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GA-A--17469

DE84 012180

REMOTE EXAMINATION OF FORT ST. VRAIN HTGR FUEL AND REFLECTOR ELEMENTS

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This is a preprint of a paper to be presented at the Annual Meeting of the American Nuclear Society, June 3-8, 1984, New Orleans, Louisiana.

Work supported by
Department of Energy
Contract DE-AT03-84SF11962

GA PROJECT 7700
MARCH 1984

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ABSTRACT

A robotic device developed at GA Technologies was used to perform remote metrological and visual examinations on 105 irradiated fuel and reflector elements removed from the High Temperature Gas Cooled Reactor (HTGR) core of the Fort St. Vrain (FSV) Nuclear Generating Station. All examinations were accomplished in a fraction of the time and at a fraction of the cost for manual methods. These examinations have been useful in the verification of core design codes, in monitoring the in-pile performance of graphite blocks, and in qualifying improved core materials.

1. INTRODUCTION

Remote metrological and visual nondestructive examinations were performed on 105 irradiated fuel and reflector elements removed from the High Temperature Gas Cooled Reactor (HTGR) core of the Fort St. Vrain (FSV) Nuclear Generating Station following two refueling operations in 1979 and 1982. Fifty one elements were examined following the first refueling, and fifty four elements were examined following the second refueling.

The fuel and reflector elements were 793 mm long graphite bodies with a hexagonal cross section of 360 mm (across-the-flats) and a total weight of 128 kg. Examinations of these large irradiated elements were performed in a fraction of the time and at a fraction of the cost of manual methods by a robotic device developed by GA Technologies (GA) as part of a DOE sponsored surveillance program[1,2]. The robot and its control and peripheral hardware, performed well during both inspections. Robot availability was nearly 100% for both tasks. These examinations were conducted to obtain data for monitoring the performance of the graphite elements in the core, for verifying core design codes and predictions, and for qualifying improved graphite.

2. DESCRIPTION OF METROLOGY ROBOT SYSTEM

The 105 elements were examined in the hot service facility (HSF) at FSV. The metrology robot (Figure 1) consists of a structural frame, rotary table, probe, and instrumentation. Irradiated core components are placed on the rotary table by the FSV fuel handling machine. The rotary table permits all points on the top and sides of a component to be positioned within the operating range of the probe. The two-finger probe (Figure 2) moves in the $\pm x$, $\pm y$, and $\pm z$ directions. Upon contact with the test object, the probe head undergoes a displacement which activates a microswitch and terminates probe movement. The probe head has a primary and backup microswitch for each direction of displacement ($\pm x$, $\pm y$, $\pm z$).

Programmable stepping motors power the four drive systems of the robot. The stepping motors are coupled with free-wheeling d.c. motors which serve as auxiliary drive systems. The motor drives are modularized for quick replacement. Each full motor step is equivalent to 0.025 mm (0.001 in.) movement in the x and y directions, 0.032 mm (0.00125 in.) in the z direction, and 0.03-degree rotation. The coordinates of a point on the surface of an element are determined by running the probe into the element and recording the position and displacement of the probe. Magnetic encoders (Sony Magnescales) and rotary potentiometers (backup) measure the position of the probe. Linear potentiometers and linear variable differential transformers (backup) measure the displacement of the probe head. A resolver measures the position of the rotary table. A second resolver serves as a backup. Resistivity thermometer devices (RTD's) monitored the temperatures of robot components. An infrared thermometer is used to measure the surface temperatures of core components. A Reuter-Stokes gamma ionization chamber and a SNOOPY-type detector system with a Reuter-Stokes fission counter are used to measure the gamma and neutron activity, respectively, of the core components.

The robot is controlled by a Nuclear Data 6620 process computer. A data logger (Accurex Autodata 9) collects the raw data from the robot's readout devices and sends these data to the computer. The computer operates under the Nuclear Data MIDAS operating system, a real time, multiprogramming executive. The computer controls the robot and the data logger, and processes the data. The robot operates in a fully automated, closed-loop mode. This includes computer verification of proper movement and corrective actions without any, or minimum, operator interface. Comparison of redundant measurement devices, as well as on-line data reduction, is done by the computer. This allows the system to automatically overcome potential malfunctions, such as motor stalling or missing an intended hole or surface. System redundancy is used to maximize data output and minimize downtime.

The robot system includes three black and white and one color TV cameras. All TV cameras are equipped with pan-tilt units and zoom lenses. Visual examinations are recorded on video tape.

3. DESCRIPTION OF REMOTE EXAMINATION

3.1 Metrological Examination

The dimensional measurements gathered by the robot may consist of up to five types of data:

1. Across-the-flats measurements - measure the across-the-flats dimensions at the top of the hexagonal element to determine radial strain at the top surface.

2. Side face measurements - map the element bow at the side faces of the element at up to 55 points per face.

3. Top surface measurements - map the element height at the top surface of the element at up to 54 points to determine bulk length change for axial strain.

4. Coolant hole measurements - measure the distance between and diameter of 40 coolant holes at the top of the element to determine the incremental radial strain.

5. Fiducial hole measurements - measure distances between predrilled fiducial holes located along the corner of preselected elements only (surveillance elements) to determine incremental changes in axial lengths and axial strain.

During each inspection of an irradiated element, repeated measurements are made on a precisely machined 25.4 mm cube mounted on the robot to check the repeatability of the robot measurements. For the first surveillance, the worst case accuracy was ±0.2 mm, with an average accuracy of ±0.05 mm. The worst case accuracy was ±0.1 mm, with an average of ±0.03 mm for the second surveillance.

The time required for a full-length metrological examination on a fueled surveillance element (approximately 600 data points) was 4-1/2 hours. This time has since been reduced to 2-1/2 hours for future examinations by the implementation of a more efficient method of collecting and transferring the robot's position data to the computer. It is estimated that approximately 80 hours would be required to collect the same data using conventonal Hot Cell measurement techniques.

3.2 Visual Examination

Visual examinations were performed concurrently with metrological examinations using the robot's TV cameras. All sides and the top and bottom surfaces of each graphite element were thoroughly inspected for surface condition and graphite integrity. Specifically, the elements were examined for the following:

1. Cracks
2. Graphite oxidation
3. Any other structural damage
4. Evidence of mechanical interaction between elements
5. Any other features of interest.

In addition, all surfaces of each element were photographed with a 35 mm camera equipped with a telephoto lens.

3.3 Gamma and Neutron Activity Measurements

Gross gamma activity and neutron measurements are used for verification of calculations necessary to ship the elements. Gamma dose rates at 91.5 cm (3 ft) were measured for each of the second surveillance elements with a Reuter-Stokes, Model RS-C4-1606-203, gamma ionization chamber. The ionization chamber has a sensitivity of 1.2×10^{-10} A/R/h and linearity of output current over a gamma flux range of 10^{-2} to 10^{4} R/h. Neutron count rates for selected segment 2 fuel elements were measured using a SNOOPY-type detector system equipped with a Reuter-Stokes, Model RS-86-0805-134, fission counter.

4. RESULTS OF THE REMOTE EXAMINATIONS

The data gathered during the remote inspections showed that the axial and radial dimensions of nearly all of the H-327 grade graphite fuel elements shrank as a result of the irradiation. Five of the elements expanded slightly in the radial direction. The maximum fuel element-average axial shrinkage and across-flat shrinkage measured were 2.92 mm and 0.94 mm, respectively. The maximum observed bow was 0.43 mm. Reflector elements underwent very little axial or radial dimensional change (less than ± 0.15 mm).

One of the elements examined during the last surveillance was fabricated from H-451 grade graphite which is designated for use in future FSV refueling segments and advanced HTGR designs. This element appeared to be in excellent condition and underwent little dimensional change as a result of irradiation. The element-average axial and radial shrinkage were 0.31 mm and 0.04 mm. The maximum bow was 0.08 mm.

The fast neutron doses received by the elements [$\leq$1.6 x 10^{25} n/m^2 (E > 29 fJ)$_{HTGR}$] were about 30% of the lifetime doses that would be received by most fuel elements in a LHTGR. At these fluences, the strains were relatively small. Figures 3 and 4 provide some perspective as to how the reference H-327 axial and radial strain data compare to the range of potential strains in FSV fuel elements.

The dimensional change data measured by the robotic device was compared with the large high temperature gas-cooled reactor design code SURVEY/STRESS[3]. The maximum absolute differences between the calculated and measured axial and radial dimensional changes were less than $\pm$0.2% and $\pm$0.4%, respectively. Measured strain data is used to correct low temperature design strain curves.

The visual inspections are important for early detection of abnormal performance. All inspected elements were in good condition. Most blemishes observed on the elements were stains, scratches, scrapes, rub marks, and coolant flow deposits (Figs. 5 and 6). Two elements from the last examination were observed to have single localized cracks which did not affect their performance, but were of concern. This concern led to an extensive destructive examination and an ongoing analytical study at GA to gain better understanding and confidence for graphite performance.

In conclusion, the remote examinations provide information from an operating reactor at a saving of time and cost. These examinations have provided verification of the methods used for predicting core performance and have assisted in the qualification of material for advanced application.

ACKNOWLEDGMENT

This work was supported by the Department of Energy under Contract DE-AT03-84SF11962.

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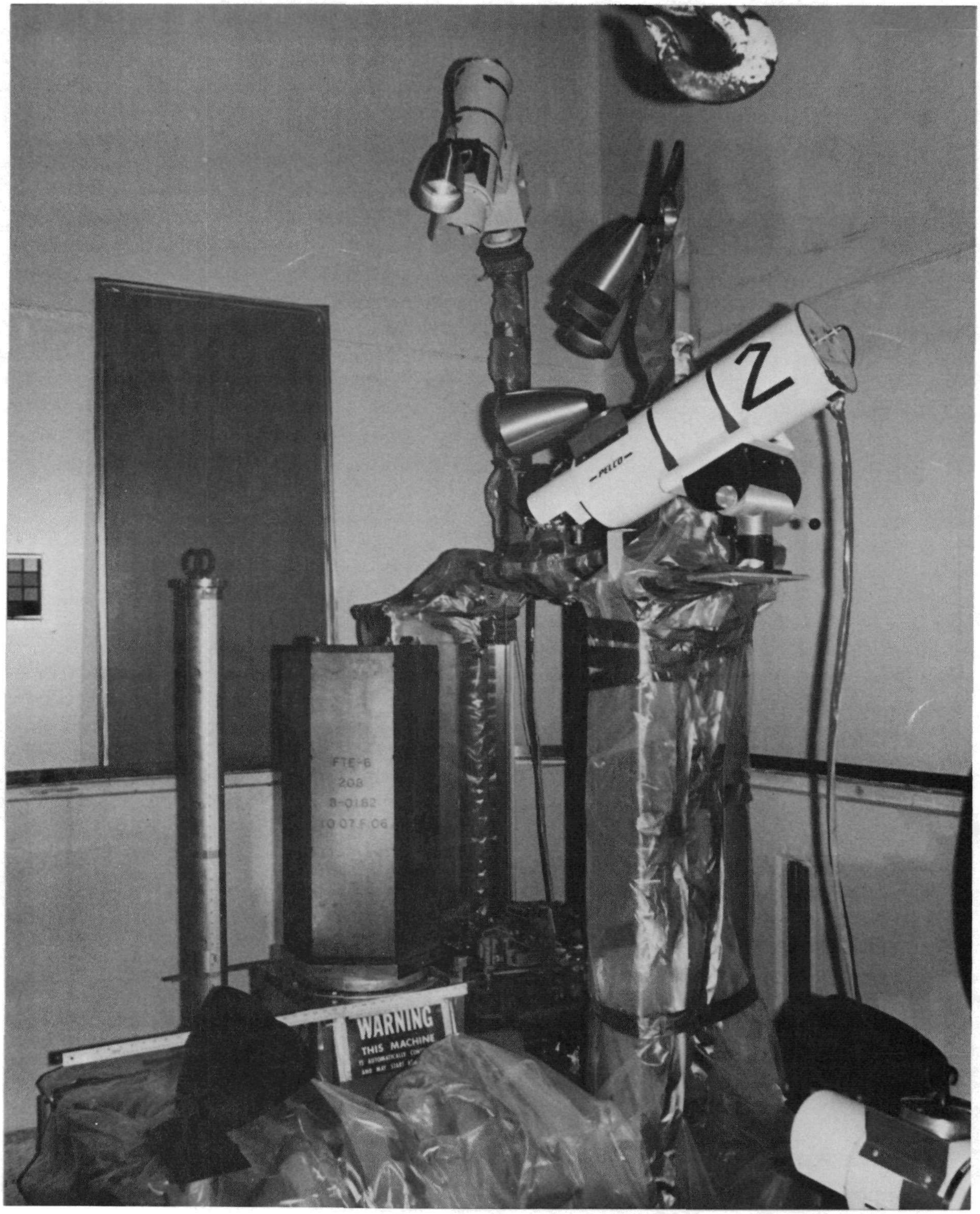

Fig. 1 Metrology robot in HSF at FSV

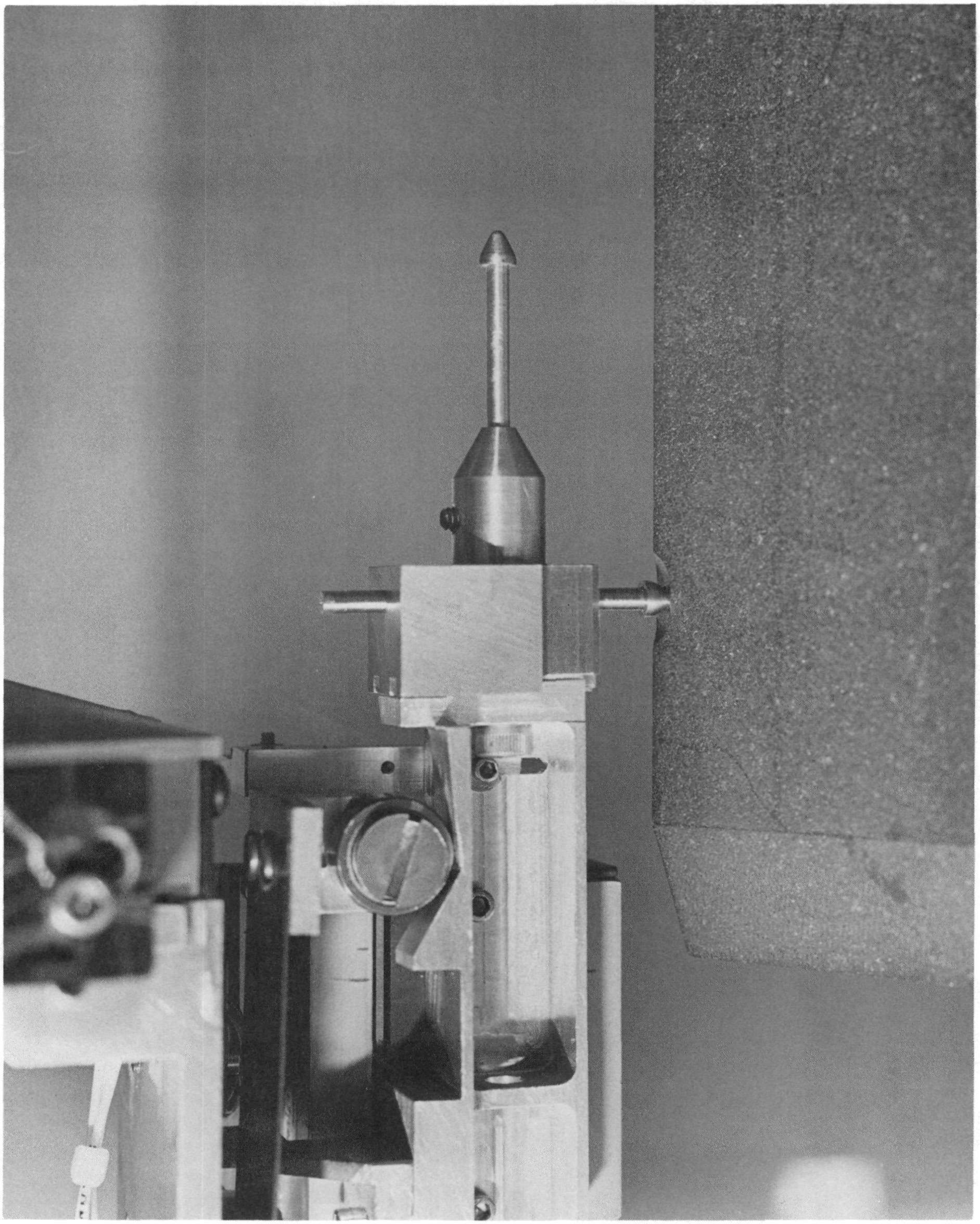

Fig. 2 Side view of the metrology robot probe; the probe leg is inserted into a fiducial hole in the corner of a surveillance fuel element

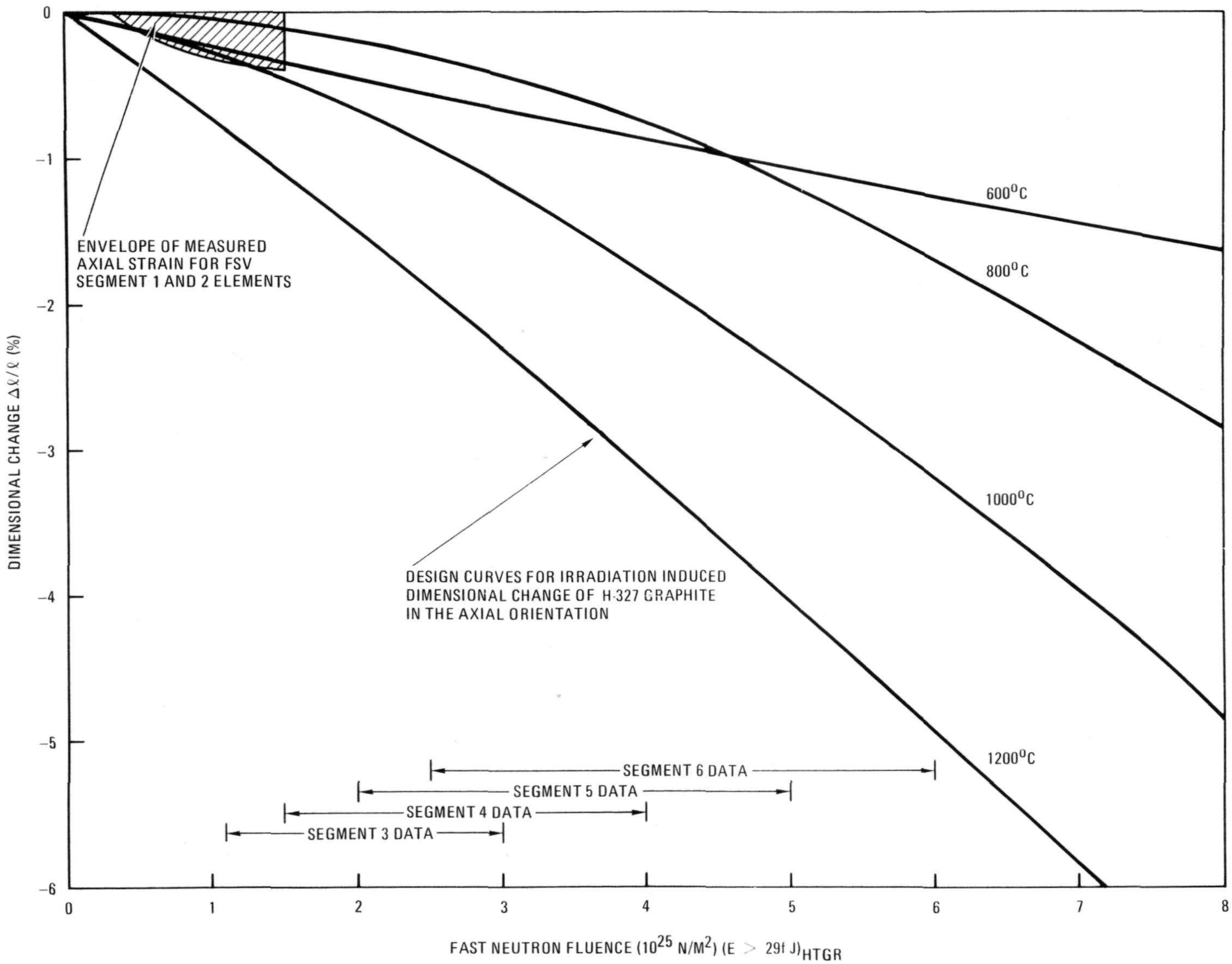

Fig. 3 Envelope of axial strains observed in FSV segment 1 and segment 2 fuel elements

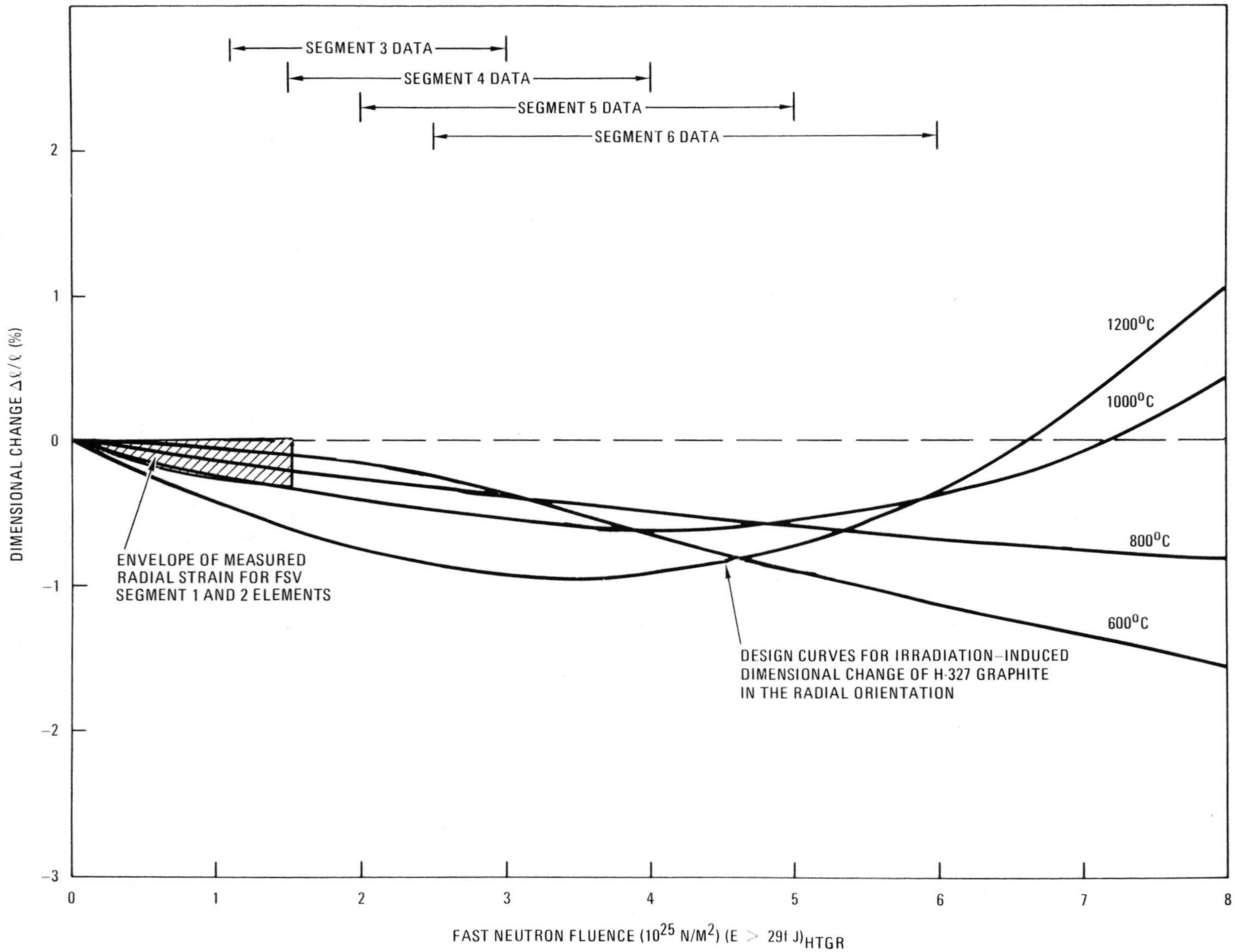

Fig. 4 Envelope of radial strains observed in FSV segment 1 and segment 2 fuel elements

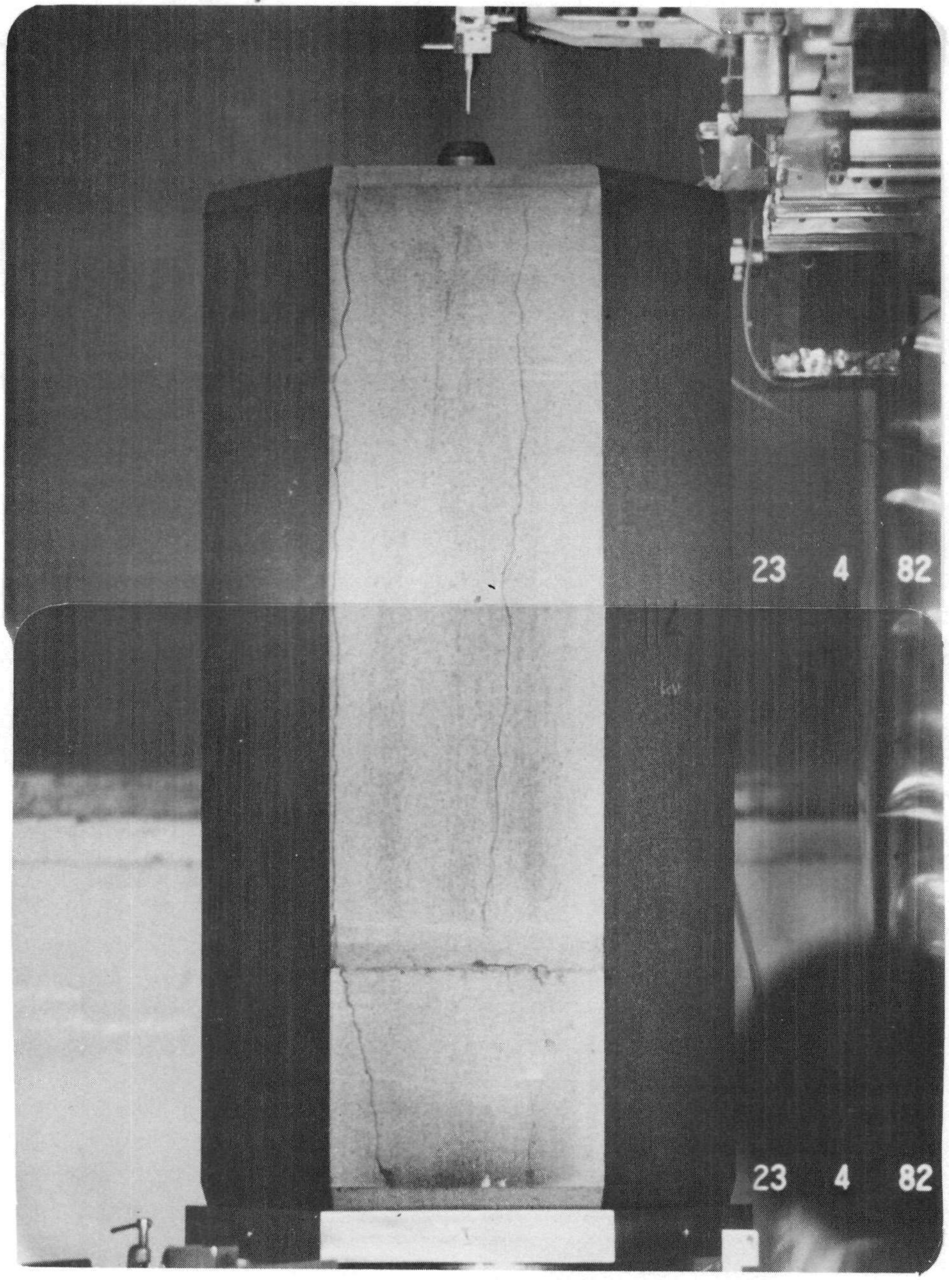

Fig. 6 Example of scratches observed near the left edge of face D on several segment 2 elements

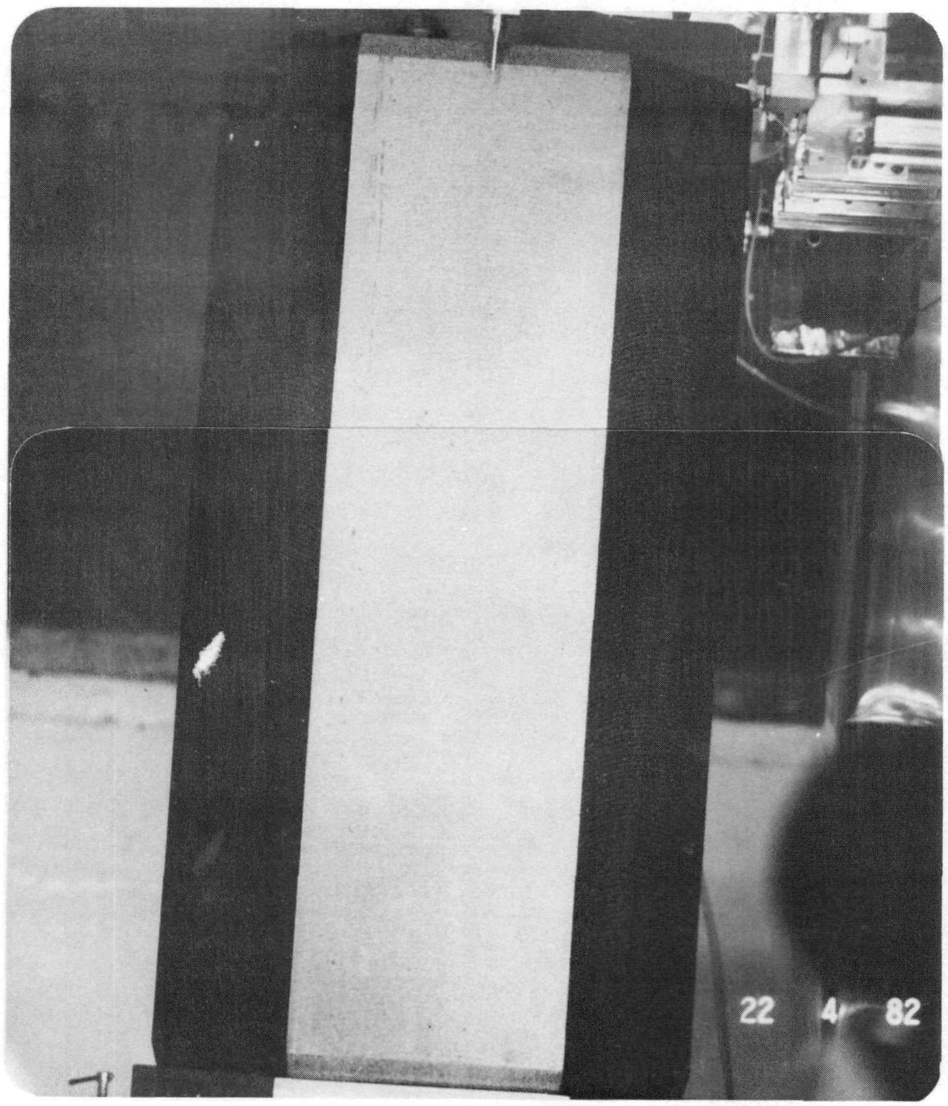

Fig. 5 Examples of horizontal and vertical stains