DESIGN AND OPERATION OF A GRAPHITE CREEP IRRADIATION EXPERIMENT*

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A series of irradiation tests has been planned to determine the creep characteristics of various graphites of interest to nuclear reactor designers. The graphites selected for testing in the first experiment of this series included grades H-327, H-451, and AFX-5QBG. A constant stress compressive test was selected as the basis for our design.

The primary and secondary creep coefficients will be determined as functions of fluence, temperature, stress, and Young's moduli of elasticity. These data will be obtained with a series of irradiation capsules that are alternately irradiated at 900, 600, and 1250°C in fluence increments of approximately 1, 1, 2, and 4 × 10^{21} neutrons/cm^2 until each set of test specimens for each test temperature has accumulated a fluence in excess of 8 × 10^{21} neutrons/cm^2. The compressive stresses at each temperature will be 13.8 MPa (2000 psi) and 20.7 MPa (3000 psi). Each graphite specimen will be characterized before neutron irradiation and subsequently after each accumulated increment of fluence. Each capsule will contain a set of unstressed control specimens that match the stress specimens. Basically, the total creep strains are determined by the dimensional differences between stressed specimens and their matching control specimens after each irradiation. The primary creep strain has been found to be recoverable under irradiation if the stress is removed.[1] Therefore, selected stress-tested specimens will be irradiated again at their test temperature to recover and thereby determine their primary creep strains.

The capsules for these experiments are being irradiated in the E-5 core facility, a flux-trapped position, of the 30-MW Oak Ridge Research Reactor (ORR).

Capsule OC-1, the first experiment in this series, was designed to irradiate twenty-eight 15.24-mm (0.600 in.) dia by 25.4-mm (1.00 in.) long compressively stressed graphite test specimens at 900°C to the first planned exposure level of 1 × 10^{21} neutrons/cm^2. A compressive stress of 13.8 MPa (2000 psi) was applied to 20 of the specimens in the test by precalibrated metal bellows expanded by gas pressure against the specimen columns. Eight of the specimens in the two columns had reduced diameters so as to increase the stress to 20.7 MPa (3000 psi). The capsule also included 28 unstressed control specimens made of the same types of graphite as were the stressed specimens.

A cross sectional view showing the two stressed specimen columns in the in-core portion of the capsule is shown in Fig. 1. The specimens have shallow holes in each end to accommodate the graphite pins and spacers which serve as centering guides for the specimen column. The force from each bellows at the top of the specimen column was transmitted through a graphite push-rod. At the end of each column, the force was sensed by an LVDT-type load cell. Although monitoring of the pressure in the bellows was the primary measure of the load being applied to the specimens, the LVDT-type load cell was intended to provide backup information during the early stages of the irradiation and ensure that the force was indeed transmitted through all of the specimen column.

The unstressed control specimens were stacked and centered in a manner similar to the stressed specimens, except that a longitudinal hole was provided to serve as a guide for the 3.2-mm (1/8 in.) dia stainless-steel sheathed Chromel-Alumel movable thermocouple that was installed in each column. These thermocouples could be moved through a 0.39 m (15 in.) stroke, thus providing temperature traverses from the midplane of the uppermost specimen to the midplane of the lowest specimen in each column.

The capsule was designed to operate on gamma heat alone approximately 100°C below design temperature. A gas gap was provided between the specimen holder sleeve (see Fig. 1) and the water-cooled capsule vessel so that the thermal conductance could be controlled by gas gap size and inert gas composition. Design operating temperature and control were achieved by twenty 1.6-mm (1/16 in.) dia stainless-steel-sheathed MgO-insulated Nichrome V heaters wrapped around the specimen holder as shown in Fig. 1, and retained there by the graphite sleeve that is slipped over the holder.

Because of the need to maintain a precise temperature control along the specimen column, a computer was acquired to control the experiment temperatures automatically and to record the data. Algorithms were developed which related the thermocouple temperatures to the specimen temperatures which the computer used to adjust the heaters to the required operating levels.

Irradiation of capsule OC-1 was conducted from April 1 to May 22, 1976. The capsule was operated at a nominal specimen temperature of 900°C in the ORR E-5 core position for about 34,170 MWhr with the reactor operating at 30 MW for a total peak fluence of about 1.3 × 10^{21} neutrons/cm^2 (E > 0.18 MeV).

We had difficulty in maintaining the 900 ± 10°C uniform temperature along the length of the specimen columns. Temperatures of the specimens were high and off-design in the upper 16% of the specimen column. In order to maintain the lower part of the specimen column at or near the design temperature, the specimens in the upper 100 mm were permitted to operate at up to about 930°C. Also, the temperature profile along the length of the specimen columns had a small dip approximately one-third of the way down from the tops of the specimen columns throughout the irradiation period. The two movable thermocouples provided direct monitoring of the temperatures along the length

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of the specimen columns and provided data to determine the set-points for temperature control, the latter being based on the measured temperatures in the graphite specimen holder. Results from a typical traverse of the movable thermocouples are shown in Fig. 2.

The control and data acquisitions by the computer worked very well during the entire experiment. The average temperature measured by two fixed thermocouples mounted in the graphite specimen holder in each zone was controlled by the computer to ±1°C from the requested set-point as long as adequate heater power was available to the corresponding zones to permit the computer to maintain the requested temperature as the gamma heat profile changed.

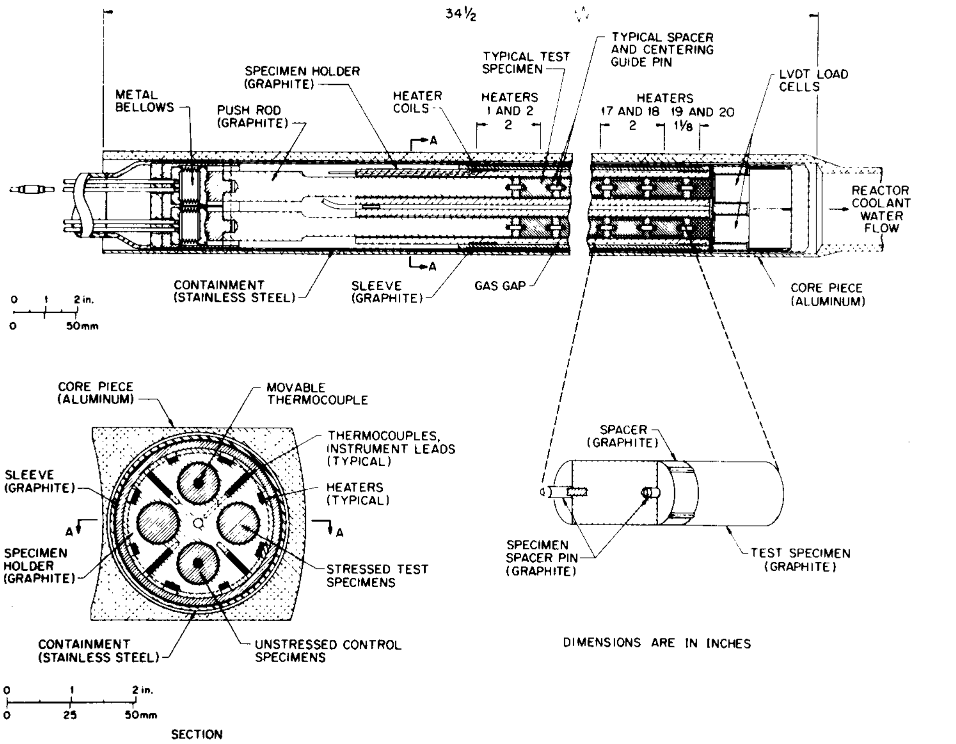
Operation of the two LVDT load cell transducers was disappointing. Attempts to calibrate the devices *in situ* before irradiation were largely unsatisfactory. They did respond to specimen loading bellows pressure changes, but large hysteresis effects in the load cell responses were noted as the bellows pressures were changed. This was particularly evident in the West specimen column, and may have been an indication that the bellows-specimen stack was becoming wedged, and a ratchetting may have occurred during increases to full reactor power and design operating temperatures. This binding would cause excessive compressive stresses on the specimens due to thermal expansion. Postirradiation examinations of the test specimens indicate that this probably occurred during the irradiation. Results from the creep measurements and other parameters being monitored in this series of tests are being presented by Kennedy *et al.*[2] at this conference.

Certain design modifications have been made for future experiments of this series. These include additional guide pins to prevent the wedging and ratchetting that occurred with the first experiment and additional clearance between the specimen centering guide and the ID of the hole in the specimen holder to prevent possible friction forces that may be caused by interference due to thermal expansion and graphite creep of the guides. A pneumatic electromechanical device, designated a PEM cell, has been designed to replace the LVDT-type load cells used in capsule OC-1. The new load cell uses metal bellows similar to those used to load the specimen columns. When the load is applied to the specimens, an insulated contact button located inside the PEM cell bellows is in electrical contact with the top flange of the bellows. The PEM cell bellows is then pressurized with helium to a high enough pressure to overcome the load on the specimens and open the electrical contact. By measuring the pressure required and detecting the resistance between the contact button and the grounded bellows (infinite when open), a determination of the load being applied to the specimen column can be made, thus ensuring that the load is indeed being applied to the column. By virtue of its all-metal construction, except for the alumina insulator, we expect the PEM cell to be relatively insensitive to damage from high temperature and radiation.

References

(1) R. J. Price, GA-A12332 (November 1, 1972).

(2) C. R. Kennedy *et al.*, this conference.



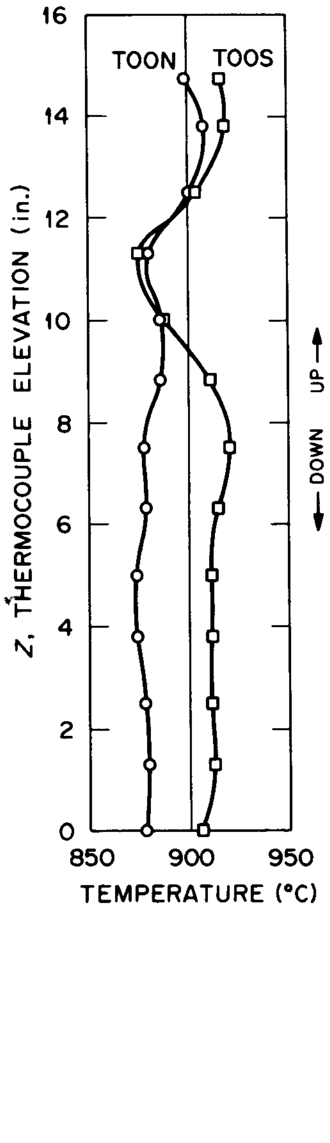


Fig. 1 (Left) Cross-Sectional View of In-Core Portion of Graphite Creep Capsule OC-1. Fig. 2 (Right) ORR Capsule OC-1. Results from Typical Movable Thermocouple Traverse.