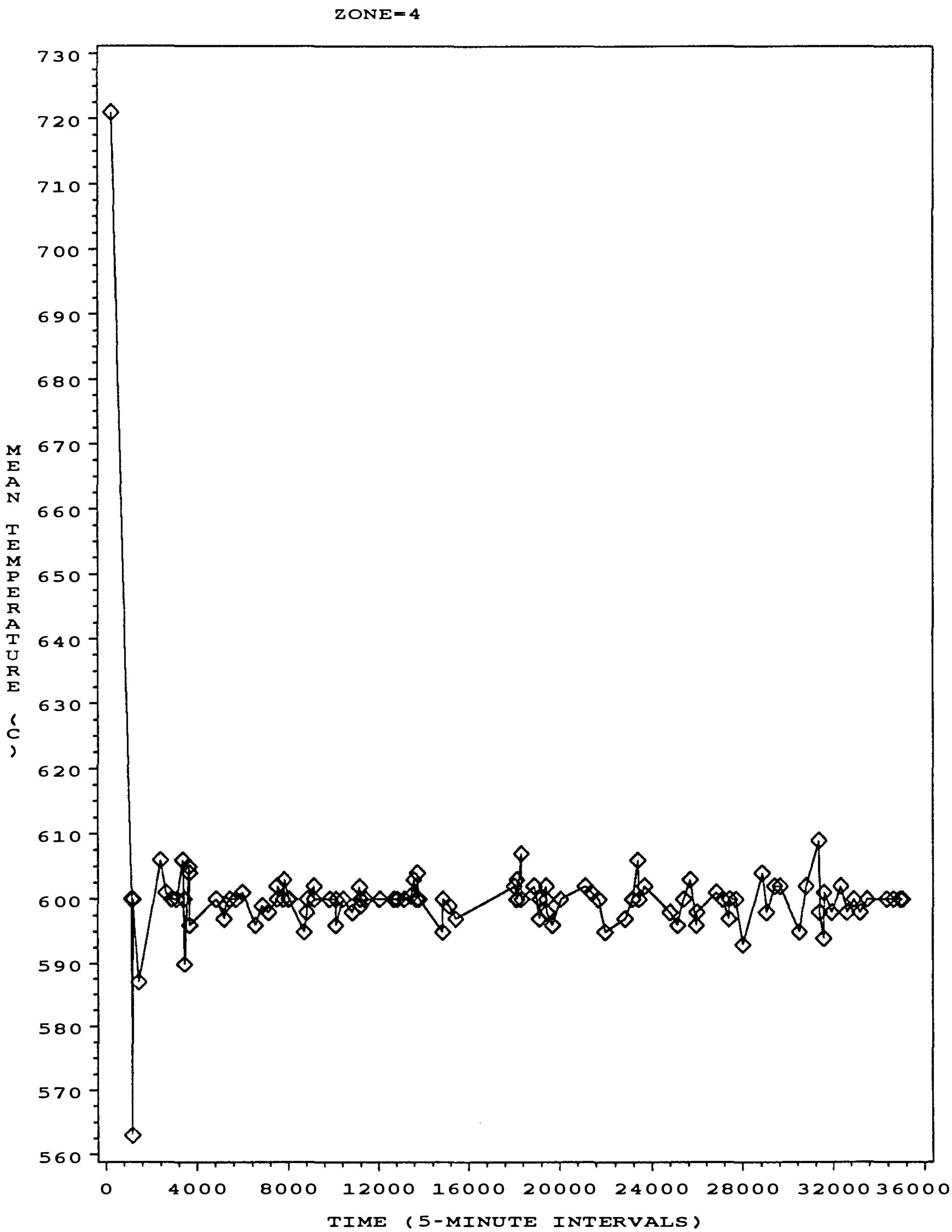

Figure D-13. Variation of the mean temperature (at z-trace time) for zone 4 of the specimen columns of OC-4.

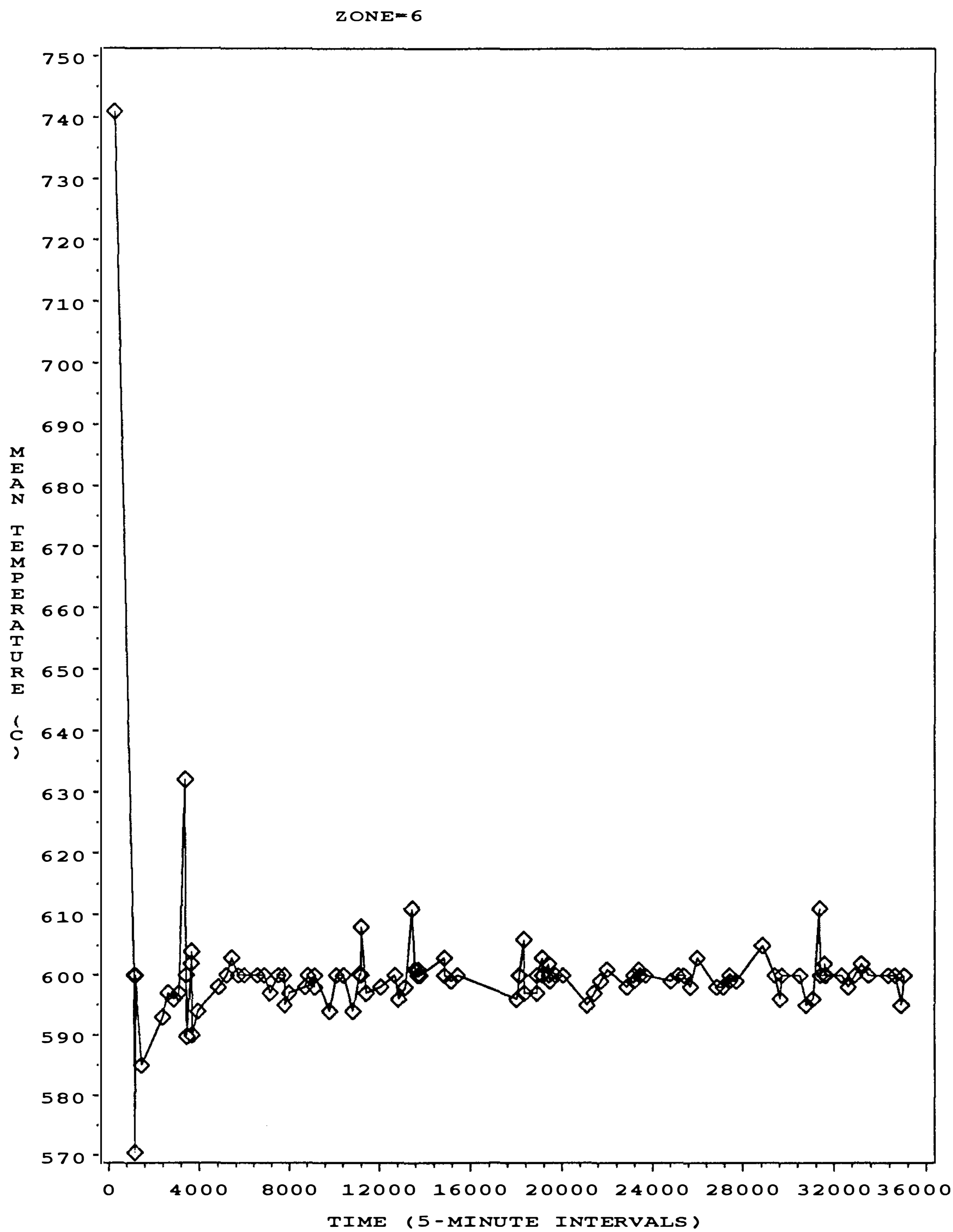

Figure D-14. Variation of the mean temperature (at z-trace time) for zone 6 of the specimen columns of OC-4.

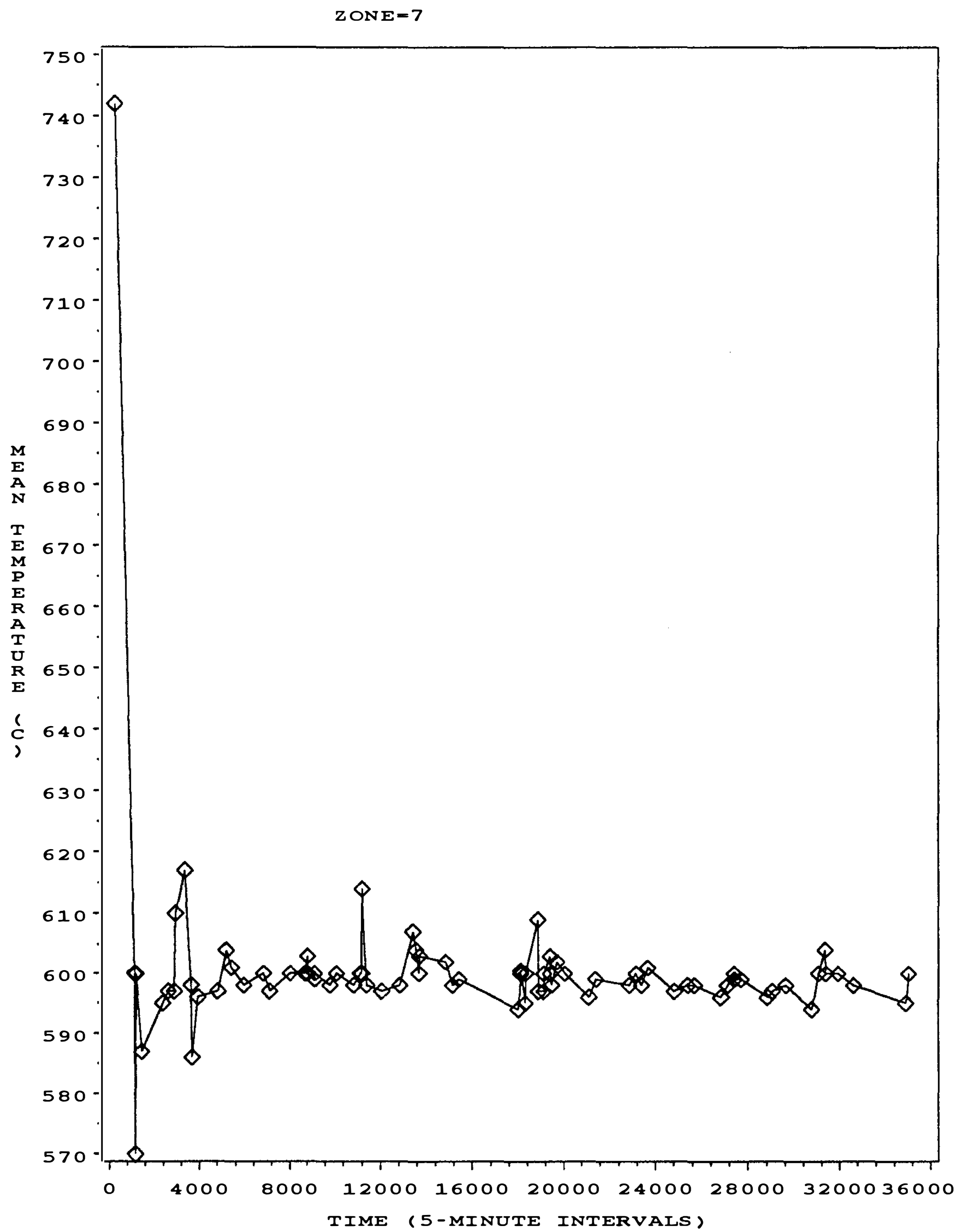

Figure D-15. Variation of the mean temperature (at z-trace time) for zone 7 of the specimen columns of OC-4.

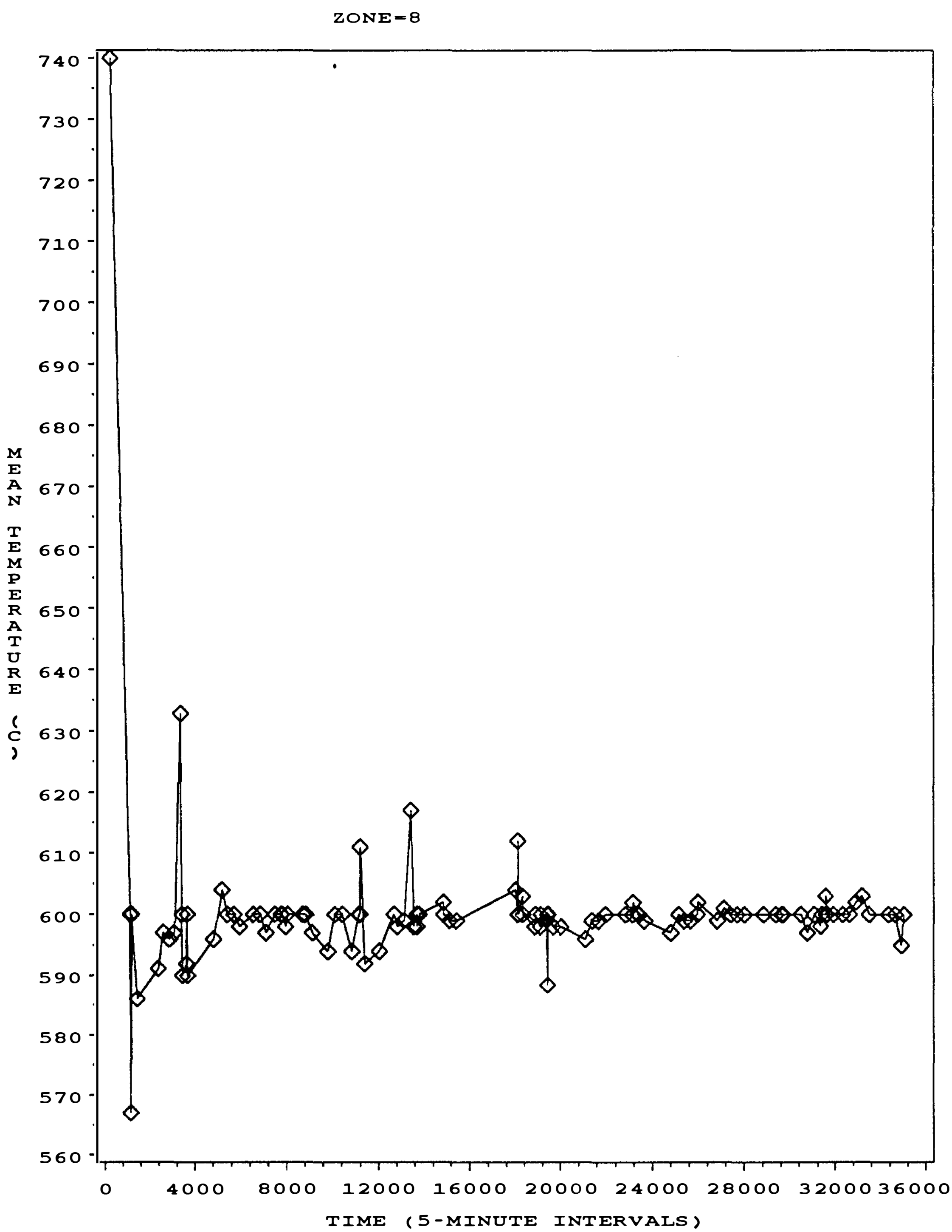

Figure D-16. Variation of the mean temperature (at z-trace time) for zone 8 of the specimen columns of OC-4.

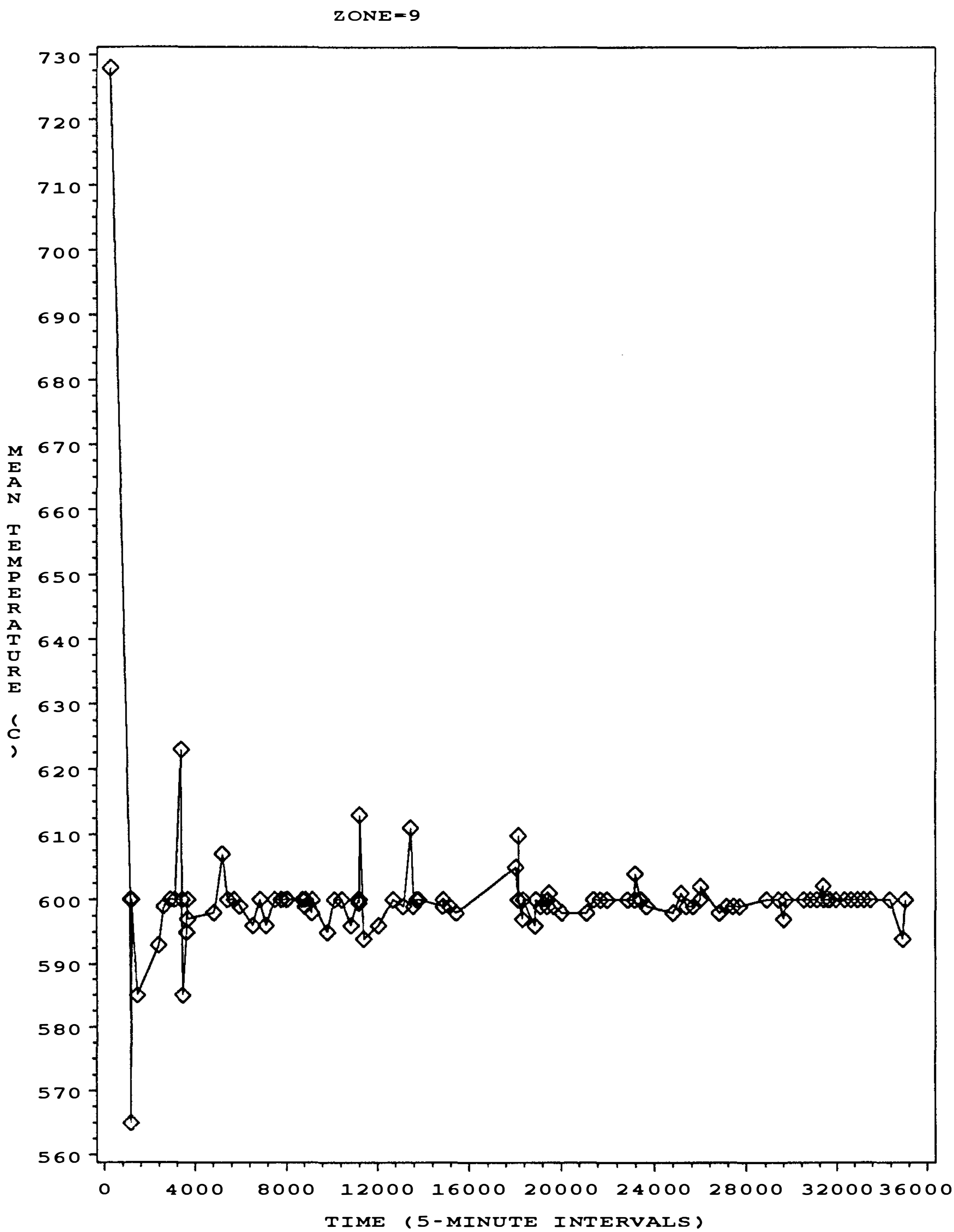

Figure D-17. Variation of the mean temperature (at z-trace time) for zone 9 of the specimen columns of OC-4.

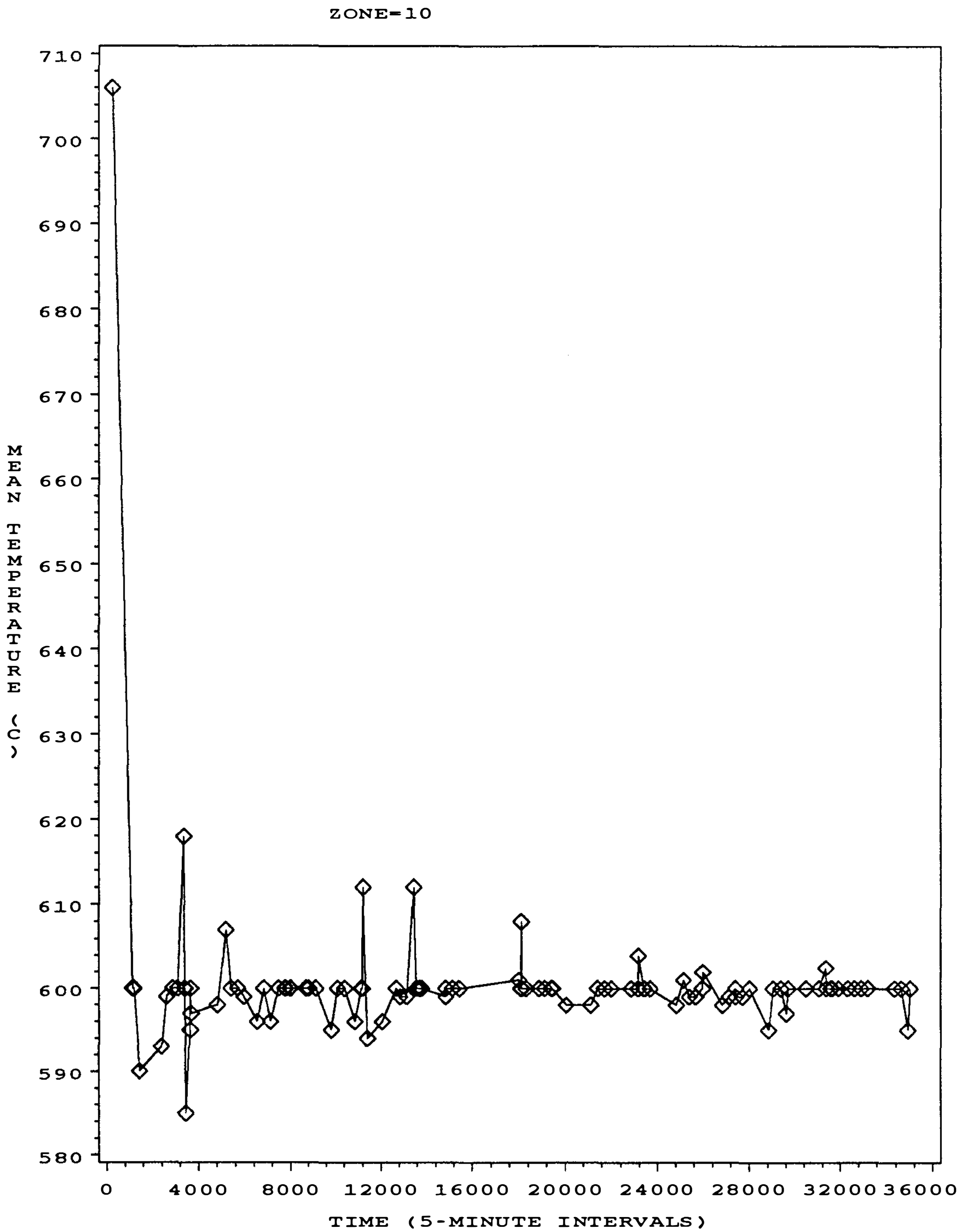

Figure D-18. Variation of the mean temperature (at z-trace time) for zone 10 of the specimen columns of OC-4.

APPENDIX E

SAS CODE TO DETERMINE THE VARIATION OF SETPOINT VALUES WITH TIME

```
//SETPOINT JOB ,'AMIR MOBASHERAN',GROUP=J64571,USER=P72098,CLASS=T,
// MSGCLASS=H,TIME=(19,59),PASSWORD=?
//*NOTIFY UTKVX.AMOBASH
/*ROUTE CMSRJO USERID=PB72098,CODEWORD=JOB
/*ROUTE PRINT RMTO
/*JOBPARM LINES=99,COPIES=1,ROOM=BIN4
/*UTPARM NONEWS
//STEP1 EXEC SAS,WORK='50,10'
//INDATA DD DSN=OC3.TRANSLAT,VOL=SER=(021571,003353),
//  UNIT=TAPE
//DDOUT DD UNIT=3380,VOL=SER=ONLIN2,
//   DISP=(NEW,CATLG),
//   DSN='J64571.SETPT2.DEG900',
//   DCB=(RECFM=FB,LRECL=80,BLKSIZE=800),
//   SPACE=(TRK,(5,2),RLSE)
//SYSIN  DD  *
*-----------------------------------------------------------------*
|      This SAS program creates a SAS data set containing         |
|      information about the setpoint values and the times        |
|      at which they have been adjusted for OC-3                  |
*-----------------------------------------------------------------*;
DATA OC3; INFILE INDATA;
    INPUT SENSOR $ 1-3 @5 DATE DATE9. @15 TIME TIME8. POINT $ 24-29
       GAINCHAN 30-35 FLAGWORD 36-41 SEQUENCE 42-47 SENSTYPE $ 49-51
       REALDATA 52-65 RAWDATA 66-71;
    IF SENSOR=71 OR SENSOR=72 OR 84<= SENSOR <=102;
    IF REALDATA=0 THEN REALDATA=.;
*---------------------------------------*;
*          ZONE 1                       *;
*---------------------------------------*;
*-----------------------------------------------------------------*;
DATA SPT01A; SET OC3;
    IF SENSOR=93;
       T01ASP=REALDATA;
       KEEP DATE TIME T01ASP;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------*;
DATA SPT01B; SET OC3;
    IF SENSOR=92;
       T01BSP=REALDATA;
       KEEP DATE TIME T01BSP;
       PROC SORT;
           BY DATE TIME;
DATA I;
    MERGE SPT01A SPT01B;
       BY DATE TIME;
SPA=T01ASP;
SPB=T01BSP;
DATA A;
  SET I;
```

```
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T01ASP T01BSP;
DATA B;
 SET A;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
ZONE=1;
FORMAT DAY DATE9. T TIME8.;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTA
      MTC_B MN_DT MTC_MN;
DATA C;
  SET B;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
  VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;
*-------------------------------------------------------------------*;

*----------------------------------------*;
*          ZONE 2                        *;
*----------------------------------------*;
DATA SPT02A; SET OC3;
    IF SENSOR=91;
       T02ASP=REALDATA;
       KEEP DATE TIME T02ASP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
```

```
DATA SPT02B; SET OC3;
    IF SENSOR=90;
       T02BSP=REALDATA;
       KEEP DATE TIME T02BSP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA II;
    MERGE SPT02A SPT02B;
       BY DATE TIME;
SPA=T02ASP;
SPB=T02BSP;
*------------------------------------------------------------------*;
DATA A2;
  SET II;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T02ASP T02BSP;
DATA B2;
 SET A2;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=2;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C2;
  SET B2;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
```

```
OPTIONS LS=72;
PROC PRINT;
  VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;

*--------------------------------------*;
*         ZONE 3                       *;
*--------------------------------------*;
*--------------------------------------------------------------------*;
**OPTIONS LS=132;
DATA SPT03A; SET OC3;
    IF SENSOR=89;
       T03ASP=REALDATA;
       KEEP DATE TIME T03ASP;
       PROC SORT;
           BY DATE TIME;
*--------------------------------------------------------------------*;
DATA SPT03B; SET OC3;
    IF SENSOR=88;
       T03BSP=REALDATA;
       KEEP DATE TIME T03BSP;
       PROC SORT;
           BY DATE TIME;
DATA III;
    MERGE SPT03A SPT03B;
       BY DATE TIME;
SPA=T03ASP;
SPB=T03BSP;
DATA A3;
  SET III;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T03ASP T03BSP;
DATA B3;
 SET A3;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
```

```
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=3;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C3;
  SET B3;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;

*-------------------------------------*;
*          ZONE 4                     *;
*-------------------------------------*;
*-----------------------------------------------------------------*;
*OPTIONS LS=132;
DATA SPT04A; SET OC3;
    IF SENSOR=87;
       T04ASP=REALDATA;
       KEEP DATE TIME T04ASP;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------*;
DATA SPT04B; SET OC3;
    IF SENSOR=86;
       T04BSP=REALDATA;
       KEEP DATE TIME T04BSP;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------*;
DATA IV;
    MERGE SPT04A SPT04B;
       BY DATE TIME;
SPA=T04ASP;
SPB=T04BSP;
DATA A4;
  SET IV;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
```

```
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T04ASP T04BSP;
DATA B4;
 SET A4;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=4;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C4;
  SET B4;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;
*---------------------------------------*;
*          ZONE 5                       *;
*---------------------------------------*;
*OPTIONS LS=132;
DATA SPT05A; SET OC3;
    IF SENSOR=84;
       T05ASP=REALDATA;
       KEEP DATE TIME T05ASP;
       PROC SORT;
           BY DATE TIME;
*--------------------------------------------------------------------*;
DATA SPT05B; SET OC3;
    IF SENSOR=85;
       T05BSP=REALDATA;
       KEEP DATE TIME T05BSP;
       PROC SORT;
           BY DATE TIME;
*--------------------------------------------------------------------*;
DATA V;
```

```
    MERGE SPT05A SPT05B;
       BY DATE TIME;
SPA=T05ASP;
SPB=T05BSP;
DATA A5;
  SET V;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T05ASP T05BSP;
DATA B5;
 SET A5;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=5;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C5;
  SET B5;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;

*---------------------------------------*;
*          ZONE 6                       *;
*---------------------------------------*;
*OPTIONS LS=132;
DATA SPT06A; SET OC3;
```

```
    IF SENSOR=102;
       T06ASP=REALDATA;
       KEEP DATE TIME T06ASP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA SPT06B; SET OC3;
    IF SENSOR=101;
       T06BSP=REALDATA;
       KEEP DATE TIME T06BSP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA VI;
    MERGE SPT06A SPT06B;
       BY DATE TIME;
SPA=T06ASP;
SPB=T06BSP;
DATA A6;
  SET VI;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T06ASP T06BSP;
DATA B6;
 SET A6;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=6;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
```

```
      MTC_B MN_DT MTC_MN;
DATA C6;
  SET B6;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;

*---------------------------------------*;
*          ZONE 7                       *;
*---------------------------------------*;
*OPTIONS LS=132;
DATA SPT07A; SET OC3;
    IF SENSOR=100;
       T07ASP=REALDATA;
       KEEP DATE TIME T07ASP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPT07B; SET OC3;
    IF SENSOR=99;
       T07BSP=REALDATA;
       KEEP DATE TIME T07BSP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA VII;
    MERGE SPT07A SPT07B;
       BY DATE TIME;
SPA=T07ASP;
SPB=T07BSP;
DATA A7;
  SET VII;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T07ASP T07BSP;
DATA B7;
 SET A7;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
```

```
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=7;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C7;
  SET B7;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;

*--------------------------------------*;
*          ZONE 8                      *;
*--------------------------------------*;
*------------------------------------------------------------------*;
*OPTIONS LS=132;
DATA SPT08A; SET OC3;
    IF SENSOR=98;
       T08ASP=REALDATA;
       KEEP DATE TIME T08ASP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA SPT08B; SET OC3;
    IF SENSOR=95;
       T08BSP=REALDATA;
       KEEP DATE TIME T08BSP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA VIII;
    MERGE SPT08A SPT08B;
       BY DATE TIME;
SPA=T08ASP;
SPB=T08BSP;
DATA A8;
  SET VIII;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
```

```
    COUNTER=1;
    OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
    COUNTER=COUNTER-1;
    OUTPUT;
END;
DROP T08ASP T08BSP;
DATA B8;
 SET A8;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=8;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C8;
  SET B8;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;

*---------------------------------------*;
*          ZONE 9                       *;
*---------------------------------------*;
*-------------------------------------------------------------------*;
*OPTIONS LS=132;
DATA SPT09A; SET OC3;
    IF SENSOR=97;
       T09ASP=REALDATA;
       KEEP DATE TIME T09ASP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPT09B; SET OC3;
```

```
    IF SENSOR=71;
       T09BSP=REALDATA;
       KEEP DATE TIME T09BSP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA IX;
    MERGE SPT09A SPT09B;
       BY DATE TIME;
SPA=T09ASP;
SPB=T09BSP;
DATA A9;
  SET IX;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T09ASP T09BSP;
DATA B9;
 SET A9;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=9;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C9;
  SET B9;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
```

```
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;

*---------------------------------------*;
*          ZONE 10                      *;
*---------------------------------------*;
*---------------------------------------------------------------------*;
*OPTIONS LS=132;
DATA SPT10A; SET OC3;
    IF SENSOR=72;
       T10ASP=REALDATA;
       KEEP DATE TIME T10ASP;
       PROC SORT;
           BY DATE TIME;
*---------------------------------------------------------------------*;
DATA SPT10B; SET OC3;
    IF SENSOR=96;
       T10BSP=REALDATA;
       KEEP DATE TIME T10BSP;
       PROC SORT;
           BY DATE TIME;
DATA X;
    MERGE SPT10A SPT10B;
       BY DATE TIME;
SPA=T10ASP;
SPB=T10BSP;
DATA A10;
  SET X;
  BY SPA NOTSORTED;
  IF FIRST.SPA THEN DO;
     COUNTER=1;
     OUTPUT;
  END;
  COUNTER+1;
  IF LAST.SPA THEN DO;
     COUNTER=COUNTER-1;
     OUTPUT;
END;
DROP T10ASP T10BSP;
DATA B10;
 SET A10;
DAY=LAG1(DATE);
T=LAG1(TIME);
OLDSPA=LAG1(SPA);
NEWSPA=SPA;
OLDSPB=LAG1(SPB);
NEWSPB=SPB;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900+MN_DT;
MTC_A=900+DTA;
```

```
MTC_B=900+DTB;
TL=LAG1(COUNTER);
FORMAT DAY DATE9. T TIME8.;
ZONE=10;
OPTIONS LS=132;
PROC PRINT;
  VAR ZONE DAY T TL COUNTER OLDSPA NEWSPA DTA MTC_A OLDSPB NEWSPB DTB
      MTC_B MN_DT MTC_MN;
DATA C10;
  SET B10;
DROP DATE TIME SPA SPB COUNTER;
IF TL=1 THEN DELETE;
OPTIONS LS=72;
PROC PRINT;
   VAR ZONE DAY T TL OLDSPA NEWSPA OLDSPB NEWSPB;
*====================================================================*;
DATA ALL;
  SET C C2 C3 C4 C5 C6 C7 C8 C9 C10;
FORMAT DAY DATE9. T TIME8.;
PROC SORT;
  BY ZONE DAY T;
DATA ALL;
  SET ALL;
FILE DDOUT;
PUT ZONE 1-2 @3 DAY DATE9. @12 T TIME8. TL 20-23
    OLDSPA 24-37 .3 NEWSPA 38-51 .3 OLDSPB 52-65 .3 NEWSPB 66-79 .3;
ENDSAS;
*====================================================================*;
*====================================================================*;
```

```
*****************************************************************************
*                                                                           *
* This SAS program, when run, creates a SAS data set under the name         *
* ALL.SASEB$DATA for the second program in this appendix.                   *
*                                                                           *
*****************************************************************************;
*---------------------------------------------------------------------------*;
*  ZONE 1                                                                   *;
*---------------------------------------------------------------------------*;
OPTIONS FIRSTOBS=2 LS=72;
DATA Z1;
INPUT ZONE 1-2 @3 DAY DATE9. @12 T TIME8. TL 20-23
    OLDSPA 24-37 NEWSPA 38-51 OLDSPB 52-65 NEWSPB 66-79;
DROP DAY T;
*FORMAT DAY DATE9. T TIME8.;
CARDS;
 1        .       .   .          .           830.000          .          830.000
 128FEB197916:58:01 114       830.000      823.215       830.000       826.785
 128FEB197917:28:01   6       823.215      823.065       826.785       826.934
 128FEB197923:03:02  67       823.065      823.064       826.934       826.935
 101MAR197910:08:00 133       823.064      833.000       826.935       836.787
 102MAR197910:08:00 288       833.000      836.655       836.787       841.132
 102MAR197914:33:00  53       836.655      844.354       841.132       849.432
 105MAR197915:35:00 876       844.354      844.199       849.432       849.587
 105MAR197919:00:00  41       844.199      844.349       849.587       849.437
 106MAR197912:25:00 209       844.349      846.050       849.437       851.737
 107MAR197911:25:00 276       846.050      845.899       851.737       851.888
 108MAR197913:20:03 263       845.899      830.000       851.888       830.000
 108MAR197915:45:00  29       830.000      828.062       830.000       831.938
 108MAR197917:05:01  16       828.062      854.000       831.938       857.000
 108MAR197919:35:00  30       854.000      853.100       857.000       857.900
 108MAR197921:20:00  21       853.100      853.101       857.900       857.899
 109MAR197911:50:01 174       853.101      846.601       857.899       851.399
 112MAR197910:00:00 842       846.601      846.604       851.399       851.395
 113MAR197910:50:01 298       846.604      849.604       851.395       854.395
 114MAR197911:00:00 290       849.604      848.803       854.395       854.197
 115MAR197911:20:00 292       848.803      847.653       854.197       853.346
 116MAR197914:30:00 326       847.653      847.504       853.346       853.496
 119MAR197910:55:00 821       847.504      845.905       853.496       853.095
 120MAR197910:45:00 286       845.905      847.056       853.095       853.944
 121MAR197911:25:00 296       847.056      846.256       853.944       853.745
 122MAR197910:15:00 274       846.256      854.000       853.745       857.000
 122MAR197914:05:00  46       854.000      852.651       857.000       858.349
 122MAR197915:50:00  21       852.651      856.651       858.349       862.349
 123MAR197910:50:00 228       856.651      856.648       862.349       862.352
 123MAR197912:25:00  19       856.648      854.648       862.352       860.352
 126MAR197910:05:00 836       854.648      853.799       860.352       859.201
 127MAR197914:25:00 340       853.799      854.050       859.201       860.950
 104APR197918:59:01 630       854.050      854.399       860.950       858.601
 105APR1979 9:49:00 178       854.399      849.250       858.601       853.750
 105APR197911:49:00  24       849.250      853.253       853.750       857.747
```

106APR197910:04:00 267	853.253	851.250	857.747	855.749
109APR197910:59:00 875	851.250	850.952	855.749	856.048
110APR197910:14:00 279	850.952	847.952	856.048	853.048
111APR197910:44:00 294	847.952	851.954	853.048	857.046
112APR197910:59:00 291	851.954	851.801	857.046	857.199
116APR197910:24:001145	851.801	850.502	857.199	856.498
117APR197913:24:00 324	850.502	851.502	856.498	857.498
118APR1979 9:24:00 240	851.502	851.501	857.498	857.499
118APR197914:39:00 63	851.501	847.501	857.499	853.499
119APR197910:49:00 242	847.501	849.205	853.499	855.795
123APR1979 9:04:001131	849.205	852.000	855.795	858.000
103MAY197916:19:00 103	852.000	863.000	858.000	866.299
103MAY197918:34:00 27	863.000	864.545	866.299	868.754
104MAY197912:44:01 218	864.545	861.544	868.754	865.755
105MAY197916:09:00 329	861.544	857.745	865.755	862.554
107MAY197912:14:00 529	857.745	857.048	862.554	861.251
109MAY1979 9:59:00 549	857.048	859.048	861.251	863.251
110MAY197910:04:02 289	859.048	856.897	863.251	861.402
111MAY197913:54:01 334	856.897	858.598	861.402	863.701
114MAY197911:08:00 659	858.598	857.897	863.701	862.402
116MAY197910:23:00 566	857.897	857.748	862.402	862.552
117MAY197910:48:00 293	857.748	854.747	862.552	859.552
118MAY197910:53:00 289	854.747	852.899	859.552	857.400
121MAY197910:48:00 863	852.899	850.600	857.400	855.700
123MAY1979 8:41:00 269	850.600	863.000	855.700	866.000
123MAY197913:56:00 63	863.000	855.095	866.000	859.905
123MAY197916:21:02 29	855.095	855.249	859.905	859.750
124MAY1979 9:31:02 206	855.249	851.399	859.750	855.601
125MAY197911:31:02 312	851.399	851.551	855.601	855.449
128MAY197912:26:00 870	851.551	849.701	855.449	853.299
129MAY197913:06:00 296	849.701	851.552	853.299	855.447
131MAY197910:31:02 545	851.552	852.402	855.447	856.598
101JUN1979 9:41:02 278	852.402	851.401	856.598	855.599
104JUN197911:36:00 887	851.401	852.102	855.599	856.898
106JUN197910:51:02 567	852.102	848.951	856.898	854.049
108JUN1979 9:56:00 565	848.951	849.953	854.049	855.047
111JUN197913:56:00 912	849.953	855.000	855.047	859.000
112JUN197913:21:02 281	855.000	851.299	859.000	856.701
112JUN197915:51:02 30	851.299	855.302	856.701	860.698
113JUN197910:16:00 221	855.302	849.749	860.698	854.251
114JUN197914:26:00 338	849.749	849.603	854.251	854.397
115JUN1979 9:26:00 228	849.603	843.752	854.397	848.248
116JUN197920:46:01 424	843.752	841.756	848.248	846.244
118JUN197911:26:00 464	841.756	843.906	846.244	848.094
120JUN197910:36:00 566	843.906	839.905	848.094	844.095
120JUN197913:31:00 35	839.905	839.057	844.095	842.943
125JUN197910:56:00 875	839.057	840.609	842.943	845.391
125JUN197911:21:02 5	840.609	840.309	845.391	845.691
126JUN1979 9:26:00 265	840.309	855.000	845.691	859.000
126JUN197917:06:00 92	855.000	856.457	859.000	861.543
126JUN197917:36:00 6	856.457	851.602	861.543	856.398

```
 126JUN197920:26:00  34       851.602       844.601       856.398       849.399
 126JUN197922:36:00  26       844.601       844.606       849.399       849.394
 127JUN197910:01:01 137       844.606       843.605       849.394       848.394
 128JUN197919:51:02 406       843.605       842.307       848.394       847.693
 129JUN197913:21:02 210       842.307       841.457       847.693       846.543
 102JUL197911:21:00 840       841.457       841.168       846.543       852.832
 105JUL1979 9:41:02 844       841.168       842.306       852.832       847.694
 106JUL197911:11:00 306       842.306       843.457       847.694       848.543
 106JUL197911:11:00 825       842.306          .          848.543          .
;
OPTIONS FIRSTOBS=1;
DATA T1;
  SET Z1;
N=_N_;
L1=LAG1(TL);
L2=LAG2(TL);
L3=LAG3(TL);
L4=LAG4(TL);
L5=LAG5(TL);
L6=LAG6(TL);
L7=LAG7(TL);
L8=LAG8(TL);
L9=LAG9(TL);
L10=LAG10(TL);
L11=LAG11(TL);
L12=LAG12(TL);
L13=LAG13(TL);
L14=LAG14(TL);
L15=LAG15(TL);
L16=LAG16(TL);
L17=LAG17(TL);
L18=LAG18(TL);
L19=LAG19(TL);
L20=LAG20(TL);
L21=LAG21(TL);
L22=LAG22(TL);
L23=LAG23(TL);
L24=LAG24(TL);
L25=LAG25(TL);
L26=LAG26(TL);
L27=LAG27(TL);
L28=LAG28(TL);
L29=LAG29(TL);
L30=LAG30(TL);
L31=LAG31(TL);
L32=LAG32(TL);
L33=LAG33(TL);
L34=LAG34(TL);
L35=LAG35(TL);
L36=LAG36(TL);
L37=LAG37(TL);
```

```
L38=LAG38(TL);
L39=LAG39(TL);
L40=LAG40(TL);
L41=LAG41(TL);
L42=LAG42(TL);
L43=LAG43(TL);
L44=LAG44(TL);
L45=LAG45(TL);
L46=LAG46(TL);
L47=LAG47(TL);
L48=LAG48(TL);
L49=LAG49(TL);
L50=LAG50(TL);
L51=LAG51(TL);
L52=LAG52(TL);
L53=LAG53(TL);
L54=LAG54(TL);
L55=LAG55(TL);
L56=LAG56(TL);
L57=LAG57(TL);
L58=LAG58(TL);
L59=LAG59(TL);
L60=LAG60(TL);
L61=LAG61(TL);
L62=LAG62(TL);
L63=LAG63(TL);
L64=LAG64(TL);
L65=LAG65(TL);
L66=LAG66(TL);
L67=LAG67(TL);
L68=LAG68(TL);
L69=LAG69(TL);
L70=LAG70(TL);
L71=LAG71(TL);
L72=LAG72(TL);
L73=LAG73(TL);
L74=LAG74(TL);
L75=LAG75(TL);
L76=LAG76(TL);
L77=LAG77(TL);
L78=LAG78(TL);
L79=LAG79(TL);
L80=LAG80(TL);
L81=LAG81(TL);
L82=LAG82(TL);
L83=LAG83(TL);
L84=LAG84(TL);
L85=LAG85(TL);
L86=LAG86(TL);
L87=LAG87(TL);
L88=LAG88(TL);
```

```
L89=LAG89(TL);
L90=LAG90(TL);
L91=LAG91(TL);
L92=LAG92(TL);
L93=LAG93(TL);
IF N=1 THEN TIME=TL;
ELSE IF N=2 THEN TIME=TL+L1;
ELSE IF N=3 THEN TIME=TL+L1+L2;
ELSE IF N=4 THEN TIME=TL+L1+L2+L3;
ELSE IF N=5 THEN TIME=TL+L1+L2+L3+L4;
ELSE IF N=6 THEN TIME=TL+L1+L2+L3+L4+L5;
ELSE IF N=7 THEN TIME=TL+L1+L2+L3+L4+L5+L6;
ELSE IF N=8 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7;
ELSE IF N=9 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7+L8;
ELSE IF N=10 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7+L8+L9;
ELSE IF N=11 THEN TIME=TL+(SUM(OF L1--L10));
ELSE IF N=12 THEN TIME=TL+(SUM(OF L1--L11));
ELSE IF N=13 THEN TIME=TL+(SUM(OF L1--L12));
ELSE IF N=14 THEN TIME=TL+(SUM(OF L1--L13));
ELSE IF N=15 THEN TIME=TL+(SUM(OF L1--L14));
ELSE IF N=16 THEN TIME=TL+(SUM(OF L1--L15));
ELSE IF N=17 THEN TIME=TL+(SUM(OF L1--L16));
ELSE IF N=18 THEN TIME=TL+(SUM(OF L1--L17));
ELSE IF N=19 THEN TIME=TL+(SUM(OF L1--L18));
ELSE IF N=20 THEN TIME=TL+(SUM(OF L1--L19));
ELSE IF N=21 THEN TIME=TL+(SUM(OF L1--L20));
ELSE IF N=22 THEN TIME=TL+(SUM(OF L1--L21));
ELSE IF N=23 THEN TIME=TL+(SUM(OF L1--L22));
ELSE IF N=24 THEN TIME=TL+(SUM(OF L1--L23));
ELSE IF N=25 THEN TIME=TL+(SUM(OF L1--L24));
ELSE IF N=26 THEN TIME=TL+(SUM(OF L1--L25));
ELSE IF N=27 THEN TIME=TL+(SUM(OF L1--L26));
ELSE IF N=28 THEN TIME=TL+(SUM(OF L1--L27));
ELSE IF N=29 THEN TIME=TL+(SUM(OF L1--L28));
ELSE IF N=30 THEN TIME=TL+(SUM(OF L1--L29));
ELSE IF N=31 THEN TIME=TL+(SUM(OF L1--L30));
ELSE IF N=32 THEN TIME=TL+(SUM(OF L1--L31));
ELSE IF N=33 THEN TIME=TL+(SUM(OF L1--L32));
ELSE IF N=34 THEN TIME=TL+(SUM(OF L1--L33));
ELSE IF N=35 THEN TIME=TL+(SUM(OF L1--L34));
ELSE IF N=36 THEN TIME=TL+(SUM(OF L1--L35));
ELSE IF N=37 THEN TIME=TL+(SUM(OF L1--L36));
ELSE IF N=38 THEN TIME=TL+(SUM(OF L1--L37));
ELSE IF N=39 THEN TIME=TL+(SUM(OF L1--L38));
ELSE IF N=40 THEN TIME=TL+(SUM(OF L1--L39));
ELSE IF N=41 THEN TIME=TL+(SUM(OF L1--L40));
ELSE IF N=42 THEN TIME=TL+(SUM(OF L1--L41));
ELSE IF N=43 THEN TIME=TL+(SUM(OF L1--L42));
ELSE IF N=44 THEN TIME=TL+(SUM(OF L1--L43));
ELSE IF N=45 THEN TIME=TL+(SUM(OF L1--L44));
ELSE IF N=46 THEN TIME=TL+(SUM(OF L1--L45));
```

```
ELSE IF N=47 THEN TIME=TL+(SUM(OF L1--L46));
ELSE IF N=48 THEN TIME=TL+(SUM(OF L1--L47));
ELSE IF N=49 THEN TIME=TL+(SUM(OF L1--L48));
ELSE IF N=50 THEN TIME=TL+(SUM(OF L1--L49));
ELSE IF N=51 THEN TIME=TL+(SUM(OF L1--L50));
ELSE IF N=52 THEN TIME=TL+(SUM(OF L1--L51));
ELSE IF N=53 THEN TIME=TL+(SUM(OF L1--L52));
ELSE IF N=54 THEN TIME=TL+(SUM(OF L1--L53));
ELSE IF N=55 THEN TIME=TL+(SUM(OF L1--L54));
ELSE IF N=56 THEN TIME=TL+(SUM(OF L1--L55));
ELSE IF N=57 THEN TIME=TL+(SUM(OF L1--L56));
ELSE IF N=58 THEN TIME=TL+(SUM(OF L1--L57));
ELSE IF N=59 THEN TIME=TL+(SUM(OF L1--L58));
ELSE IF N=60 THEN TIME=TL+(SUM(OF L1--L59));
ELSE IF N=61 THEN TIME=TL+(SUM(OF L1--L60));
ELSE IF N=62 THEN TIME=TL+(SUM(OF L1--L61));
ELSE IF N=63 THEN TIME=TL+(SUM(OF L1--L62));
ELSE IF N=64 THEN TIME=TL+(SUM(OF L1--L63));
ELSE IF N=65 THEN TIME=TL+(SUM(OF L1--L64));
ELSE IF N=66 THEN TIME=TL+(SUM(OF L1--L65));
ELSE IF N=67 THEN TIME=TL+(SUM(OF L1--L66));
ELSE IF N=68 THEN TIME=TL+(SUM(OF L1--L67));
ELSE IF N=69 THEN TIME=TL+(SUM(OF L1--L68));
ELSE IF N=70 THEN TIME=TL+(SUM(OF L1--L69));
ELSE IF N=71 THEN TIME=TL+(SUM(OF L1--L70));
ELSE IF N=72 THEN TIME=TL+(SUM(OF L1--L71));
ELSE IF N=73 THEN TIME=TL+(SUM(OF L1--L72));
ELSE IF N=74 THEN TIME=TL+(SUM(OF L1--L73));
ELSE IF N=75 THEN TIME=TL+(SUM(OF L1--L74));
ELSE IF N=76 THEN TIME=TL+(SUM(OF L1--L75));
ELSE IF N=77 THEN TIME=TL+(SUM(OF L1--L76));
ELSE IF N=78 THEN TIME=TL+(SUM(OF L1--L77));
ELSE IF N=79 THEN TIME=TL+(SUM(OF L1--L78));
ELSE IF N=80 THEN TIME=TL+(SUM(OF L1--L79));
ELSE IF N=81 THEN TIME=TL+(SUM(OF L1--L80));
ELSE IF N=82 THEN TIME=TL+(SUM(OF L1--L81));
ELSE IF N=83 THEN TIME=TL+(SUM(OF L1--L82));
ELSE IF N=84 THEN TIME=TL+(SUM(OF L1--L83));
ELSE IF N=85 THEN TIME=TL+(SUM(OF L1--L84));
ELSE IF N=86 THEN TIME=TL+(SUM(OF L1--L85));
ELSE IF N=87 THEN TIME=TL+(SUM(OF L1--L86));
ELSE IF N=88 THEN TIME=TL+(SUM(OF L1--L87));
ELSE IF N=89 THEN TIME=TL+(SUM(OF L1--L88));
ELSE IF N=90 THEN TIME=TL+(SUM(OF L1--L89));
ELSE IF N=91 THEN TIME=TL+(SUM(OF L1--L90));
ELSE IF N=92 THEN TIME=TL+(SUM(OF L1--L91));
ELSE IF N=93 THEN TIME=TL+(SUM(OF L1--L92));
ELSE IF N=94 THEN TIME=TL+(SUM(OF L1--L93));
ELSE TIME=.;
DTA=OLDSPA-NEWSPA;
DTB=OLDSPB-NEWSPB;
```

```
MN_DT=MEAN(OF DTA DTB);
MTC_MN=900-MN_DT;
MTC_A=900-DTA;
MTC_B=900-DTB;
*---------------------------------------------------------------------------*;

*---------------------------------------------------------------------------*;
*  ZONE 2  (This zone and the remaining zones are treated in a similar way) *;
*---------------------------------------------------------------------------*;
OPTIONS FIRSTOBS=2 LS=72;
*---------------------------------------------------------------------*;
DATA ALL;
 SET T1 T2 T3 T4 T5 T6 T7 T8 T9 T10;
DROP L1-L93 N;
LIBNAME STPT900  '[AMOBASH.ORROC3.SP900]';
DATA STPT900.ALL;
  SET ALL;
ENDSAS;
DATA ZONE1;
SET ALL;
IF ZONE=1;
\end{small}
```

```
*==============================================================================*
*  This SAS/GRAPH program generates the following plots                        *
*  for each zone of the OC-3 irradiation capsule:                              *
*                                                                              *
*       1. The setpoint vs. time for the west column (square  symbol).         *
*       2. The setpoint vs. time for the east column (triang. symbol).         *
*       3. The overlayed plots for 1 and 2.                                    *
*       4. The temperature of west column vs time (square  symbol).            *
*       5. The temperature of east column vs time (triang. symbol).            *
*       6. The overlayed plots for 4 and 5.                                    *
*       7. The mean value of 4 and 5 (diamond symbol).                         *
*==============================================================================*;
FILENAME POSTSC 'SP900ZALLP.PS';
GOPTIONS DEVICE=PS300 GSFMODE=APPEND GSFNAME=POSTSC NOPROMPT
  NODISPLAY HSIZE=7.0 VSIZE=9.5;
OPTIONS LS=72;
*-----------------------------------------------------------------------------;
LIBNAME STPT900 '[AMOBASH.ORROC3.SP900]';
DATA SP900;
  SET STPT900.ALL;

    LABEL       TL = 'NO. OF 5-MINUTE INTERVALS'
            OLDSPA = 'SETPOINT'
            NEWSPA = 'SETPOINT'
               DTA = 'OLDSPA - NEWSPA (C)'
            OLDSPB = 'SETPOINT'
            NEWSPB = 'SETPOINT'
               DTB = 'OLDSPB - NEWSPB (C)'
             MN_DT = 'MEAN DELTA T (C)'
            MTC_MN = 'MEAN TEMPERATURE (C)'
             MTC_A = 'TEMPERATURE (C)'
             MTC_B = 'TEMPERATURE (C)'
              TIME = 'TIME (5-MINUTE INTERVALS)';
*-----------------------------------------------------------------------------;
DATA ZONEALL;
   SET SP900;
*=============================================================================;
PROC SORT;
BY ZONE;
*=============================================================================;
*=============================================================================;
PROC GPLOT;
  BY ZONE;
    TITLE1 '                        OC-3 (900 C), WEST COL           ';
    TITLE2 '       ';
*.............................................................................;
    TITLE3      HEIGHT=8   ANGLE=90  '         ';
    TITLE4      HEIGHT=2   ANGLE=90  '         ';
*.............................................................................;
    FOOTNOTE1   HEIGHT=8             '         ';
    FOOTNOTE2   HEIGHT=8             '         ';
```

```
   FOOTNOTE3   HEIGHT=2              '          ';
*===============================================================================;
   PLOT NEWSPA * TIME=1/
                         HAXIS=0 TO 32000 BY 4000 FRAME;
*-------------------------------------------------------------------------------;
   SYMBOL1 H=2 LINE=1 COLOR=BLACK  VALUE=SQUARE    I=JOIN;
*===============================================================================;
*===============================================================================;
PROC GPLOT;
  BY ZONE;
   TITLE1 '                        OC-3 (900 C), EAST COL           ';
   TITLE2 '       ';
*...............................................................................;
   TITLE3      HEIGHT=8   ANGLE=90  '          ';
   TITLE4      HEIGHT=2   ANGLE=90  '          ';
*...............................................................................;
   FOOTNOTE1   HEIGHT=8              '          ';
   FOOTNOTE2   HEIGHT=8              '          ';
   FOOTNOTE3   HEIGHT=2              '          ';
*===============================================================================;
   PLOT NEWSPB * TIME=1/
                         HAXIS=0 TO 32000 BY 4000 FRAME;
*-------------------------------------------------------------------------------;
   SYMBOL1 H=2 LINE=1 COLOR=BLACK  VALUE=TRIANGLE  I=JOIN;
*===============================================================================;
*===============================================================================;
PROC GPLOT;
  BY ZONE;
   TITLE1 '                        OC-3 (900 C), W&E COL            ';
   TITLE2 '       ';
   TITLE3 '            WEST COL                         EAST COL        ';
*...............................................................................;
   TITLE4      HEIGHT=8   ANGLE=90  '          ';
   TITLE5      HEIGHT=2   ANGLE=90  '          ';
*...............................................................................;
   FOOTNOTE1   HEIGHT=8              '          ';
   FOOTNOTE2   HEIGHT=8              '          ';
   FOOTNOTE3   HEIGHT=2              '          ';
*===============================================================================;
   PLOT NEWSPA * TIME=1 NEWSPB * TIME=2/OVERLAY
                                          HAXIS=0 TO 32000 BY 4000 FRAME;
*-------------------------------------------------------------------------------;
   SYMBOL1 H=2 LINE=1 COLOR=BLACK  VALUE=SQUARE    I=JOIN;
   SYMBOL2 H=2 LINE=2 COLOR=BLACK  VALUE=TRIANGLE  I=JOIN;
*===============================================================================;
*===============================================================================;
PROC GPLOT;
  BY ZONE;
   TITLE1 '                        OC-3 (900 C), WEST COL              ';
   TITLE2 '       ';
*...............................................................................;
```

```
   TITLE3      HEIGHT=8   ANGLE=90  '         ';
   TITLE4      HEIGHT=2   ANGLE=90  '         ';
*.............................................................................;
   FOOTNOTE1   HEIGHT=8             '         ';
   FOOTNOTE2   HEIGHT=8             '         ';
   FOOTNOTE3   HEIGHT=2             '         ';
*=============================================================================;
   PLOT MTC_A * TIME=1/
                     HAXIS=0 TO 32000 BY 4000 FRAME;
*-----------------------------------------------------------------------------;
   SYMBOL1 H=2 LINE=1 COLOR=BLACK  VALUE=SQUARE    I=JOIN;
*=============================================================================;
*=============================================================================;
PROC GPLOT;
  BY ZONE;
   TITLE1 '                        OC-3 (900 C), EAST COL              ';
   TITLE2 '       ';
*.............................................................................;
   TITLE3      HEIGHT=8   ANGLE=90  '         ';
   TITLE4      HEIGHT=2   ANGLE=90  '         ';
*.............................................................................;
   FOOTNOTE1   HEIGHT=8             '         ';
   FOOTNOTE2   HEIGHT=8             '         ';
   FOOTNOTE3   HEIGHT=2             '         ';
*=============================================================================;
   PLOT MTC_B  * TIME=1/
                      HAXIS=0 TO 32000 BY 4000 FRAME;
*-----------------------------------------------------------------------------;
   SYMBOL1 H=2 LINE=1 COLOR=BLACK  VALUE=TRIANGLE  I=JOIN;
*=============================================================================;
*=============================================================================;
PROC GPLOT;
  BY ZONE;
   TITLE1 '                       OC-3 (900 C), W&E COL                ';
   TITLE2 '       ';
   TITLE3 '            WEST COL                          EAST COL        ';
*.............................................................................;
   TITLE4      HEIGHT=8   ANGLE=90  '         ';
   TITLE5      HEIGHT=2   ANGLE=90  '         ';
*.............................................................................;
   FOOTNOTE1   HEIGHT=8             '         ';
   FOOTNOTE2   HEIGHT=8             '         ';
   FOOTNOTE3   HEIGHT=2             '         ';
*=============================================================================;
   PLOT MTC_A * TIME=1 MTC_B * TIME=2/OVERLAY
                                   HAXIS=0 TO 32000 BY 4000 FRAME;
*-----------------------------------------------------------------------------;
   SYMBOL1 H=2 LINE=1 COLOR=BLACK  VALUE=SQUARE    I=JOIN;
   SYMBOL2 H=2 LINE=2 COLOR=BLACK  VALUE=TRIANGLE  I=JOIN;
*=============================================================================;
*=============================================================================;
```

```
PROC GPLOT;
  BY ZONE;
    TITLE1 '                          OC-3 (900 C), MEAN TEMP                  ';
    TITLE2 '       ';
*...................................................................;
    TITLE3      HEIGHT=8   ANGLE=90  '         ';
    TITLE4      HEIGHT=2   ANGLE=90  '         ';
*...................................................................;
    FOOTNOTE1   HEIGHT=8             '         ';
    FOOTNOTE2   HEIGHT=8             '         ';
    FOOTNOTE3   HEIGHT=2             '         ';
*===================================================================;
    PLOT MTC_MN * TIME=1/
                      HAXIS=0 TO 32000 BY 4000 FRAME;
*-------------------------------------------------------------------;
    SYMBOL1 H=2 LINE=1 COLOR=BLACK VALUE=DIAMOND   I=JOIN;
*===================================================================;
```

APPENDIX F

SAS CODE FOR DETAILED TEMPERATURE ANALYSIS

```
//FTCMTC JOB ,'AMIR MOBASHERAN',GROUP=J64571,USER=P72098,CLASS=T,
// MSGCLASS=H,TIME=(39,59),PASSWORD=?
/*NOTIFY UTKVM1.PB72098
/*ROUTE CMSRJO USERID=PB72098,CODEWORD=JOB
/*ROUTE PRINT RMTO
/*JOBPARM LINES=99,COPIES=1,ROOM=BIN4
/*UTPARM NONEWS
//STEP1 EXEC SAS,REGION=9M,WORK='250,50'
//INDATA  DD  DSN=OC3.TRANSLAT,VOL=SER=(021571,003353),UNIT=TAPE
//SYSIN  DD  *
*-------------------------------------------------------------------*
|      This SAS program performs a detailed temperature analysis    |
|      for the OC-3 experiment based on the reports from the fixed  |
|      thermocouples (FTC's) and the values of the setpoints        |
|      associated with them.                                        |
*-------------------------------------------------------------------*;
DATA OC3; INFILE INDATA;
    INPUT SENSOR $ 1-3 @5 DATE DATE9. @15 TIME TIME8. POINT $ 24-29
       GAINCHAN 30-35 FLAGWORD 36-41 SEQUENCE 42-47 SENSTYPE $ 49-51
       REALDATA 52-65 RAWDATA 66-71;

    IF 2<=SENSOR<=20 OR 84<=SENSOR<=93 OR 95<=SENSOR<=102
       OR SENSOR=71 OR SENSOR=72;
    IF REALDATA=0 THEN REALDATA=.;
*-------------------------------------------------------------------*;
             /*
DATA POWER; SET OC3;
  IF SENSOR=67;
REAPWR=REALDATA;
KEEP DATE TIME REAPWR;
PROC SORT;
  BY DATE TIME;
          */
*-------------------------------------------------------------------*;
DATA TZONE1A; SET OC3;
IF SENSOR=2;
ZONE=1;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA TZONE1B; SET OC3;
    IF SENSOR=3;
ZONE=1;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA TZONE2A; SET OC3;
```

```
    IF SENSOR=4;
ZONE=2;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------------*;
DATA TZONE2B; SET OC3;
    IF SENSOR=5;
ZONE=2;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------------*;
DATA TZONE3A; SET OC3;
    IF SENSOR=6;       * OR SENSOR=7;
ZONE=3;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------------*;
DATA TZONE3B; SET OC3;
    IF SENSOR=7;       * OR SENSOR=7;
ZONE=3;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------------*;
DATA TZONE4A; SET OC3;
    IF SENSOR=8;         *OR SENSOR=9;
ZONE=4;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------------*;
DATA TZONE4B; SET OC3;
    IF SENSOR=9;         *OR SENSOR=9;
ZONE=4;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------------*;
DATA TZONE5A; SET OC3;
    IF SENSOR=10;  *OR SENSOR=11 OR SENSOR=81 OR SENSOR=82 OR SENSOR=83;
ZONE=5;
FTCA=REALDATA;
```

```
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*---------------------------------------------------------------------*;
DATA TZONE5B; SET OC3;
    IF SENSOR=11; *OR SENSOR=11 OR SENSOR=81 OR SENSOR=82 OR SENSOR=83;
ZONE=5;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*---------------------------------------------------------------------*;
DATA TZONE6A; SET OC3;
    IF SENSOR=12;
ZONE=6;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*---------------------------------------------------------------------*;
DATA TZONE6B; SET OC3;
    IF SENSOR=13;
ZONE=6;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*---------------------------------------------------------------------*;
DATA TZONE7A; SET OC3;
    IF SENSOR=14;
ZONE=7;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*---------------------------------------------------------------------*;
DATA TZONE7B; SET OC3;
    IF SENSOR=15;
ZONE=7;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*---------------------------------------------------------------------*;
DATA TZONE8A; SET OC3;
    IF SENSOR=16;
ZONE=8;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
```

```
*-----------------------------------------------------------------*;
DATA TZONE8B; SET OC3;
    IF SENSOR=17;
ZONE=8;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------*;
DATA TZONE9A; SET OC3;
    IF SENSOR=18;
ZONE=9;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------*;
DATA TZONE9B; SET OC3;
    IF SENSOR=19;
ZONE=9;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------*;
DATA TZONE10A; SET OC3;
    IF SENSOR=20;
ZONE=10;
FTCA=REALDATA;
KEEP DATE TIME ZONE FTCA;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------*;
DATA TZONE10B; SET OC3;
    IF SENSOR=21;
ZONE=10;
FTCB=REALDATA;
KEEP DATE TIME ZONE FTCB;
       PROC SORT;
           BY DATE TIME;
*=================================================================*;
DATA II;
    MERGE TZONE1A TZONE1B;
       BY DATE TIME;
*-----------------------------------------------------------------*;
DATA III;
    MERGE TZONE2A TZONE2B;
       BY DATE TIME;
*-----------------------------------------------------------------*;
DATA IV;
    MERGE TZONE3A TZONE3B;
```

```
       BY DATE TIME;
*------------------------------------------------------------------*;
DATA V;
    MERGE TZONE4A TZONE4B;
       BY DATE TIME;
*------------------------------------------------------------------*;
DATA VI;
    MERGE TZONE5A TZONE5B;
       BY DATE TIME;
*------------------------------------------------------------------*;
DATA VII;
    MERGE TZONE6A TZONE6B;
       BY DATE TIME;
*------------------------------------------------------------------*;
DATA VIII;
    MERGE TZONE7A TZONE7B;
       BY DATE TIME;
*------------------------------------------------------------------*;
DATA IX;
    MERGE TZONE8A TZONE8B;
       BY DATE TIME;
*------------------------------------------------------------------*;
DATA X;
    MERGE TZONE9A TZONE9B;
       BY DATE TIME;
*------------------------------------------------------------------*;
DATA XI;
    MERGE TZONE10A TZONE10B;
       BY DATE TIME;
DATA FTC;
  SET II III IV V VI VII VIII IX X XI;
PROC SORT; BY DATE TIME ZONE;
*==================================================================*;

*------------------------------------------------------------------*
|                                                                  |
|                                                                  |
|                                                                  |
|                                                                  |
*------------------------------------------------------------------*;
*-------------------------------------*;
*          ZONE 1                     *;
*-------------------------------------*;
*------------------------------------------------------------------*;
DATA SPT01A; SET OC3;
    IF SENSOR=93;
ZONE=1;
       T01ASP=REALDATA;
       KEEP DATE TIME ZONE T01ASP;
       PROC SORT;
           BY DATE TIME;
```

```
*-------------------------------------------------------------------*;
DATA SPT01B; SET OC3;
    IF SENSOR=92;
ZONE=1;
       T01BSP=REALDATA;
       KEEP DATE TIME ZONE T01BSP;
       PROC SORT;
           BY DATE TIME;
DATA SPI;
    MERGE SPT01A SPT01B;
       BY DATE TIME;
SPA=T01ASP;
SPB=T01BSP;
KEEP DATE TIME ZONE SPA SPB;
*-------------------------------------------------------------------*;

*--------------------------------------*;
*          ZONE 2                      *;
*--------------------------------------*;
DATA SPT02A; SET OC3;
    IF SENSOR=91;
ZONE=2;
       T02ASP=REALDATA;
       KEEP DATE TIME ZONE T02ASP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPT02B; SET OC3;
    IF SENSOR=90;
ZONE=2;
       T02BSP=REALDATA;
       KEEP DATE TIME ZONE T02BSP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPII;
    MERGE SPT02A SPT02B;
       BY DATE TIME;
SPA=T02ASP;
SPB=T02BSP;
KEEP DATE TIME ZONE SPA SPB;
*-------------------------------------------------------------------*;
*--------------------------------------*;
*          ZONE 3                      *;
*--------------------------------------*;
*-------------------------------------------------------------------*;
DATA SPT03A; SET OC3;
    IF SENSOR=89;
ZONE=3;
       T03ASP=REALDATA;
       KEEP DATE TIME ZONE T03ASP;
```

```
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------------*;
DATA SPT03B; SET OC3;
    IF SENSOR=88;
ZONE=3;
       T03BSP=REALDATA;
       KEEP DATE TIME ZONE T03BSP;
       PROC SORT;
           BY DATE TIME;
DATA SPIII;
    MERGE SPT03A SPT03B;
       BY DATE TIME;
SPA=T03ASP;
SPB=T03BSP;
KEEP DATE TIME ZONE SPA SPB;
*----------------------------------------*;
*          ZONE 4                        *;
*----------------------------------------*;
*-----------------------------------------------------------------------*;
DATA SPT04A; SET OC3;
    IF SENSOR=87;
ZONE=4;
       T04ASP=REALDATA;
       KEEP DATE TIME ZONE T04ASP;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------------*;
DATA SPT04B; SET OC3;
    IF SENSOR=86;
ZONE=4;
       T04BSP=REALDATA;
       KEEP DATE TIME ZONE T04BSP;
       PROC SORT;
           BY DATE TIME;
*-----------------------------------------------------------------------*;
DATA SPIV;
    MERGE SPT04A SPT04B;
       BY DATE TIME;
SPA=T04ASP;
SPB=T04BSP;
KEEP DATE TIME ZONE SPA SPB;
*----------------------------------------*;
*          ZONE 5                        *;
*----------------------------------------*;
DATA SPT05A; SET OC3;
    IF SENSOR=84;
ZONE=5;
       T05ASP=REALDATA;
       KEEP DATE TIME ZONE T05ASP;
       PROC SORT;
```

```
          BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPT05B; SET OC3;
    IF SENSOR=85;
ZONE=5;
       T05BSP=REALDATA;
       KEEP DATE TIME ZONE T05BSP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPV;
    MERGE SPT05A SPT05B;
       BY DATE TIME;
SPA=T05ASP;
SPB=T05BSP;
KEEP DATE TIME ZONE SPA SPB;
*---------------------------------------*;
*          ZONE 6                       *;
*---------------------------------------*;
DATA SPT06A; SET OC3;
    IF SENSOR=102;
ZONE=6;
       T06ASP=REALDATA;
       KEEP DATE TIME ZONE T06ASP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPT06B; SET OC3;
    IF SENSOR=101;
ZONE=6;
       T06BSP=REALDATA;
       KEEP DATE TIME ZONE T06BSP;
       PROC SORT;
           BY DATE TIME;
*-------------------------------------------------------------------*;
DATA SPVI;
    MERGE SPT06A SPT06B;
       BY DATE TIME;
SPA=T06ASP;
SPB=T06BSP;
KEEP DATE TIME ZONE SPA SPB;
*---------------------------------------*;
*          ZONE 7                       *;
*---------------------------------------*;
DATA SPT07A; SET OC3;
    IF SENSOR=100;
ZONE=7;
       T07ASP=REALDATA;
       KEEP DATE TIME ZONE T07ASP;
       PROC SORT;
           BY DATE TIME;
```

```
*----------------------------------------------------------------*;
DATA SPT07B; SET OC3;
    IF SENSOR=99;
ZONE=7;
       T07BSP=REALDATA;
       KEEP DATE TIME ZONE T07BSP;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------*;
DATA SPVII;
    MERGE SPT07A SPT07B;
       BY DATE TIME;
SPA=T07ASP;
SPB=T07BSP;
KEEP DATE TIME ZONE SPA SPB;
*--------------------------------------*;
*          ZONE 8                      *;
*--------------------------------------*;
*----------------------------------------------------------------*;
DATA SPT08A; SET OC3;
    IF SENSOR=98;
ZONE=8;
       T08ASP=REALDATA;
       KEEP DATE TIME ZONE T08ASP;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------*;
DATA SPT08B; SET OC3;
    IF SENSOR=95;
ZONE=8;
       T08BSP=REALDATA;
       KEEP DATE TIME ZONE T08BSP;
       PROC SORT;
           BY DATE TIME;
*----------------------------------------------------------------*;
DATA SPVIII;
    MERGE SPT08A SPT08B;
       BY DATE TIME;
SPA=T08ASP;
SPB=T08BSP;
KEEP DATE TIME ZONE SPA SPB;
*--------------------------------------*;
*          ZONE 9                      *;
*--------------------------------------*;
*----------------------------------------------------------------*;
DATA SPT09A; SET OC3;
    IF SENSOR=97;
ZONE=9;
       T09ASP=REALDATA;
       KEEP DATE TIME ZONE T09ASP;
       PROC SORT;
```

```
          BY DATE TIME;
*------------------------------------------------------------------*;
DATA SPT09B; SET OC3;
    IF SENSOR=71;
ZONE=9;
       T09BSP=REALDATA;
       KEEP DATE TIME ZONE T09BSP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA SPIX;
    MERGE SPT09A SPT09B;
       BY DATE TIME;
SPA=T09ASP;
SPB=T09BSP;
KEEP DATE TIME ZONE SPA SPB;
*--------------------------------------*;
*          ZONE 10                     *;
*--------------------------------------*;
*------------------------------------------------------------------*;
DATA SPT10A; SET OC3;
    IF SENSOR=72;
ZONE=10;
       T10ASP=REALDATA;
       KEEP DATE TIME ZONE T10ASP;
       PROC SORT;
           BY DATE TIME;
*------------------------------------------------------------------*;
DATA SPT10B; SET OC3;
    IF SENSOR=96;
ZONE=10;
       T10BSP=REALDATA;
       KEEP DATE TIME ZONE T10BSP;
       PROC SORT;
           BY DATE TIME;
DATA SPX;
    MERGE SPT10A SPT10B;
       BY DATE TIME;
SPA=T10ASP;
SPB=T10BSP;
KEEP DATE TIME ZONE SPA SPB;
DATA SETPOINT;
  SET SPI SPII SPIII SPIV SPV SPVI SPVII SPVIII SPIX SPX;
PROC SORT;
  BY DATE TIME ZONE;
*--------------ZZZ ----------------------*;
           /*
PROC FORMAT;
  VALUE SG 1='ABOVE 900 C'
          -1='BELOW 900 C';
  VALUE M  1='>=-600 C'
```

```
         -1='< -600 C';
  VALUE NOT 1='>=-500 C'
           -1='< -500 C';
  VALUE SC 1='0-5'
           2='5-10'
           3='10-15'
           4='15-20'
           5='20-25'
           6='25-30'
           7='30-35'
           8='35-40'
           9='>40'
          -1='-5 -0'
          -2='-10 -5'
          -3='-15 -10'
          -4='-20 -15'
          -5='-25 -20'
          -6='-30 -25'
          -7='-35 -30'
          -8='-40 -35'
          -9='<-40';
             */

*------------------------------------------------------------*;
*  MERGED DATA SET CONTAINING SET POINTS AND FTC READINGS  *;
*  BY DAY TIME AND ZONE                                      *;
*------------------------------------------------------------*;
DATA TEMPS;
  MERGE FTC SETPOINT;
  BY DATE TIME ZONE;
DELTA_A=FTCA-SPA;
DELTA_B=FTCB-SPB;
DELTA_MN=MEAN(OF DELTA_A DELTA_B);

TEMP_A=DELTA_A+900;

TEMP_B=DELTA_B+900;

TEMP_MN=DELTA_MN+900;

PROC SORT;
  BY ZONE;

PROC MEANS N MEAN STD MIN MAX;
  VAR TEMP_A TEMP_B TEMP_MN;
  BY ZONE;


PROC MEANS N MEAN STD MIN MAX;
  VAR TEMP_A TEMP_B TEMP_MN;
```

```
ENDSAS;


IF DELTA_A<-600 THEN MTCA600=-1;
ELSE IF DELTA_A>=-600 THEN MTCA600=1;
ELSE MTCA600=.;

IF DELTA_B<-600 THEN MTCB600=-1;
ELSE IF DELTA_B>=-600 THEN MTCB600=1;
ELSE MTCB600=.;

IF DELTA_MN<-600 THEN MNMTC600=-1;
ELSE IF DELTA_MN>=-600 THEN MNMTC600=1;
ELSE MNMTC600=.;

IF DELTA_A<-500 THEN MTCA500=-1;
ELSE IF DELTA_A>=-500 THEN MTCA500=1;
ELSE MTCA500=.;

IF DELTA_B<-500 THEN MTCB500=-1;
ELSE IF DELTA_B>=-500 THEN MTCB500=1;
ELSE MTCB500=.;

IF DELTA_MN<-500 THEN MNMTC500=-1;
ELSE IF DELTA_MN>=-500 THEN MNMTC500=1;
ELSE MNMTC500=.;


IF DELTA_A>0 THEN DTA900=1;
ELSE DTA900=-1;
IF DELTA_B>0 THEN DTB900=1;
ELSE DTB900=-1;
IF DELTA_MN>0 THEN MNDT900=1;
ELSE MNDT900=-1;


*-----------------------------------------------------------*;
*  CREATING DELTA T CATEGORIES BASED ON DEGREES ABOVE AND   *;
*  BELOW 900 DEGREES                                        *;
*-----------------------------------------------------------*;
IF DELTA_A=0 THEN DTARANGE=0;
ELSE IF 0<DELTA_A<=5 THEN DTARANGE=1;
ELSE IF 5<DELTA_A<=10 THEN DTARANGE=2;
ELSE IF 10<DELTA_A<=15 THEN DTARANGE=3;
ELSE IF 15<DELTA_A<=20 THEN DTARANGE=4;
ELSE IF 20<DELTA_A<=25 THEN DTARANGE=5;
ELSE IF 25<DELTA_A<=30 THEN DTARANGE=6;
ELSE IF 30<DELTA_A<=35 THEN DTARANGE=7;
ELSE IF 35<DELTA_A<=40 THEN DTARANGE=8;
ELSE IF DELTA_A>40 THEN DTARANGE=9;
ELSE IF -5<=DELTA_A<0 THEN DTARANGE=-1;
```

```
ELSE IF -10<=DELTA_A<-5 THEN DTARANGE=-2;
ELSE IF -15<=DELTA_A<-10 THEN DTARANGE=-3;
ELSE IF -20<=DELTA_A<-15 THEN DTARANGE=-4;
ELSE IF -25<=DELTA_A<-20 THEN DTARANGE=-5;
ELSE IF -30<=DELTA_A<-25 THEN DTARANGE=-6;
ELSE IF -35<=DELTA_A<-30 THEN DTARANGE=-7;
ELSE IF -40<=DELTA_A<-35 THEN DTARANGE=-8;
ELSE IF DELTA_A<-40 THEN DTARANGE=-9;
ELSE DTARANGE=.;

IF DELTA_B=0 THEN DTBRANGE=0;
ELSE IF 0<DELTA_B<=5 THEN DTBRANGE=1;
ELSE IF 5<DELTA_B<=10 THEN DTBRANGE=2;
ELSE IF 10<DELTA_B<=15 THEN DTBRANGE=3;
ELSE IF 15<DELTA_B<=20 THEN DTBRANGE=4;
ELSE IF 20<DELTA_B<=25 THEN DTBRANGE=5;
ELSE IF 25<DELTA_B<=30 THEN DTBRANGE=6;
ELSE IF 30<DELTA_B<=35 THEN DTBRANGE=7;
ELSE IF 35<DELTA_B<=40 THEN DTBRANGE=8;
ELSE IF DELTA_B>40 THEN DTBRANGE=9;
ELSE IF -5<=DELTA_B<0 THEN DTBRANGE=-1;
ELSE IF -10<=DELTA_B<-5 THEN DTBRANGE=-2;
ELSE IF -15<=DELTA_B<-10 THEN DTBRANGE=-3;
ELSE IF -20<=DELTA_B<-15 THEN DTBRANGE=-4;
ELSE IF -25<=DELTA_B<-20 THEN DTBRANGE=-5;
ELSE IF -30<=DELTA_B<-25 THEN DTBRANGE=-6;
ELSE IF -35<=DELTA_B<-30 THEN DTBRANGE=-7;
ELSE IF -40<=DELTA_B<-35 THEN DTBRANGE=-8;
ELSE IF DELTA_B<-40 THEN DTBRANGE=-9;
ELSE DTBRANGE=.;

IF DELTA_MN=0 THEN MNRANGE=0;
ELSE IF 0<DELTA_MN<=5 THEN MNRANGE=1;
ELSE IF 5<DELTA_MN<=10 THEN MNRANGE=2;
ELSE IF 10<DELTA_MN<=15 THEN MNRANGE=3;
ELSE IF 15<DELTA_MN<=20 THEN MNRANGE=4;
ELSE IF 20<DELTA_MN<=25 THEN MNRANGE=5;
ELSE IF 25<DELTA_MN<=30 THEN MNRANGE=6;
ELSE IF 30<DELTA_MN<=35 THEN MNRANGE=7;
ELSE IF 35<DELTA_MN<=40 THEN MNRANGE=8;
ELSE IF DELTA_MN>40 THEN MNRANGE=9;
ELSE IF -5<=DELTA_MN<0 THEN MNRANGE=-1;
ELSE IF -10<=DELTA_MN<-5 THEN MNRANGE=-2;
ELSE IF -15<=DELTA_MN<-10 THEN MNRANGE=-3;
ELSE IF -20<=DELTA_MN<-15 THEN MNRANGE=-4;
ELSE IF -25<=DELTA_MN<-20 THEN MNRANGE=-5;
ELSE IF -30<=DELTA_MN<-25 THEN MNRANGE=-6;
ELSE IF -35<=DELTA_MN<-30 THEN MNRANGE=-7;
ELSE IF -40<=DELTA_MN<-35 THEN MNRANGE=-8;
ELSE IF DELTA_MN<-40 THEN MNRANGE=-9;
ELSE MNRANGE=.;
```

```
LABEL DTA900='A <OR> 900 C'
      DTB900='B <OR> 900 C'
      MNDT900='MEAN <OR> 900 C'
      DTARANGE='A < OR > 0 C'
      DTBRANGE='B < OR > 0 C'
      MNRANGE='MEAN < OR > 0 C'
      MTCA600='MTCA <OR> 600 C'
      MTCB600='MTCB <OR> 600 C'
      MNMTC600='MNMTC <OR> 600 C'
      MTCA500='MTCA <OR> 500 C'
      MTCB500='MTCB <OR> 500 C'
      MNMTC500='MNMTC <OR> 500 C';

FORMAT DATE DATE9. TIME TIME8. DTA900 DTB900 MNDT900 SG. MTCA600
       MTCB600 MNMTC600 M. DTARANGE DTBRANGE MNRANGE SC.
       MTCA500 MTCB500 MNMTC500 NOT.;

*---------------UNIVARIATE TABLES -------------------------*;
*---------------FOR DELTAS ABOVE AND BELOW 900 (0)C  ----------*;
OPTIONS LS=132 NODATE NONUMBER;

TITLE 'OC1, OC3,  AND OC5 (900 C)';
PROC SORT;
  BY ZONE DTA900;
PROC UNIVARIATE NOPRINT;
  VAR DELTA_A;
OUTPUT OUT=DAA N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE DTA900;

PROC PRINT DATA=DAA SPLIT='*';
  LABEL DTA900='A <OR>*  0 C';
  VAR ZONE DTA900 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW 0 C";

*----------------MEAN TEMPS BY ZONE FOR TABLE COMPRISING A, B, AND MEAN --*;
PROC SORT DATA=TEMPS;
  BY ZONE;
PROC MEANS DATA=TEMPS MEAN STD NOPRINT;
  VAR DELTA_A;
OUTPUT OUT=DAA2 MEAN=MEAN STD=STDA;
BY ZONE;
DATA DAA2; SET DAA2;
AT=900+MEAN;
KEEP ZONE AT STDA;
PROC SORT; BY ZONE;

PROC SORT DATA=TEMPS;
  BY ZONE DTB900;
```

```
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_B;
OUTPUT OUT=DBA N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE DTB900;

PROC PRINT DATA=DBA SPLIT='*';
  LABEL DTB900='B <OR>*  0 C';
  VAR ZONE DTB900 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW 0 C";


PROC SORT DATA=TEMPS;
  BY ZONE;
PROC MEANS DATA=TEMPS MEAN STD NOPRINT;
  VAR DELTA_B;
OUTPUT OUT=DBA2 MEAN=MEAN STD=STDB;
BY ZONE;
DATA DBA2; SET DBA2;
BT=900+MEAN;
KEEP ZONE BT STDB;
PROC SORT; BY ZONE;


PROC SORT DATA=TEMPS;
  BY ZONE MNDT900;
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_MN;
OUTPUT OUT=DMNA N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE MNDT900;

PROC PRINT DATA=DMNA SPLIT='*';
  LABEL MNDT900='MN <OR>*  0 C';
  VAR ZONE MNDT900 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW 0 C";

PROC SORT DATA=TEMPS;
  BY ZONE;
PROC MEANS DATA=TEMPS MEAN STD NOPRINT;
  VAR DELTA_MN;
OUTPUT OUT=DMNA2 MEAN=MEAN STD=STDMN;
BY ZONE;

DATA DMNA2; SET DMNA2;
MT=900+MEAN;
KEEP ZONE MT STDMN;
PROC SORT; BY ZONE;
```

```
*---------------UNIVARIATE TABLES --------------------------*;
*---------------FOR MTCS ABOVE AND BELOW -600 C  ----------*;
PROC SORT DATA=TEMPS;
  BY ZONE MTCA600;
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_A;
OUTPUT OUT=DAB N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE MTCA600;
PROC PRINT DATA=DAB SPLIT='*';
  LABEL MTCA600='A <OR>*-600 C';
  VAR ZONE MTCA600 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW -600 C";

PROC SORT DATA=TEMPS;
  BY ZONE MTCB600;
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_B;
OUTPUT OUT=DBB N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE MTCB600;
PROC PRINT DATA=DBB SPLIT='*';
  LABEL MTCB600='B <OR>*-600 C';
  VAR ZONE MTCB600 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW -600 C";


PROC SORT DATA=TEMPS;
  BY ZONE MNMTC600;
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_MN;
OUTPUT OUT=DMNB N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE MNMTC600;
PROC PRINT DATA=DMNB SPLIT='*';
  LABEL MNMTC600='MNMTC <OR>*-600 C';
  VAR ZONE MNMTC600 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW -600 C";


*---------------UNIVARIATE TABLES --------------------------*;
*---------------FOR MTCS ABOVE AND BELOW -500 C  ----------*;
PROC SORT DATA=TEMPS;
  BY ZONE MTCA500;
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_A;
OUTPUT OUT=DAB N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
```

```
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE MTCA500;
PROC PRINT DATA=DAB SPLIT='*';
  LABEL MTCA600='A <OR>*-500 C';
  VAR ZONE MTCA500 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW -500 C";

PROC SORT DATA=TEMPS;
  BY ZONE MTCB500;
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_B;
OUTPUT OUT=DBB N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE MTCB500;
PROC PRINT DATA=DBB SPLIT='*';
  LABEL MTCB500='B <OR>*-500 C';
  VAR ZONE MTCB500 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW -500 C";


PROC SORT DATA=TEMPS;
  BY ZONE MNMTC500;
PROC UNIVARIATE DATA=TEMPS NOPRINT;
  VAR DELTA_MN;
OUTPUT OUT=DMNB N=NUM MEAN=MEAN STD=STD MIN=MIN MAX=MAX Q1=Q1
               MEDIAN=MEDIAN Q3=Q3 MODE=MODE;
BY ZONE MNMTC500;
PROC PRINT DATA=DMNB SPLIT='*';
  LABEL MNMTC500='MNMTC <OR>*-500 C';
  VAR ZONE MNMTC500 NUM MEAN STD MODE MIN Q1 MEDIAN Q3 MAX;
TITLE2 'DESCRIPTIVE STATISTICS FOR TEMPERATURE BY ZONES:';
TITLE3 "GROUPED BY DELTA T's ABOVE AND BELOW -500 C";


*--------------  BAR CHARTS       --------------------------*;
*---------------FOR RANGE OF DELTAS ABOVE AND BELOW 900 C-*;
DATA TEMPS;
  SET TEMPS;
PROC SORT;
  BY ZONE;
OPTIONS LS=132;
PROC CHART;
  HBAR DTARANGE DTBRANGE MNRANGE/DISCRETE;
  BY ZONE;
TITLE2 "DISTRIBUTION OF DELTA T's ABOVE AND BELOW 0 C";
TITLE3 '            ';
*--------------  BAR CHARTS       --------------------------*;
*---------------FOR RANGE OF DELTAS ABOVE AND BELOW 900 C-*;
OPTIONS LS=132;
```

```
PROC CHART;
  VBAR DTARANGE DTBRANGE MNRANGE/DISCRETE NOSPACE;
  BY ZONE;
TITLE2 "DISTRIBUTION OF DELTA T's ABOVE AND BELOW 0 C";
TITLE3 '             ';

*--------------TABLES       -------------------------*;
*---------------FOR AVERAGE TEMPERATURES BY ZONE      ----*;
DATA A;
  MERGE DAA2 DBA2;
  BY ZONE;
OPTIONS LS=132;
DATA AVGT;
  MERGE A DMNA2;
  BY ZONE;
PROC PRINT DATA=AVGT SPLIT='*' NOOBS;
  LABEL AT='AVG TEMP*   A'
        BT='AVG TEMP*   B'
        MT='AVG TEMP*  MEAN'
        STDA='STD DEV*   A   '
        STDB='STD DEV*   B   '
        STDMN='STD DEV* MEAN  ';

  VAR ZONE AT STDA BT STDB MT STDMN;
TITLE2 'AVERAGE TEMPERATURES BY ZONES:';
TITLE3 "BASED ON DEVIATION OF DELTA T's ABOUT 0 C";


*--------------FREQUENCY TABLES -------------------------*;
*---------------FOR RANGE OF DELTAS ABOVE AND BELOW 900 C-*;
PROC FREQ DATA=TEMPS;
  TABLES ZONE*(DTARANGE DTBRANGE MNRANGE)/LIST;
OPTIONS LS=72;
TITLE2 "FREQUENCY DISTRIBUTION FOR RANGE OF DELTA T's";
TITLE3 'ABOVE AND BELOW 0 C';
ENDSAS;
*==============================================================*;
*==============================================================*;
*==============================================================*;
*==============================================================*;
    PROC PRINT;
       VAR DATE TIME;
       FORMAT DATE DATE9. TIME TIME8.;
*--------------------------------------------------------------*;
```

APPENDIX G

SAS CODES FOR REACTOR POWER ANALYSIS

```
*-------------------------------------------------------------------------*;
* This SAS program creates a SAS data set ( ALL.SASEB$DATA) for reactor    *;
* power for the OC-3 experiment.  Then, the second program in this appendix *;
* can be run to generate some plots for reactor power (REAPWR) versus time  *;
*-------------------------------------------------------------------------*;

*-------------------------------------------------------------------------*;
*  ZONE 1                                                                 *;
*-------------------------------------------------------------------------*;
OPTIONS FIRSTOBS=2 LS=72;
DATA Z1;
INPUT ZONE 1-2 @3 DAY DATE9. @12 T TIME8. TL 20-23
    OLDSPA 24-37 NEWSPA 38-51 REAPWR 52-65;
DROP DAY T;
CARDS;
 1        .       .   .          .          830.000     24256.390
 128FEB197916:58:01 114       830.000       823.215  29896000.000
 128FEB197917:28:01   6       823.215       823.065  29871740.000
 128FEB197923:03:02  67       823.065       823.064  29859620.000
 101MAR197910:08:00 133       823.064       833.000  29993020.000
 102MAR197910:08:00 288       833.000       836.655  29956640.000
 102MAR197914:33:00  53       836.655       844.354  30174940.000
 105MAR197915:35:00 876       844.354       844.199  29908130.000
 105MAR197919:00:00  41       844.199       844.349  30102180.000
 106MAR197912:25:00 209       844.349       846.050  30029410.000
 107MAR197911:25:00 276       846.050       845.899  29896000.000
 108MAR197913:20:03 263       845.899       830.000     12128.200
 108MAR197915:45:00  29       830.000       828.062  28925740.000
 108MAR197917:05:01  16       828.062       854.000  29010640.000
 108MAR197919:35:00  30       854.000       853.100  29604910.000
 108MAR197921:20:00  21       853.100       853.101  29495760.000
 109MAR197911:50:01 174       853.101       846.601  29629170.000
 112MAR197910:00:00 842       846.601       846.604  29677700.000
 113MAR197910:50:01 298       846.604       849.604  29726210.000
 114MAR197911:00:00 290       849.604       848.803  29726210.000
 115MAR197911:20:00 292       848.803       847.653  29738340.000
 116MAR197914:30:00 326       847.653       847.504  29835360.000
 119MAR197910:55:00 821       847.504       845.905  29641300.000
 120MAR197910:45:00 286       845.905       847.056  29532140.000
 121MAR197911:25:00 296       847.056       846.256  29726210.000
 122MAR197910:15:00 274       846.256       854.000     12128.200
 122MAR197914:05:00  46       854.000       852.651  28901490.000
 122MAR197915:50:00  21       852.651       856.651  29495760.000
 123MAR197910:50:00 228       856.651       856.648  29871740.000
 123MAR197912:25:00  19       856.648       854.648  29726210.000
 126MAR197910:05:00 836       854.648       853.799  29665550.000
 127MAR197914:25:00 340       853.799       854.050  30114300.000
 104APR197918:59:01 630       854.050       854.399  29920260.000
 105APR1979 9:49:00 178       854.399       849.250  29471500.000
 105APR197911:49:00  24       849.250       853.253  29641300.000
 106APR197910:04:00 267       853.253       851.250  29871740.000
```

109APR197910:59:00 875	851.250	850.952	29447250.000
110APR197910:14:00 279	850.952	847.952	29677700.000
111APR197910:44:00 294	847.952	851.954	29750460.000
112APR197910:59:00 291	851.954	851.801	29580660.000
116APR197910:24:001145	851.801	850.502	29908130.000
117APR197913:24:00 324	850.502	851.502	29871740.000
118APR1979 9:24:00 240	851.502	851.501	29859620.000
118APR197914:39:00 63	851.501	847.501	29726210.000
119APR197910:49:00 242	847.501	849.205	29762590.000
123APR1979 9:04:001131	849.205	852.000	12128.200
103MAY197916:19:00 103	852.000	863.000	29786850.000
103MAY197918:34:00 27	863.000	864.545	29835360.000
104MAY197912:44:01 218	864.545	861.544	29495760.000
105MAY197916:09:00 329	861.544	857.745	29604910.000
107MAY197912:14:00 529	857.745	857.048	29968770.000
109MAY1979 9:59:00 549	857.048	859.048	29823230.000
110MAY197910:04:02 289	859.048	856.897	29956640.000
111MAY197913:54:01 334	856.897	858.598	29968770.000
114MAY197911:08:00 659	858.598	857.897	29410860.000
116MAY197910:23:00 566	857.897	857.748	29883870.000
117MAY197910:48:00 293	857.748	854.747	29956640.000
118MAY197910:53:00 289	854.747	852.899	29944510.000
121MAY197910:48:00 863	852.899	850.600	30041540.000
123MAY1979 8:41:00 269	850.600	863.000	12128.200
123MAY197913:56:00 63	863.000	855.095	29641300.000
123MAY197916:21:02 29	855.095	855.249	29726210.000
124MAY1979 9:31:02 206	855.249	851.399	29641300.000
125MAY197911:31:02 312	851.399	851.551	29604910.000
128MAY197912:26:00 870	851.551	849.701	29798980.000
129MAY197913:06:00 296	849.701	851.552	30029410.000
131MAY197910:31:02 545	851.552	852.402	29714080.000
101JUN1979 9:41:02 278	852.402	851.401	29823230.000
104JUN197911:36:00 887	851.401	852.102	29689820.000
106JUN197910:51:02 567	852.102	848.951	29665550.000
108JUN1979 9:56:00 565	848.951	849.953	29726210.000
111JUN197913:56:00 912	849.953	855.000	12128.200
112JUN197913:21:02 281	855.000	851.299	29993020.000
112JUN197915:51:02 30	851.299	855.302	30138560.000
113JUN197910:16:00 221	855.302	849.749	29993020.000
114JUN197914:26:00 338	849.749	849.603	29908130.000
115JUN1979 9:26:00 228	849.603	843.752	29920260.000
116JUN197920:46:01 424	843.752	841.756	29883870.000
118JUN197911:26:00 464	841.756	843.906	29798980.000
120JUN197910:36:00 566	843.906	839.905	29835360.000
120JUN197913:31:00 35	839.905	839.057	29835360.000
125JUN197910:56:00 875	839.057	840.609	29835360.000
125JUN197911:21:02 5	840.609	840.309	29835360.000
126JUN1979 9:26:00 265	840.309	855.000	24256.390
126JUN197917:06:00 92	855.000	856.457	30187070.000
126JUN197917:36:00 6	856.457	851.602	30174940.000
126JUN197920:26:00 34	851.602	844.601	30284100.000

```
 126JUN197922:36:00  26       844.601        844.606  30126430.000
 127JUN197910:01:01 137       844.606        843.605  29762590.000
 128JUN197919:51:02 406       843.605        842.307  29471500.000
 129JUN197913:21:02 210       842.307        841.457  29859620.000
 102JUL197911:21:00 840       841.457        841.168  29871740.000
 105JUL1979 9:41:02 844       841.168        842.306  30077920.000
 106JUL197911:11:00 306       842.306        843.457  29604910.000
;
OPTIONS FIRSTOBS=1;
DATA T1;
  SET Z1;
N=_N_;
L1=LAG1(TL);
L2=LAG2(TL);
L3=LAG3(TL);
L4=LAG4(TL);
L5=LAG5(TL);
L6=LAG6(TL);
L7=LAG7(TL);
L8=LAG8(TL);
L9=LAG9(TL);
L10=LAG10(TL);
L11=LAG11(TL);
L12=LAG12(TL);
L13=LAG13(TL);
L14=LAG14(TL);
L15=LAG15(TL);
L16=LAG16(TL);
L17=LAG17(TL);
L18=LAG18(TL);
L19=LAG19(TL);
L20=LAG20(TL);
L21=LAG21(TL);
L22=LAG22(TL);
L23=LAG23(TL);
L24=LAG24(TL);
L25=LAG25(TL);
L26=LAG26(TL);
L27=LAG27(TL);
L28=LAG28(TL);
L29=LAG29(TL);
L30=LAG30(TL);
L31=LAG31(TL);
L32=LAG32(TL);
L33=LAG33(TL);
L34=LAG34(TL);
L35=LAG35(TL);
L36=LAG36(TL);
L37=LAG37(TL);
L38=LAG38(TL);
L39=LAG39(TL);
```

```
L40=LAG40(TL);
L41=LAG41(TL);
L42=LAG42(TL);
L43=LAG43(TL);
L44=LAG44(TL);
L45=LAG45(TL);
L46=LAG46(TL);
L47=LAG47(TL);
L48=LAG48(TL);
L49=LAG49(TL);
L50=LAG50(TL);
L51=LAG51(TL);
L52=LAG52(TL);
L53=LAG53(TL);
L54=LAG54(TL);
L55=LAG55(TL);
L56=LAG56(TL);
L57=LAG57(TL);
L58=LAG58(TL);
L59=LAG59(TL);
L60=LAG60(TL);
L61=LAG61(TL);
L62=LAG62(TL);
L63=LAG63(TL);
L64=LAG64(TL);
L65=LAG65(TL);
L66=LAG66(TL);
L67=LAG67(TL);
L68=LAG68(TL);
L69=LAG69(TL);
L70=LAG70(TL);
L71=LAG71(TL);
L72=LAG72(TL);
L73=LAG73(TL);
L74=LAG74(TL);
L75=LAG75(TL);
L76=LAG76(TL);
L77=LAG77(TL);
L78=LAG78(TL);
L79=LAG79(TL);
L80=LAG80(TL);
L81=LAG81(TL);
L82=LAG82(TL);
L83=LAG83(TL);
L84=LAG84(TL);
L85=LAG85(TL);
L86=LAG86(TL);
L87=LAG87(TL);
L88=LAG88(TL);
L89=LAG89(TL);
L90=LAG90(TL);
```

```
L91=LAG91(TL);
L92=LAG92(TL);
L93=LAG93(TL);
IF N=1 THEN TIME=TL;
ELSE IF N=2 THEN TIME=TL+L1;
ELSE IF N=3 THEN TIME=TL+L1+L2;
ELSE IF N=4 THEN TIME=TL+L1+L2+L3;
ELSE IF N=5 THEN TIME=TL+L1+L2+L3+L4;
ELSE IF N=6 THEN TIME=TL+L1+L2+L3+L4+L5;
ELSE IF N=7 THEN TIME=TL+L1+L2+L3+L4+L5+L6;
ELSE IF N=8 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7;
ELSE IF N=9 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7+L8;
ELSE IF N=10 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7+L8+L9;
ELSE IF N=11 THEN TIME=TL+(SUM(OF L1--L10));
ELSE IF N=12 THEN TIME=TL+(SUM(OF L1--L11));
ELSE IF N=13 THEN TIME=TL+(SUM(OF L1--L12));
ELSE IF N=14 THEN TIME=TL+(SUM(OF L1--L13));
ELSE IF N=15 THEN TIME=TL+(SUM(OF L1--L14));
ELSE IF N=16 THEN TIME=TL+(SUM(OF L1--L15));
ELSE IF N=17 THEN TIME=TL+(SUM(OF L1--L16));
ELSE IF N=18 THEN TIME=TL+(SUM(OF L1--L17));
ELSE IF N=19 THEN TIME=TL+(SUM(OF L1--L18));
ELSE IF N=20 THEN TIME=TL+(SUM(OF L1--L19));
ELSE IF N=21 THEN TIME=TL+(SUM(OF L1--L20));
ELSE IF N=22 THEN TIME=TL+(SUM(OF L1--L21));
ELSE IF N=23 THEN TIME=TL+(SUM(OF L1--L22));
ELSE IF N=24 THEN TIME=TL+(SUM(OF L1--L23));
ELSE IF N=25 THEN TIME=TL+(SUM(OF L1--L24));
ELSE IF N=26 THEN TIME=TL+(SUM(OF L1--L25));
ELSE IF N=27 THEN TIME=TL+(SUM(OF L1--L26));
ELSE IF N=28 THEN TIME=TL+(SUM(OF L1--L27));
ELSE IF N=29 THEN TIME=TL+(SUM(OF L1--L28));
ELSE IF N=30 THEN TIME=TL+(SUM(OF L1--L29));
ELSE IF N=31 THEN TIME=TL+(SUM(OF L1--L30));
ELSE IF N=32 THEN TIME=TL+(SUM(OF L1--L31));
ELSE IF N=33 THEN TIME=TL+(SUM(OF L1--L32));
ELSE IF N=34 THEN TIME=TL+(SUM(OF L1--L33));
ELSE IF N=35 THEN TIME=TL+(SUM(OF L1--L34));
ELSE IF N=36 THEN TIME=TL+(SUM(OF L1--L35));
ELSE IF N=37 THEN TIME=TL+(SUM(OF L1--L36));
ELSE IF N=38 THEN TIME=TL+(SUM(OF L1--L37));
ELSE IF N=39 THEN TIME=TL+(SUM(OF L1--L38));
ELSE IF N=40 THEN TIME=TL+(SUM(OF L1--L39));
ELSE IF N=41 THEN TIME=TL+(SUM(OF L1--L40));
ELSE IF N=42 THEN TIME=TL+(SUM(OF L1--L41));
ELSE IF N=43 THEN TIME=TL+(SUM(OF L1--L42));
ELSE IF N=44 THEN TIME=TL+(SUM(OF L1--L43));
ELSE IF N=45 THEN TIME=TL+(SUM(OF L1--L44));
ELSE IF N=46 THEN TIME=TL+(SUM(OF L1--L45));
ELSE IF N=47 THEN TIME=TL+(SUM(OF L1--L46));
ELSE IF N=48 THEN TIME=TL+(SUM(OF L1--L47));
```

```
ELSE IF N=49 THEN TIME=TL+(SUM(OF L1--L48));
ELSE IF N=50 THEN TIME=TL+(SUM(OF L1--L49));
ELSE IF N=51 THEN TIME=TL+(SUM(OF L1--L50));
ELSE IF N=52 THEN TIME=TL+(SUM(OF L1--L51));
ELSE IF N=53 THEN TIME=TL+(SUM(OF L1--L52));
ELSE IF N=54 THEN TIME=TL+(SUM(OF L1--L53));
ELSE IF N=55 THEN TIME=TL+(SUM(OF L1--L54));
ELSE IF N=56 THEN TIME=TL+(SUM(OF L1--L55));
ELSE IF N=57 THEN TIME=TL+(SUM(OF L1--L56));
ELSE IF N=58 THEN TIME=TL+(SUM(OF L1--L57));
ELSE IF N=59 THEN TIME=TL+(SUM(OF L1--L58));
ELSE IF N=60 THEN TIME=TL+(SUM(OF L1--L59));
ELSE IF N=61 THEN TIME=TL+(SUM(OF L1--L60));
ELSE IF N=62 THEN TIME=TL+(SUM(OF L1--L61));
ELSE IF N=63 THEN TIME=TL+(SUM(OF L1--L62));
ELSE IF N=64 THEN TIME=TL+(SUM(OF L1--L63));
ELSE IF N=65 THEN TIME=TL+(SUM(OF L1--L64));
ELSE IF N=66 THEN TIME=TL+(SUM(OF L1--L65));
ELSE IF N=67 THEN TIME=TL+(SUM(OF L1--L66));
ELSE IF N=68 THEN TIME=TL+(SUM(OF L1--L67));
ELSE IF N=69 THEN TIME=TL+(SUM(OF L1--L68));
ELSE IF N=70 THEN TIME=TL+(SUM(OF L1--L69));
ELSE IF N=71 THEN TIME=TL+(SUM(OF L1--L70));
ELSE IF N=72 THEN TIME=TL+(SUM(OF L1--L71));
ELSE IF N=73 THEN TIME=TL+(SUM(OF L1--L72));
ELSE IF N=74 THEN TIME=TL+(SUM(OF L1--L73));
ELSE IF N=75 THEN TIME=TL+(SUM(OF L1--L74));
ELSE IF N=76 THEN TIME=TL+(SUM(OF L1--L75));
ELSE IF N=77 THEN TIME=TL+(SUM(OF L1--L76));
ELSE IF N=78 THEN TIME=TL+(SUM(OF L1--L77));
ELSE IF N=79 THEN TIME=TL+(SUM(OF L1--L78));
ELSE IF N=80 THEN TIME=TL+(SUM(OF L1--L79));
ELSE IF N=81 THEN TIME=TL+(SUM(OF L1--L80));
ELSE IF N=82 THEN TIME=TL+(SUM(OF L1--L81));
ELSE IF N=83 THEN TIME=TL+(SUM(OF L1--L82));
ELSE IF N=84 THEN TIME=TL+(SUM(OF L1--L83));
ELSE IF N=85 THEN TIME=TL+(SUM(OF L1--L84));
ELSE IF N=86 THEN TIME=TL+(SUM(OF L1--L85));
ELSE IF N=87 THEN TIME=TL+(SUM(OF L1--L86));
ELSE IF N=88 THEN TIME=TL+(SUM(OF L1--L87));
ELSE IF N=89 THEN TIME=TL+(SUM(OF L1--L88));
ELSE IF N=90 THEN TIME=TL+(SUM(OF L1--L89));
ELSE IF N=91 THEN TIME=TL+(SUM(OF L1--L90));
ELSE IF N=92 THEN TIME=TL+(SUM(OF L1--L91));
ELSE IF N=93 THEN TIME=TL+(SUM(OF L1--L92));
ELSE IF N=94 THEN TIME=TL+(SUM(OF L1--L93));
ELSE TIME=.;
*-----------------------------------------------------------------------*;
*-----------------------------------------------------------------------*;
*  ZONE 2                                                               *;
*-----------------------------------------------------------------------*;
```

```
OPTIONS FIRSTOBS=2 LS=72;
DATA Z2;
INPUT ZONE 1-2 @3 DAY DATE9. @12 T TIME8. TL 20-23
    OLDSPA 24-37 NEWSPA 38-51 REAPWR 52-65;
DROP DAY T;
CARDS;
 2        .       .  .           .           820.000     24256.390
 228FEB197916:58:01 114       820.000        830.000  29896000.000
 228FEB197917:28:01   6       830.000        836.662  29871740.000
 228FEB197923:03:02  67       836.662        840.664  29859620.000
 201MAR197910:08:00 133       840.664        844.964  29993020.000
 202MAR197910:08:00 288       844.964        840.120  29956640.000
 202MAR197914:33:00  53       840.120        846.411  30174940.000
 205MAR197915:35:00 876       846.411        844.717  29908130.000
 205MAR197919:00:00  41       844.717        845.014  30102180.000
 206MAR197912:25:00 209       845.014        848.312  30029410.000
 207MAR197911:25:00 276       848.312        848.466  29896000.000
 208MAR197913:20:03 263       848.466        820.000     12128.200
 208MAR197915:45:00  29       820.000        824.313  28925740.000
 208MAR197917:05:01  16       824.313        850.000  29010640.000
 208MAR197919:35:00  30       850.000        851.690  29604910.000
 208MAR197921:20:00  21       851.690        851.691  29495760.000
 209MAR197911:50:01 174       851.691        846.840  29629170.000
 212MAR197910:00:00 842       846.840        845.985  29677700.000
 213MAR197910:50:01 298       845.985        850.283  29726210.000
 214MAR197911:00:00 290       850.283        849.586  29726210.000
 215MAR197911:20:00 292       849.586        848.085  29738340.000
 216MAR197914:30:00 326       848.085        848.383  29835360.000
 219MAR197910:55:00 821       848.383        847.683  29641300.000
 220MAR197910:45:00 286       847.683        850.329  29532140.000
 221MAR197911:25:00 296       850.329        850.483  29726210.000
 222MAR197910:15:00 274       850.483        850.000     12128.200
 222MAR197914:05:00  46       850.000        851.936  28901490.000
 222MAR197915:50:00  21       851.936        856.088  29495760.000
 223MAR197910:50:00 228       856.088        856.393  29871740.000
 223MAR197912:25:00  19       856.393        854.542  29726210.000
 226MAR197910:05:00 836       854.542        852.690  29665550.000
 227MAR197914:25:00 340       852.690        854.985  30114300.000
 204APR197918:59:01 630       854.985        853.593  29920260.000
 205APR1979 9:49:00 178       853.593        849.343  29471500.000
 205APR197911:49:00  24       849.343        853.637  29641300.000
 206APR197910:04:00 267       853.637        851.342  29871740.000
 209APR197910:59:00 875       851.342        851.490  29447250.000
 210APR197910:14:00 279       851.490        849.341  29677700.000
 211APR197910:44:00 294       849.341        853.936  29750460.000
 212APR197910:59:00 291       853.936        854.540  29580660.000
 216APR197910:24:001145       854.540        851.790  29908130.000
 217APR197913:24:00 324       851.790        853.937  29871740.000
 218APR1979 9:24:00 240       853.937        853.792  29859620.000
 218APR197914:39:00  63       853.792        850.941  29726210.000
 219APR197910:49:00 242       850.941        853.235  29762590.000
```

```
 223APR1979 9:04:001131        853.235        851.000     12128.200
 203MAY197916:19:00 103        851.000        859.941  29786850.000
 203MAY197918:34:00  27        859.941        859.220  29835360.000
 204MAY197912:44:01 218        859.220        859.370  29495760.000
 205MAY197916:09:00 329        859.370        854.370  29604910.000
 207MAY197912:14:00 529        854.370        852.370  29968770.000
 210MAY197910:04:02 838        852.370        851.370  29956640.000
 211MAY197913:54:01 334        851.370        852.370  29968770.000
 214MAY197911:08:00 659        852.370        851.370  29410860.000
 217MAY197910:48:00 859        851.370        848.370  29956640.000
 218MAY197910:53:00 289        848.370        846.370  29944510.000
 221MAY197910:48:00 863        846.370        843.370  30041540.000
 223MAY1979 8:41:00 269        843.370        859.000     12128.200
 223MAY197913:56:00  63        859.000        847.900  29641300.000
 223MAY197916:21:02  29        847.900        849.025  29726210.000
 224MAY1979 9:31:02 206        849.025        846.025  29641300.000
 225MAY197911:31:02 312        846.025        845.025  29604910.000
 228MAY197912:26:00 870        845.025        843.025  29798980.000
 229MAY197913:06:00 296        843.025        845.025  30029410.000
 231MAY197910:31:02 545        845.025        844.875  29714080.000
 201JUN1979 9:41:02 278        844.875        843.025  29823230.000
 204JUN197911:36:00 887        843.025        843.875  29689820.000
 206JUN197910:51:02 567        843.875        841.025  29665550.000
 208JUN1979 9:56:00 565        841.025        842.025  29726210.000
 211JUN197913:56:00 912        842.025        849.000     12128.200
 212JUN197913:21:02 281        849.000        846.000  29993020.000
 212JUN197915:51:02  30        846.000        850.000  30138560.000
 213JUN197910:16:00 221        850.000        843.000  29993020.000
 214JUN197914:26:00 338        843.000        846.000  29908130.000
 215JUN1979 9:26:00 228        846.000        847.000  29920260.000
 216JUN197920:46:01 424        847.000        845.000  29883870.000
 218JUN197911:26:00 464        845.000        848.000  29798980.000
 220JUN197910:36:00 566        848.000        845.850  29835360.000
 220JUN197913:31:00  35        845.850        846.000  29835360.000
 225JUN197910:56:00 875        846.000        843.000  29835360.000
 225JUN197911:21:02   5        843.000        847.850  29835360.000
 226JUN1979 9:26:00 265        847.850        849.000     24256.390
 226JUN197917:06:00  92        849.000        850.850  30187070.000
 226JUN197917:36:00   6        850.850        851.000  30174940.000
 226JUN197920:26:00  34        851.000        843.000  30284100.000
 228JUN197919:51:02 569        843.000        843.500  29471500.000
 229JUN197913:21:02 210        843.500        842.649  29859620.000
 202JUL197911:21:00 840        842.649        846.351  29871740.000
 205JUL1979 9:41:02 844        846.351        844.000  30077920.000
 206JUL197911:11:00 306        844.000        843.851  29604910.000
;
OPTIONS FIRSTOBS=1;
DATA T2;
  SET Z2;
N=_N_;
L1=LAG1(TL);
```

```
L2=LAG2(TL);
L3=LAG3(TL);
L4=LAG4(TL);
L5=LAG5(TL);
L6=LAG6(TL);
L7=LAG7(TL);
L8=LAG8(TL);
L9=LAG9(TL);
L10=LAG10(TL);
L11=LAG11(TL);
L12=LAG12(TL);
L13=LAG13(TL);
L14=LAG14(TL);
L15=LAG15(TL);
L16=LAG16(TL);
L17=LAG17(TL);
L18=LAG18(TL);
L19=LAG19(TL);
L20=LAG20(TL);
L21=LAG21(TL);
L22=LAG22(TL);
L23=LAG23(TL);
L24=LAG24(TL);
L25=LAG25(TL);
L26=LAG26(TL);
L27=LAG27(TL);
L28=LAG28(TL);
L29=LAG29(TL);
L30=LAG30(TL);
L31=LAG31(TL);
L32=LAG32(TL);
L33=LAG33(TL);
L34=LAG34(TL);
L35=LAG35(TL);
L36=LAG36(TL);
L37=LAG37(TL);
L38=LAG38(TL);
L39=LAG39(TL);
L40=LAG40(TL);
L41=LAG41(TL);
L42=LAG42(TL);
L43=LAG43(TL);
L44=LAG44(TL);
L45=LAG45(TL);
L46=LAG46(TL);
L47=LAG47(TL);
L48=LAG48(TL);
L49=LAG49(TL);
L50=LAG50(TL);
L51=LAG51(TL);
L52=LAG52(TL);
```

```
L53=LAG53(TL);
L54=LAG54(TL);
L55=LAG55(TL);
L56=LAG56(TL);
L57=LAG57(TL);
L58=LAG58(TL);
L59=LAG59(TL);
L60=LAG60(TL);
L61=LAG61(TL);
L62=LAG62(TL);
L63=LAG63(TL);
L64=LAG64(TL);
L65=LAG65(TL);
L66=LAG66(TL);
L67=LAG67(TL);
L68=LAG68(TL);
L69=LAG69(TL);
L70=LAG70(TL);
L71=LAG71(TL);
L72=LAG72(TL);
L73=LAG73(TL);
L74=LAG74(TL);
L75=LAG75(TL);
L76=LAG76(TL);
L77=LAG77(TL);
L78=LAG78(TL);
L79=LAG79(TL);
L80=LAG80(TL);
L81=LAG81(TL);
L82=LAG82(TL);
L83=LAG83(TL);
L84=LAG84(TL);
L85=LAG85(TL);
L86=LAG86(TL);
L87=LAG87(TL);
L88=LAG88(TL);
L89=LAG89(TL);
L90=LAG90(TL);
L91=LAG91(TL);
L92=LAG92(TL);
L93=LAG93(TL);
IF N=1 THEN TIME=TL;
ELSE IF N=2 THEN TIME=TL+L1;
ELSE IF N=3 THEN TIME=TL+L1+L2;
ELSE IF N=4 THEN TIME=TL+L1+L2+L3;
ELSE IF N=5 THEN TIME=TL+L1+L2+L3+L4;
ELSE IF N=6 THEN TIME=TL+L1+L2+L3+L4+L5;
ELSE IF N=7 THEN TIME=TL+L1+L2+L3+L4+L5+L6;
ELSE IF N=8 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7;
ELSE IF N=9 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7+L8;
ELSE IF N=10 THEN TIME=TL+L1+L2+L3+L4+L5+L6+L7+L8+L9;
```

```
ELSE IF N=11 THEN TIME=TL+(SUM(OF L1--L10));
ELSE IF N=12 THEN TIME=TL+(SUM(OF L1--L11));
ELSE IF N=13 THEN TIME=TL+(SUM(OF L1--L12));
ELSE IF N=14 THEN TIME=TL+(SUM(OF L1--L13));
ELSE IF N=15 THEN TIME=TL+(SUM(OF L1--L14));
ELSE IF N=16 THEN TIME=TL+(SUM(OF L1--L15));
ELSE IF N=17 THEN TIME=TL+(SUM(OF L1--L16));
ELSE IF N=18 THEN TIME=TL+(SUM(OF L1--L17));
ELSE IF N=19 THEN TIME=TL+(SUM(OF L1--L18));
ELSE IF N=20 THEN TIME=TL+(SUM(OF L1--L19));
ELSE IF N=21 THEN TIME=TL+(SUM(OF L1--L20));
ELSE IF N=22 THEN TIME=TL+(SUM(OF L1--L21));
ELSE IF N=23 THEN TIME=TL+(SUM(OF L1--L22));
ELSE IF N=24 THEN TIME=TL+(SUM(OF L1--L23));
ELSE IF N=25 THEN TIME=TL+(SUM(OF L1--L24));
ELSE IF N=26 THEN TIME=TL+(SUM(OF L1--L25));
ELSE IF N=27 THEN TIME=TL+(SUM(OF L1--L26));
ELSE IF N=28 THEN TIME=TL+(SUM(OF L1--L27));
ELSE IF N=29 THEN TIME=TL+(SUM(OF L1--L28));
ELSE IF N=30 THEN TIME=TL+(SUM(OF L1--L29));
ELSE IF N=31 THEN TIME=TL+(SUM(OF L1--L30));
ELSE IF N=32 THEN TIME=TL+(SUM(OF L1--L31));
ELSE IF N=33 THEN TIME=TL+(SUM(OF L1--L32));
ELSE IF N=34 THEN TIME=TL+(SUM(OF L1--L33));
ELSE IF N=35 THEN TIME=TL+(SUM(OF L1--L34));
ELSE IF N=36 THEN TIME=TL+(SUM(OF L1--L35));
ELSE IF N=37 THEN TIME=TL+(SUM(OF L1--L36));
ELSE IF N=38 THEN TIME=TL+(SUM(OF L1--L37));
ELSE IF N=39 THEN TIME=TL+(SUM(OF L1--L38));
ELSE IF N=40 THEN TIME=TL+(SUM(OF L1--L39));
ELSE IF N=41 THEN TIME=TL+(SUM(OF L1--L40));
ELSE IF N=42 THEN TIME=TL+(SUM(OF L1--L41));
ELSE IF N=43 THEN TIME=TL+(SUM(OF L1--L42));
ELSE IF N=44 THEN TIME=TL+(SUM(OF L1--L43));
ELSE IF N=45 THEN TIME=TL+(SUM(OF L1--L44));
ELSE IF N=46 THEN TIME=TL+(SUM(OF L1--L45));
ELSE IF N=47 THEN TIME=TL+(SUM(OF L1--L46));
ELSE IF N=48 THEN TIME=TL+(SUM(OF L1--L47));
ELSE IF N=49 THEN TIME=TL+(SUM(OF L1--L48));
ELSE IF N=50 THEN TIME=TL+(SUM(OF L1--L49));
ELSE IF N=51 THEN TIME=TL+(SUM(OF L1--L50));
ELSE IF N=52 THEN TIME=TL+(SUM(OF L1--L51));
ELSE IF N=53 THEN TIME=TL+(SUM(OF L1--L52));
ELSE IF N=54 THEN TIME=TL+(SUM(OF L1--L53));
ELSE IF N=55 THEN TIME=TL+(SUM(OF L1--L54));
ELSE IF N=56 THEN TIME=TL+(SUM(OF L1--L55));
ELSE IF N=57 THEN TIME=TL+(SUM(OF L1--L56));
ELSE IF N=58 THEN TIME=TL+(SUM(OF L1--L57));
ELSE IF N=59 THEN TIME=TL+(SUM(OF L1--L58));
ELSE IF N=60 THEN TIME=TL+(SUM(OF L1--L59));
ELSE IF N=61 THEN TIME=TL+(SUM(OF L1--L60));
```

```
ELSE IF N=62 THEN TIME=TL+(SUM(OF L1--L61));
ELSE IF N=63 THEN TIME=TL+(SUM(OF L1--L62));
ELSE IF N=64 THEN TIME=TL+(SUM(OF L1--L63));
ELSE IF N=65 THEN TIME=TL+(SUM(OF L1--L64));
ELSE IF N=66 THEN TIME=TL+(SUM(OF L1--L65));
ELSE IF N=67 THEN TIME=TL+(SUM(OF L1--L66));
ELSE IF N=68 THEN TIME=TL+(SUM(OF L1--L67));
ELSE IF N=69 THEN TIME=TL+(SUM(OF L1--L68));
ELSE IF N=70 THEN TIME=TL+(SUM(OF L1--L69));
ELSE IF N=71 THEN TIME=TL+(SUM(OF L1--L70));
ELSE IF N=72 THEN TIME=TL+(SUM(OF L1--L71));
ELSE IF N=73 THEN TIME=TL+(SUM(OF L1--L72));
ELSE IF N=74 THEN TIME=TL+(SUM(OF L1--L73));
ELSE IF N=75 THEN TIME=TL+(SUM(OF L1--L74));
ELSE IF N=76 THEN TIME=TL+(SUM(OF L1--L75));
ELSE IF N=77 THEN TIME=TL+(SUM(OF L1--L76));
ELSE IF N=78 THEN TIME=TL+(SUM(OF L1--L77));
ELSE IF N=79 THEN TIME=TL+(SUM(OF L1--L78));
ELSE IF N=80 THEN TIME=TL+(SUM(OF L1--L79));
ELSE IF N=81 THEN TIME=TL+(SUM(OF L1--L80));
ELSE IF N=82 THEN TIME=TL+(SUM(OF L1--L81));
ELSE IF N=83 THEN TIME=TL+(SUM(OF L1--L82));
ELSE IF N=84 THEN TIME=TL+(SUM(OF L1--L83));
ELSE IF N=85 THEN TIME=TL+(SUM(OF L1--L84));
ELSE IF N=86 THEN TIME=TL+(SUM(OF L1--L85));
ELSE IF N=87 THEN TIME=TL+(SUM(OF L1--L86));
ELSE IF N=88 THEN TIME=TL+(SUM(OF L1--L87));
ELSE IF N=89 THEN TIME=TL+(SUM(OF L1--L88));
ELSE IF N=90 THEN TIME=TL+(SUM(OF L1--L89));
ELSE IF N=91 THEN TIME=TL+(SUM(OF L1--L90));
ELSE IF N=92 THEN TIME=TL+(SUM(OF L1--L91));
ELSE IF N=93 THEN TIME=TL+(SUM(OF L1--L92));
ELSE IF N=94 THEN TIME=TL+(SUM(OF L1--L93));
ELSE TIME=.;
*----------------------------------------------------------------------*;

*----------------------------------------------------------------------*;
*  The remaining zones (zones 3 through 10) should be treated in a similar  *;
*  manner.                                                              *;
*----------------------------------------------------------------------*;
*------------------------------------------------------------------*;
DATA ALL;
 SET T1 T2 T3 T4 T5 T6 T7 T8 T9 T10;
DROP L1-L93 N;
LIBNAME REAP900  '[AMOBASH.ORROC3.REAPWR]';
DATA REAP900.ALL;
  SET ALL;
ENDSAS;
```

```
*============================================================================*
*  This SAS/GRAPH program plots the reactor power vs time for the OC-3       *
*  experiment.  The time axis (in five_minute intervals) is the time         *
*  at which a correction to the setpoint of a zone has been made.            *
*============================================================================*;
FILENAME POSTSC 'RP900ZALLP.PS';
GOPTIONS DEVICE=PS300 GSFMODE=APPEND GSFNAME=POSTSC NOPROMPT
  NODISPLAY HSIZE=7.0 VSIZE=9.5;
OPTIONS LS=72;
*-----------------------------------------------------------------------------;
LIBNAME REAP900 '[AMOBASH.ORROC3.REAPWR]';
DATA REAP;
  SET REAP900.ALL;

             REAPWR=REAPWR/1000000.0;

    LABEL       TL = 'NO. OF 5-MINUTE INTERVALS'
            OLDSPA = 'SETPOINT'
            NEWSPA = 'SETPOINT'
               DTA = 'OLDSPA - NEWSPA (C)'
            OLDSPB = 'SETPOINT'
            NEWSPB = 'SETPOINT'
               DTB = 'OLDSPB - NEWSPB (C)'
             MN_DT = 'MEAN DELTA T (C)'
            MTC_MN = 'MEAN TEMPERATURE (C)'
             MTC_A = 'TEMPERATURE (C)'
             MTC_B = 'TEMPERATURE (C)'
              TIME = 'TIME (5-MINUTE INTERVALS)';
    LABEL   REAPWR = 'REACTOR POWER (MW)';
*-----------------------------------------------------------------------------;
***DATA ZONE1;
***   SET REAP;
***    IF ZONE=1;
*=============================================================================;
PROC SORT;
  BY ZONE;
*=============================================================================;
*=============================================================================;
PROC GPLOT;
  BY ZONE;
    TITLE1 '                     REACTOR POWER, OC-3 EXPERIMENT       ';
    TITLE2 '       ';
*.............................................................................;
    TITLE3      HEIGHT=8   ANGLE=90  '         ';
    TITLE4      HEIGHT=2   ANGLE=90  '         ';
*.............................................................................;
    FOOTNOTE1   HEIGHT=8             '         ';
    FOOTNOTE2   HEIGHT=8             '         ';
    FOOTNOTE3   HEIGHT=2             '         ';
*=============================================================================;
    PLOT REAPWR * TIME=1/
```

```
                  HAXIS=0 TO 32000 BY 4000
                  VAXIS=0 TO 35    BY 5
                  FRAME;
*-----------------------------------------------------------------------------;
   SYMBOL1 H=2 LINE=1 COLOR=BLACK  VALUE=SQUARE    I=JOIN;
*=============================================================================;
*=============================================================================;
```

VITA

Amir Sassan Mobasheran was born in Tehran, Iran. He received the Bachelor of Science degree in physics from the Tehran University in September 1976. In June 1977 Amir entered the University of Tennessee, Knoxville, as a graduate student in the Nuclear Engineering Department. He was appointed as a Graduate Teaching Assistant for the College of Engineering computer programming courses in Spring of 1978. In the Fall of 1979 Amir was awarded a Graduate Research Assistantship supported by the Metals and Ceramics (M&C) Division of the Oak Ridge National Laboratory (ORNL). He received the Master of Science degree in Nuclear Engineering with a minor in mathematics in December 1981. He pursued his studies toward a doctoral degree in nuclear engineering while teaching as a GTA and performing research as a GRA. In June 1983 Amir was awarded the Graduate Student Teaching Award by the Chanceller and continued teaching the computer programming and numerical analysis courses for the College of Engineering as the Graduate Teaching Associate. He was also conducting research for the M&C Division of ORNL. In September 1989, Amir started working for the University of Tennessee Computing Center as a Graduate Consultant in the Mathematics and Engineering software group of UTCC. He received the Doctor of Philosophy degree in nuclear engineering in December 1990.