GA 1485 (REV. 10/82)

GA Technologies Inc.

ISSUE SUMMARY

RELEASED

TITLE NONDESTRUCTIVE EXAMINATION OF 62 FUEL AND REFLECTOR ELEMENTS FROM FORT ST. VRAIN CORE SEGMENT 3

☐ R & D
☒ DV & S
☐ DESIGN

APPROVAL LEVEL 2

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
N	18	RTE	7700	907785	N/C

QUALITY ASSURANCE LEVEL	SAFETY CLASSIFICATION	SEISMIC CATEGORY	ELECTRICAL CLASSIFICATION
I	N/A	N/A	N/A

ISSUE	DATE	PREPARED BY	APPROVAL				ISSUE DESCRIPTION/ CWBS NO.
			ENGINEERING	QA	FUNDING PROJECT	APPLICABLE PROJECT	
N/C	JAN 2 4 1985	F.McCord Frances McCord 1/22/85	W.J.Scheffel W.J. Scheffel 1/22/85 O.M. Stansfield O.M. Stansfield 1/22/85 R. F. Turner RF Turner 1/23/85	J. Winlaub for G.P.Connors		D.J.Kowal DJ Kowal 1/23/85 FK	Initial Release CWBS 7720 210 200

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1. INTRODUCTION

Remote metrological and visual nondestructive examinations were performed on 62 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 the January 1984 refueling operation. The examinations of these core segment 3 elements were performed in the hot service facility (HSF) at FSV from June 2 through June 23, 1984.

The standard fuel and reflector elements are 793 mm long graphite bodies with a hexagonal cross section of 359 mm (across-the-flats) and a total weight of 128 kg (Figures 1-1 and 1-2). Examinations of these large irradiated elements were performed by a metrological robotic device and an experimental gamma robotic device both developed by GA Technologies (GA). The inspected elements included all 42 fuel elements and 9 reflectors elements from region 18, a side reflector and 4 fuel elements including FTE-2 from region 22, a fuel element from region 3, 2 reflector elements and 3 fuel elements from region 13. All of the selected elements from regions 13 and 3, and 2 of the selected elements from region 22 were surveillance elements. Surveillance elements, easily recognized by the fiducial holes drilled in their corners, were extensively characterized prior to insertion into the core (Ref. 1).

The nondestructive examination included the following:

1. Dimensional measurements (all fuel elements, selected reflector elements) on the following:

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*The Fort St. Vrain Nuclear Generation Station is owned and operated by the Public Service Company of Colorado (PSC).

   a. Across-flats dimensions
   b. Length
   c. Coolant hole diameters
   d. Distances between coolant holes
   e. Distances between fiducial holes (surveillance elements and FTE-2 only)
   f. Bow

2. Gross gamma activity (selected elements) and neutron activity (selected elements) measurements.

3. Visual inspections (all elements) for the following:

   a. Cracks
   b. Graphite oxidation
   c. Any other structural damage (chips, scrathces, etc.)
   d. Evidence of mechanical interaction between elements
   e. Other features of interest (discolorations, corrosion, flow marks, etc.)

4. Fission product isotopic distributions (selected elements) (NOTE: This data will be reported in early 1985).

Table 1-1 summarizes the surveillance of FSV core segment 3.

These nondestructive examinations were performed under the FSV Fuel Surveillance Program sponsored by the Department of Energy (DOE). Previously, 51 fuel and reflector elements from core segment 1 were similarly examined in July 1979 (Ref. 2), and fifty-four fuel and reflector elements from core segment 2 were inspected in April 1982 (Ref. 3).

The nondestructive surveillances are intended to accomplish the following objectives:

- obtain graphite element strain and bow data over a range of irradiation temperatures and fast fluences for comparison with large high-temperature gas-cooled reactor (HTGR) design code calculations
- verify the structural integrity and dimensional stability of the graphite elements
- obtain gross gamma and neutron activity data for comparison with HTGR shielding code calculations
- obtain fission product isotopic distributions in fueled elements for calculating fuel burnup for comparison with HTGR design code calculations
- obtain fission product isotopic distribution on reflector elements for comparison with plateout code calculations.

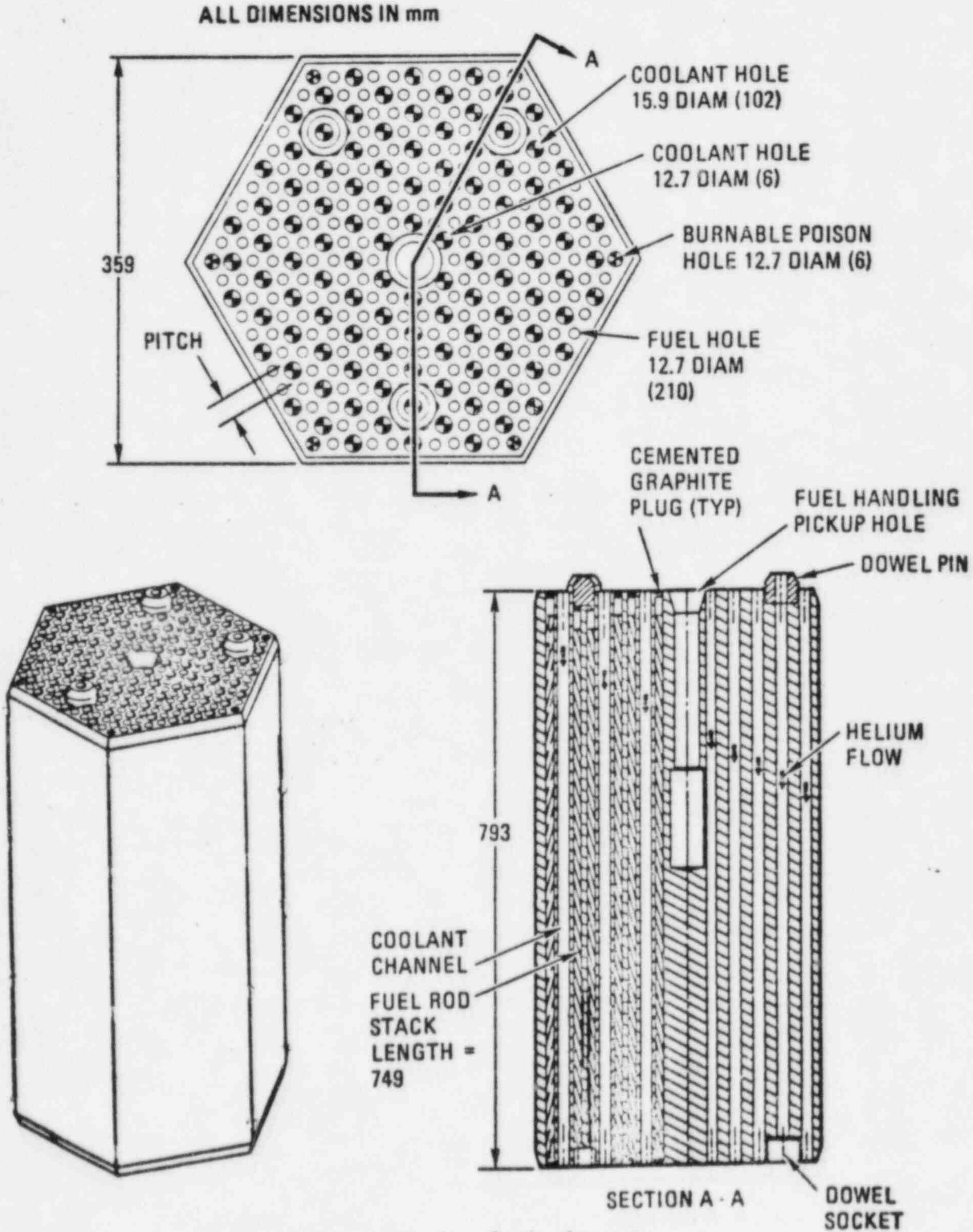

Fig. 1-1 FSV regular fuel element

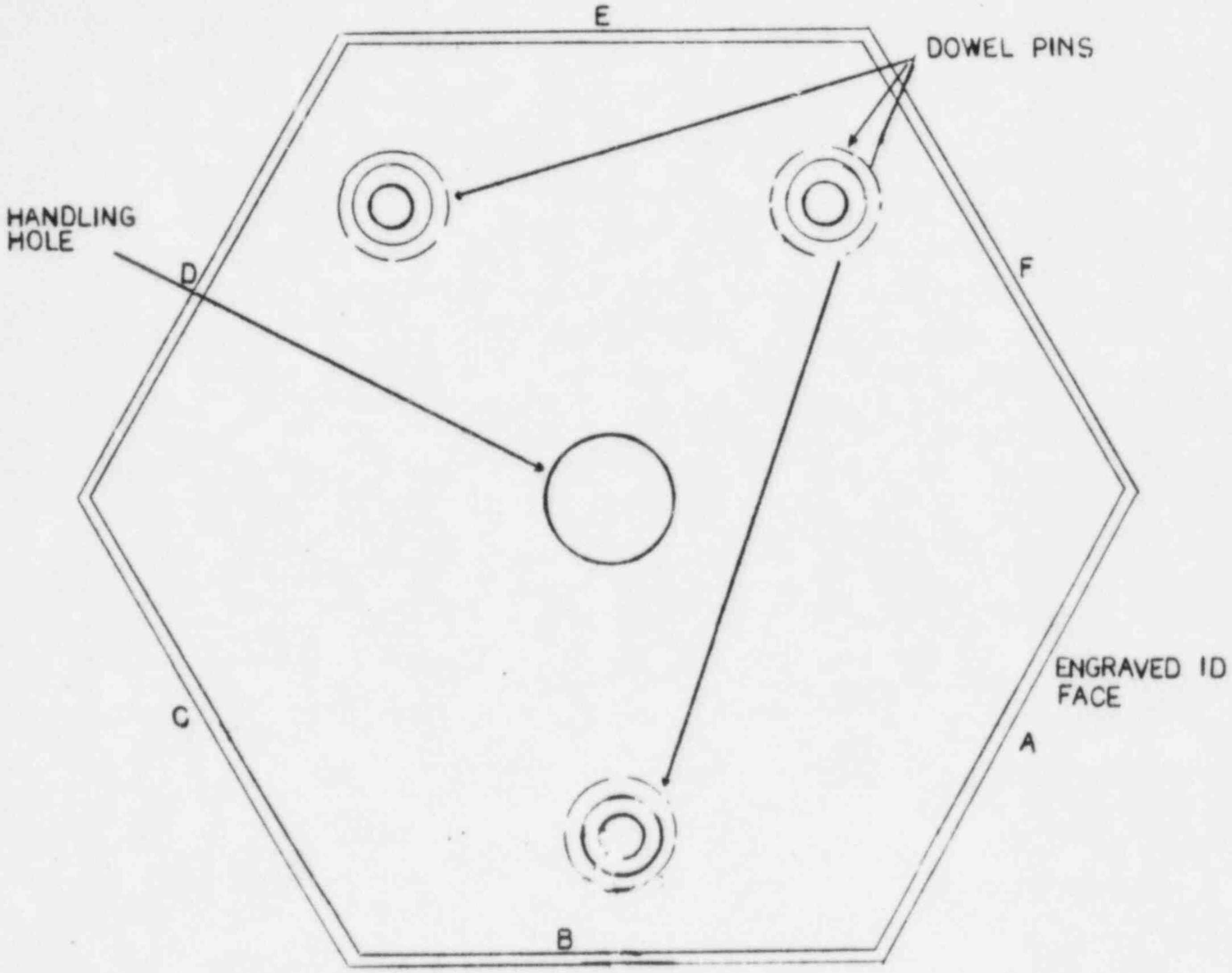

FIGURE 1-2. FSV ELEMENT SIDEFACE IDENTIFICATION

Table 1-1

SUMMARY OF FSV SEGMENT 3 CORE SURVEILLANCE(a)

Inspection No.	Element Ser. No.	Core Location(b)	Element Type	Measurement Sequences(c)	Nuclear Measurements(d)
1	42-1005	13.05.R.03	Top Reflector (Surveillance)	L,1,2,3,4,5	
2	42-1008	13.05.R.10	Bottom Reflector (Surveillance)	L,1,2,3,4,5	
3	1-2606	13.03.F.06	Fuel (Surveillance)	L,1,2,3,4,5	GG, GS
4	1-0335	13.03.F.09	Fuel (Surveillance)	L,1,2,3,4,5	GG, GS
5	2-2781	13.01.F.03	Control Rod (Surveillance)	L,1,2,3,4,5	GS
6	1-2943	03.06.F.09	Fuel (Surveillance)	L,1,2,3,4,5	GG, GS
7	41-1004	22.10.R.06	Side Reflector (Surveillance)	L,1,2,3,5	
8	5-2104	22.04.F.06	Fuel (Surveillance)	L,1,2,3	GG, GS
9	8-0206	22.06.F.06	Fuel (FTE-2)	L,1,2,3,4,5	GG
10	5-2191	22.03.F.06	Fuel (Surveillance)	L,1,2,3,5	GS
11	5-0751	22.02.F.06	Fuel	L,1,2,3,4	GG, GS
12	1-1805	18.06.F.09	Fuel	A,1,2,3,4	
13	1-0530	18.04.F.09	Fuel	A,1,2,3,4	GG, GS
14	1-1018	18.04.F.04	Fuel	A,1,2,3,4	GG, GS
15	1-2640	18.05.F.09	Fuel	A,1,2,3,4	GG
16	1-1049	18.03.F.09	Fuel	A,1,2,3,4	
17	1-2563	18.02.F.09	Fuel	A,1,2,3,4	
18	1-1397	18.05.F.06	Fuel	A,1,2,3,4	GG,GS
19	4-0463	18.03.F.04	Fuel	A,1,2,3,4	
20	1-2351	18.04.F.06	Fuel	A,1,2,3,4	GG,GS
21	1-2447	18.02.F.06	Fuel	A,1,2,3	GS

(a) Visual examination were performed for all elements (Section 5.0)

(b) Core location is given as: Region·Column·Element type (F = fuel element, R = reflector element)

(c) L = full-length vesion; A = abbreviated version; 1 = across-the-flats measurements, 2 = Side face measurements, 3 = top surface measurements, 4 = coolant hole measurements, 5 = fiducial hole measurements (see Section 3.2)

(d) N = Neutron measurement performed; GG = gross gamma activity measurement performed; GS = gamma scanned.

Table 1-1 (con't)

SUMMARY OF FSV SEGMENT 3 CORE SURVEILLANCE[(a)]

Inspection No.	Element Ser. No.	Core Location[(b)]	Element Type	Measurement Sequences[(c)]	Nuclear Measurements[(d)]
22	1-1228	18.03.F.06	Fuel	A,1,2,3,4	GS
23	1-0684	18.02.F.04	Fuel	A,1,2,3,4	
24	3-0787	18.01.F.08	Control Rod	A,1,2,3,4	
25	1-0715	18.07.F.09	Fuel	A,1,2,3,4	
26	2-1707	18.01.F.03	Control Rod	A,1,2,3,4	
27	1-1612	18.07.F.04	Fuel	A,1,2,3,4	
28	1-0647	18.06.F.04	Fuel	A,1,2,3	
29	1-2282	18.05.F.04	Fuel	A,1,2,3,4	
30	1-5217	18.06.F.07	Fuel	A,1,2,3,4	
31	1-2939	18.04.F.07	Fuel	A,1,2,3,4	GS
32	1-2396	18.04.F.08	Fuel	A,1,2,3,4	GS
33	1-4304	18.05.F.07	Fuel	A,1,2,3,4	GG
34	1-1817	18.03.F.07	Fuel	A,1,2,3,4	
35	1-0443	18.02.F.07	Fuel	A,1,2,3,4	
36	2-1120	18.01.F.05	Control Rod	A,1,2,3,4	GS
37	1-0091	18.03.F.08	Fuel	A,1,2,3,4	GG
38	1-1918	18.07.F.06	Fuel	A,1,2,3,4	GS
39	1-1621	18.02.F.08	Fuel	A,1,2,3,4	
40	1-0873	18.06.F.06	Fuel	A,1,2,3	N,GG,GS
41	2-0265	18.01.F.06	Control Rod	A,1,2,3	N,GG,GS
42	1-1773	18.07.F.07	Fuel	A,1,2,3	
43	2-1950	18.01.F.07	Control Rod	A,1,2,3	
44	1-0536	18.07.F.08	Fuel	A,1,2,3	
45	1-1337	18.06.F.08	Fuel	A,1,2,3	
46	1-1796	18.05.F.08	Fuel	A,1,2,3	
47	1-1990	18.02.F.05	Fuel	A,1,2,3	N,GG
48	1-0192	18.03.F.05	Fuel	A,1,2,3	N,GG
49	1-1555	18.05.F.05	Fuel	A,1,2,3	
50	1-1410	18.06.F.05	Fuel	A,1,2,3	

(a) Visual examination were performed for all elements (Section 5.0)

(b) Core location is given as: Region·Column·Element type (F = fuel element, R = reflector element)

(c) L = full-length vesion; A = abbreviated version; 1 = across-the-flats measurements, 2 = Side face measurements, 3 = top surface measurements, 4 = coolant hole measurements, 5 = fiducial hole measurements (see Section 3.2)

(d) N = Neutron measurement performed; GG = gross gamma activity measurement performed; GS = gamma scanned.

Table 1-1 (con't)

SUMMARY OF FSV SEGMENT 3 CORE SURVEILLANCE[(a)]

Inspection No.	Element Ser. No.	Core Location[(b)]	Element Type	Measurement Sequences(c)	Nuclear Measurements[(d)]
51	1-0974	18.07.F.05	Fuel	A,1,2,3	
52	2-2815	18.01.F.04	Control Rod	A,1,2,3	
53	1-0305	18.04.F.05	Fuel	A,1,2,3	N,GG,GS
54	17-1394	18.04.R.03	Top Reflector	A,1,2,3	N,GG,GS
55	17-1371	18.07.R.03	Top Reflector	N.M.*	
56	17-1388	18.07.R.10	Bottom Reflector	N.M.*	
57	18-1008	18.01.R.09	Bottom Reflector	N.M.*	
58	17-1412	18.05.R.10	Bottom Reflector	N.M.*	
59	17-1409	18.06.R.10	Bottom Reflector	N.M.*	
60	17-1270	18.04.R.10	Bottom Reflector	A,1,3	GS
61	17-1128	18.03.R.10	Bottom Reflector	N.M.*	
62	17-1182	18.02.R.10	Bottom Reflector	N.M.*	

(a) Visual examination were performed for all elements (Section 5.0)

(b) Core location is given as: Region·Column·Element type (F = fuel element, R = reflector element)

(c) L = full-length vesion; A = abbreviated version; 1 = across-the-flats measurements, 2 = Side face measurements, 3 = top surface measurements, 4 = coolant hole measurements, 5 = fiducial hole measurements (see Section 3.2)

(d) N = Neutron measurement performed; GG = gross gamma activity measurement performed; GS = gamma scanned.

* NM = Not Measured

2. IRRADIATION CONDITIONS

The time-and-volume-averaged graphite calculated (via the SURVEY code) irradiation temperatures for the core segment 3 fuel elements examined in the HSF at FSV ranged from 380°C to 670°C at the element midplane. The fast neutron fluences ranged from approximately 0.96 to 2.82 x 10^{25} n/m^2 (E > 29 $fJ)_{HTGR}$.

The following HTGR codes were used to simulate the irradiation conditions:

- GAUGE (Ref. 4). A two-dimensional, four-group neutron diffusion and core depletion code. GAUGE treats the core as a single layer and calculates nuclide densities as a function of time and radial core location.

- FEVER (Ref. 5). A one-dimensional, multigroup neutron diffusion and depletion program for calculating nuclide densities as a function of axial core location.

- BUG-2 (Ref. 6). A two-dimensional, multigroup neutron diffusion and depletion program for calculating nuclide densities as a function of axial core location for fuel assemblies influenced by partially inserted control rods.

- SURVEY. A computer program for the thermal and fuel performance analysis of fuel elements. The code performs coarse mesh survey analyses for large numbers of spatial positions, calculating a time history of the irradiation conditions and fuel performance for each space point. SURVEY calculations are based on radial power distributions obtained from GAUGE and axial power distribution obtained from FEVER and BUG-2.

The reactor operating power is logged hourly. However, because of the numerous changes in power during cycles 1, 2, and 3, a simulation of the actual reactor operating history would be prohibitively expensive. Consequently, the reactor power history for the cycles was represented by 651 time intervals of approximately uniform power. Cycles 1, 2, and 3 were simulated with the GAUGE code using this detailed power history. A SURVEY analysis of the segment 3 elements was then performed based on the GAUGE results. The number of time intervals was further reduced from 651 to 100 for this analysis. Figure 2-1 shows the reactor power history used for the SURVEY analysis. The time- and volume-averaged graphite irradiation temperatures for the segment 3 elements were obtained from the SURVEY code results.

The temperature uncertainty is primarily due to the uncertainty in the power. Based on the results of nuclear and thermal design verification studies performed with data from the Peach Bottom HTGR (Ref. 7), the uncertainty in the power (and fast neutron fluence) calculated for a given core location is ~±10% (1σ). The uncertainty for a given temperature is therefore approximately 10% of the difference between the calculated temperature and the gas inlet temperature (~335°C, time averaged).

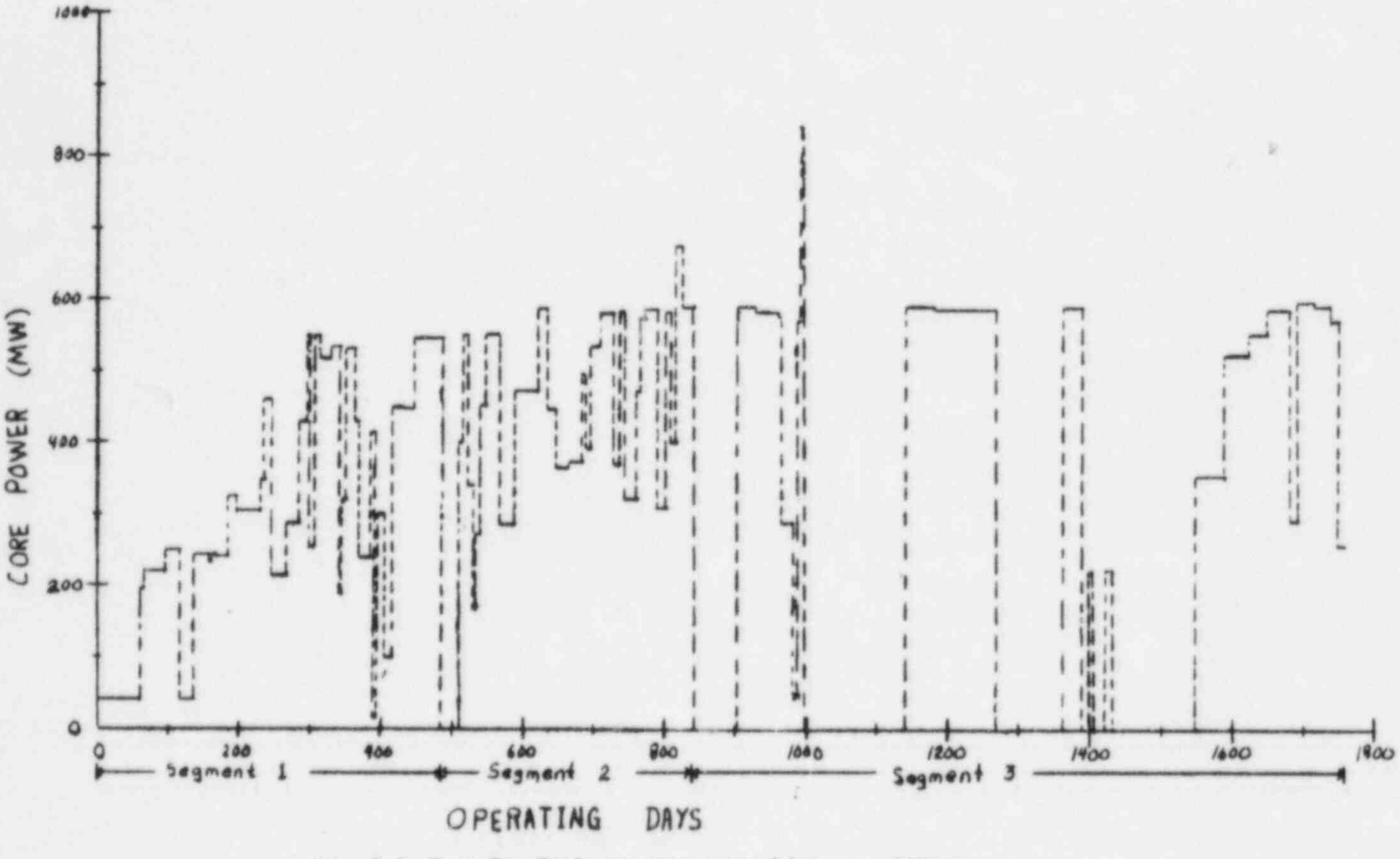

Fig. 2-1 Fort St. Vrain reactor power history: SURVEY analysis of cycles 1, 2, and 3

3. METROLOGICAL EXAMINATIONS

Metrological examinations were performed on 55 of the 62 elements inspected. Seven reflector elements from region 18 were not measured but were examined visually. The dimensional measurements were performed in the HSF at FSV with the GA metrology robot. The strains and bow data obtained from these measurements were compared with the HTGR design code strain and bow predictions.

3.1 Description of Metrology Robot System

The metrology robot (Figure 3-1) 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 3-2) moves in the ±x, ±y, and ±z directions (Fig. 3-3). 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 (±x, ±y, ±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.

The robot is controlled by a Nuclear Data 6620 process computer. The computer operates under the Nuclear data MIDAS operating system. The computer controls the robot and processes the data. A set of custom designed and fabricated circuit cards collects the raw data from the instrumentation systems of the robot. The cards are wired directly to the computer memory system so that a simple program subroutine can collect the robot data in a very short time (~1 millisecond) and deposit it directly into main memory. This more efficient method of data collection and transmission reduced the time for a full length inspection (approximately 600 data points) from 4-1/2 to 2-1/2 hours.

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.

3.2 Description of Metrological Examination

The dimensional examination of an irradiated fuel or reflector element may consist of up to five types of measurements. The measurement type and order of performance (if selected) are as follows:

1. Across-the-flats measurements: measure the across-the-flats dimensions of the hexagonal element to determine radial strain (Fig. 3-4).

2. Side face measurements: map the element bow at the side faces of the element at up to 55 points per face (Fig. 3-5).

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 (Fig. 3-6).

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 (Fig. 3-7).

5. Fiducial hole measurements: measure distances between predrilled fiducial holes located along the corner of preselected elements only (surveillance elements and FTE-2) to determine incremental changes in axial lengths and axial strain (Fig. 3-8).

The measurement sequence and length of inspection are selective. The side face, top surface, and coolant hole measurements have both full length and abbreviated versions. The full length versions are used for the surveillance and test elements. The abbreviated version is generally used for all other elements. The abbreviated version is shorter by approximately one hour.

3.3 Metrology Robot Quality Acceptance

The metrology robot was accepted by GA's Quality Assurance Department for shipment to FSV. The acceptance was in accordance with requirements specified for the calibration of the robot (Ref. 8). The detailed calibration data and a discussion of the metrology robot calibration are presented in Appendix A.

3.4 Results of Metrology Robot

Fifty-one H-327 graphite and one H-451 graphite fuel elements were metrologically examined. An infrared thermometer temperature gun was setup to perform the surface temperature measurements; however, it failed after eight inspections. A resistivity thermometer device located on the probe was then used to measure the surface temperatures. The measured element surface temperatures ranged from 33°C to 48°C. The metrological results along with the calculated results are presented in Tables 3-1 and 3-2. The core segment 3 maximum element average shrinkages in length and across-the-flats dimensions were 5.80 mm (0.23 in.) and 2.05 mm (0.08 in.), respectively. The maximum observed bow (see Fig. 3-9) was 0.69 mm (0.027 in.). The axial and radial dimensions of nearly all of the fuel elements shrank as a result of the irradiation. One H-327 graphite fuel element expanded slightly 0.03 mm (0.001 in.) across-the-flats (radial). This element was located in region 18 core layer 9. This phenomena was also noted in the core segment 2 surveillance where one fuel element and a side reflector also expanded slightly in the radial direction (Ref. 3). The core 2 fuel element was also located one layer above the reflector elements (layer 9). No core segment 3 fuel elements expanded axially. However, there was measured axial expansion in the examined reflectors (one top, one side and one bottom). The maximum expansion measured was 0.48 mm (0.02 in.) in the bottom reflector.

All of the fuel elements in region 18 were included in the core 3 surveillance. Figure 3-10 shows the axial strain and bow distributions measured for these fuel elements. The intra-element axial strains tended to be lower on the E face side and on the sides adjacent to the E face, the F and D faces. The bow in region 18 corresponded with the axial strains. The sides with lower (less negative) axial strains, faces E, D and F, had small bow or had negative bow (convex). The opposite sides, A, B and C, tended to have greater bow or positive bow (concave). The bow and axial strains in the other examined regions did not follow these trends. See Figures 3-11, 3-12, and 3-13. The radial strains tended to peak in core layer 5. This was also true of the axial strains. Figures 3-14, 3-15, and 3-16 show the intra-element measured radial strain for region 18, 22, and 13 and 3, respectively.

Each core surveillance provide additional in-pile data. These data are used to gain a better perspective of the range of potential strains in HTGR fuel elements*. The fast neutron doses received by the core segment 3 elements [$<2.8 \times 10^{25}$ n/m^2 (E < 29 fJ)$_{HTGR}$] were less than the expected lifetime doses that would be received by most fuel elements in a HTGR. Since the fast fluences were low, the measured strains were relatively small (<1.0%). Figures 3-17 and 3-18 show the envelopes of measured strains for core segments 1, 2 and 3 surveillances as compared to the range of potential strains using the H-327 graphite design curves.

3.5 Comparisons of Measured and Calculated Strains and Bow

Strain and bow predictions were obtained using the SURVEY/STRESS (Ref. 9) code. SURVEY/STRESS calculates stresses, strains and deformations (bow) in an HTGR fuel element based on viscoelastic beam theory. It is the simplest and most efficient of three codes used to calculate stresses in HTGR fuel elements. It is used to survey the entire core to identify potential critical elements which can be further studied by more refined analysis. Since SURVEY/STRESS models all the important physical effects and structural

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*The measured strains ($\Delta L/L$) include the creep strain and elastic strain as well as the irradiation-induced strain. However, the creep strain and elastic strain for these elements were small, so the measured strain is approximately equal to the irradiation-induced strain (at room temperature).

interactions, the results should correlate reasonably well with the more refined analyses. Tables 3-1 and 3-2 compare the measured axial strain and bow, and radial strain with the SURVEY/STRESS predictions.

Figures 3-19 and 3-20 show the differences between calculated and measured element-average axial and radial strains for the segment 3 elements versus fast neutron fluence. The results of core segment 3 surveillance strain comparisons are given below:

1. <u>Axial Strain</u>

   a. The calculated axial strains were consistently lower for all temperature and fluence ranges. The disagreement between measured and calculated strains increased with higher fast fluences.

   b. The agreement between measured and calculated axial strain was within the ±0.0001 mm/mm to 0.002 mm/mm range for fluences lower than 2.0 x 10^{25} n/m^2. Whereas, the agreement between measured and calculated axial strain for fluences greater than 2.0 x 10^{25} n/m^2 ranged from 0.002 mm/m to 0.0045 mm/mm.

2. <u>Radial Strain</u>

   a. The calculated radial strains were consistently lower than the measured strains.

   b. The agreement between calculated and measured strains was within ±0.003 mm/mm for all elements.

   c. The agreement between calculated and measured strains varied with fast fluence. The lower the fast fluence the better the agreement.

The polynomial expression used in SURVEY/STRESS code to represent the design data for irradiation-induced dimensional change of H-327 graphite has been revised (Ref. 10) since the core segment 2 surveillance. The revised polynomial expression no longer exaggerates the rate at which the H-327 graphite shrinks with fast neutron exposure (Ref. 3). The revised expression does not exaggerate the strain in the low temperature, low fluence ranges. At fluences between 2.0 and 3.0 x 10^{25} n/m^2 the revised expression underpredicts the strain by a ratio of 2 to 1.

3.6 FTE-2 Metrological Results

FTE-2 underwent very little dimensional change as a result of irradiation. The element average axial and radial strains were measured to be -0.262% (0.9 mm shrinkage) and -0.099% (0.4 mm shrinkage), respectively. The maximum bow was 0.10 mm. The radial and axial strain distributions, (from across-flats dimension and element length measurements), for FTE-2 are shown in Figures 3-11 and 3-15. The maximum bow for each side face is also shown in Figure 3-11.

The measured strains were compared with the calculated strains (via the SURVEY/STRESS code). The differences between calculated and measured axial and radial strains were -0.018% and -0.112%, respectively (see Tables 3-1 and 3-2). The polynomial expression used in SURVEY/STRESS to represent the design data for irradiation-induced dimensional change of H-451 graphite slightly overpredicted the strains (see Tables 3-1 and 3-2).

Fig. 3-1 Metrology robot in HSF at FSV

Fig. 3-2 Side view of metrology robot probe

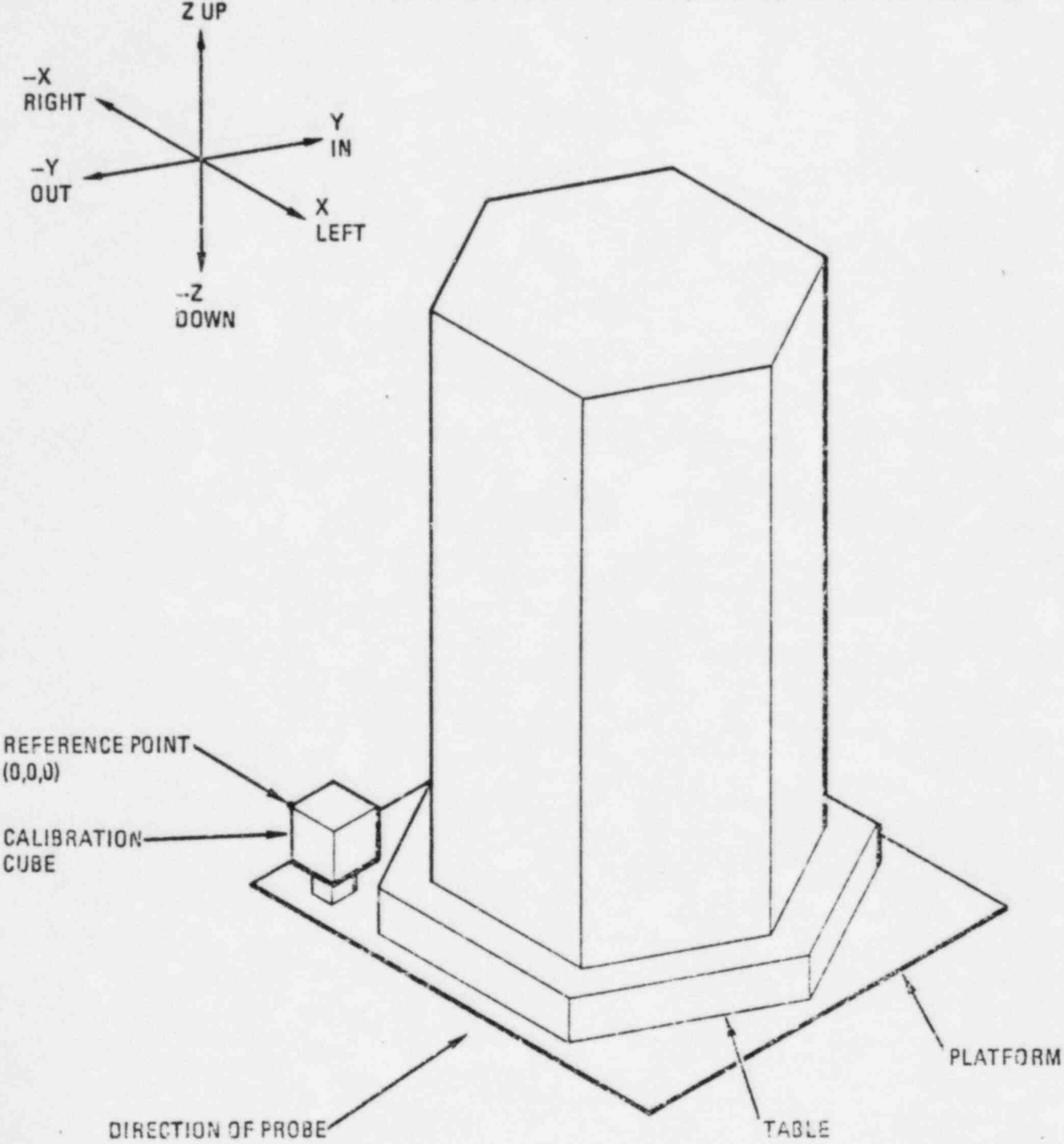
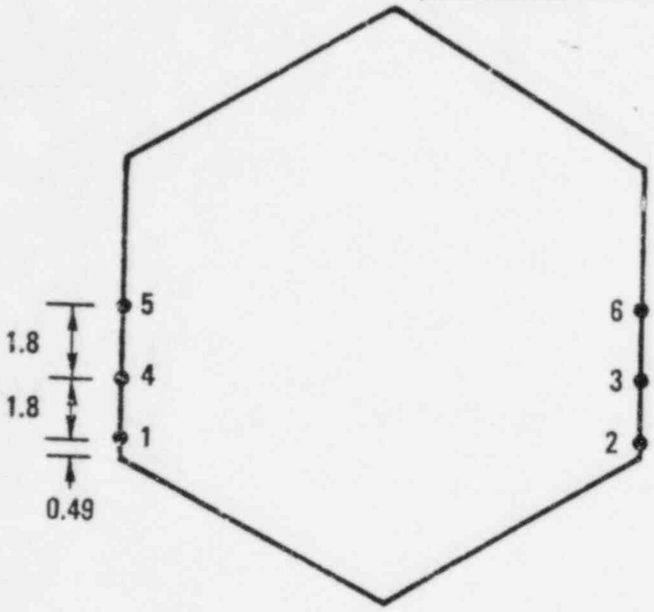
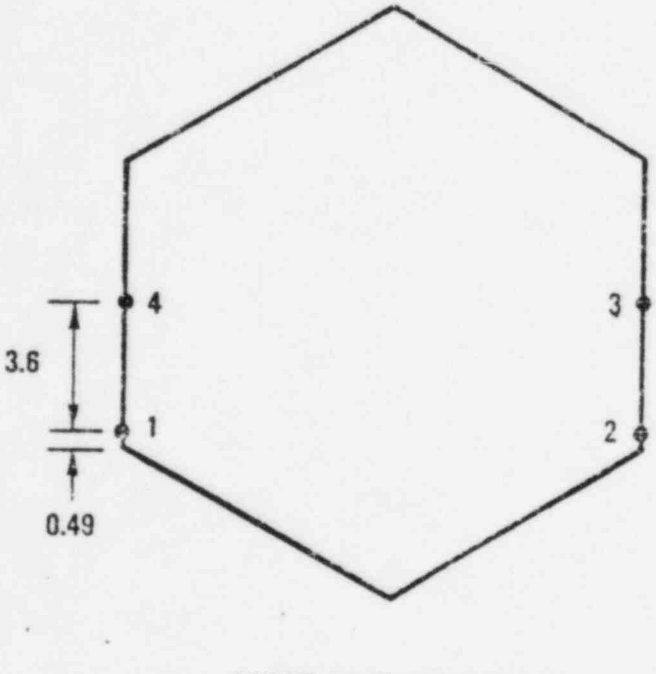


Fig. 3-3 Metrology robot coordinate system



MEASUREMENTS (POINTS) 1 THROUGH 6 REPEATED WITH EACH CORNER OF THE ELEMENT FACING THE PROBE.

FULL-LENGTH INSPECTION

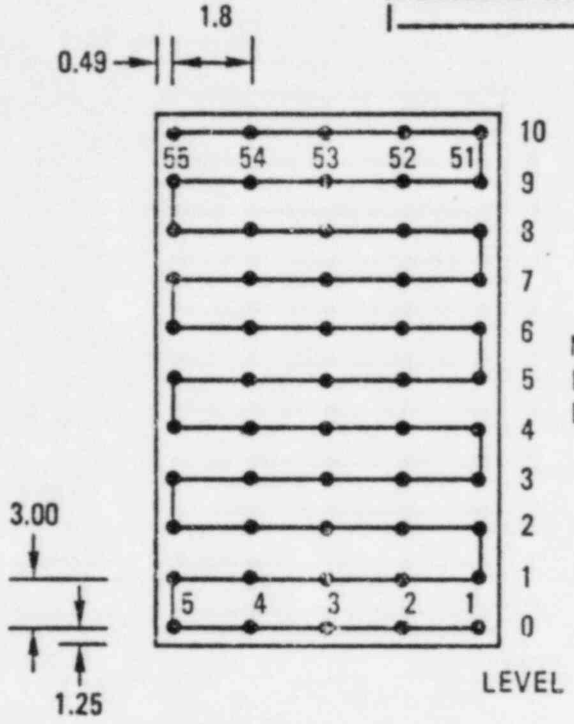


MEASUREMENTS (POINTS) 1 THROUGH 4 REPEATED WITH EACH CORNER OF THE ELEMENT FACING THE PROBE.

(ALL DIMENSIONS IN INCHES)

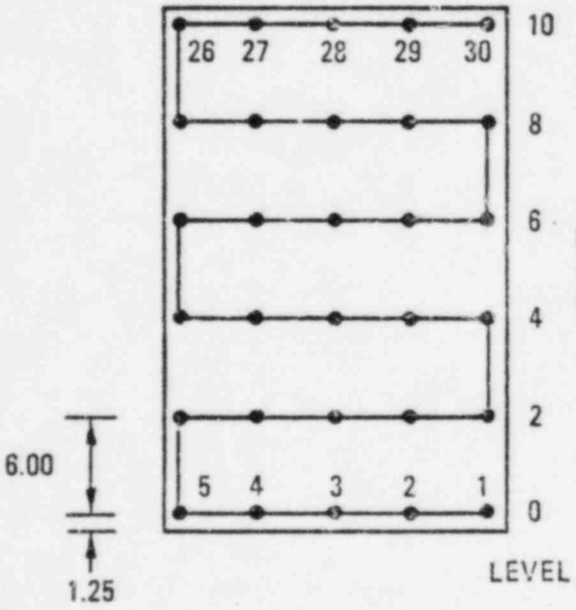
ABBREVIATED INSPECTION

Fig. 3-4 Across-the-flats measurements



MEASUREMENTS (POINTS) 1 THROUGH 55 REPEATED WITH EACH FACE OF THE ELEMENT FACING THE PROBE

FULL-LENGTH INSPECTION

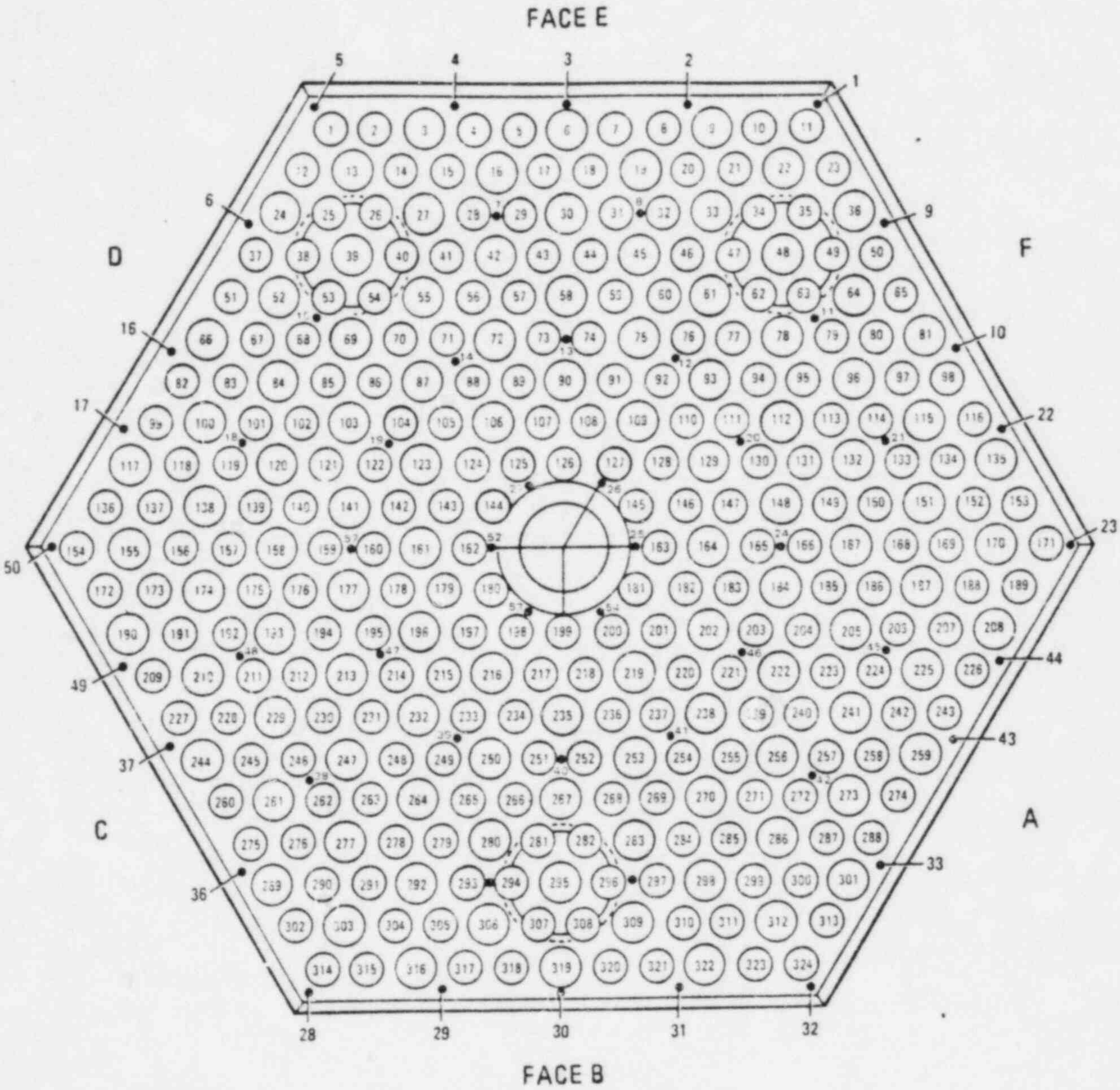


MEASUREMENTS (POINTS) 1 THROUGH 30 REPEATED WITH EACH FACE OF THE ELEMENT FACING THE PROBE

(ALL DIMENSIONS IN INCHES)

ABBREVIATED INSPECTION

Fig. 3-5 Side face measurements



(a) REGULAR FUEL ELEMENT; FULL LENGTH AND ABBREVIATED INSPECTIONS

Fig. 3-6 Top surface measurements (Sheet 1 of 2)

TITLE: NONDESTRUCTIVE EXAMINATION OF 62 FUEL AND REFLECTOR ELEMENTS FROM FORT ST. VRAIN CORE SEGMENT 3

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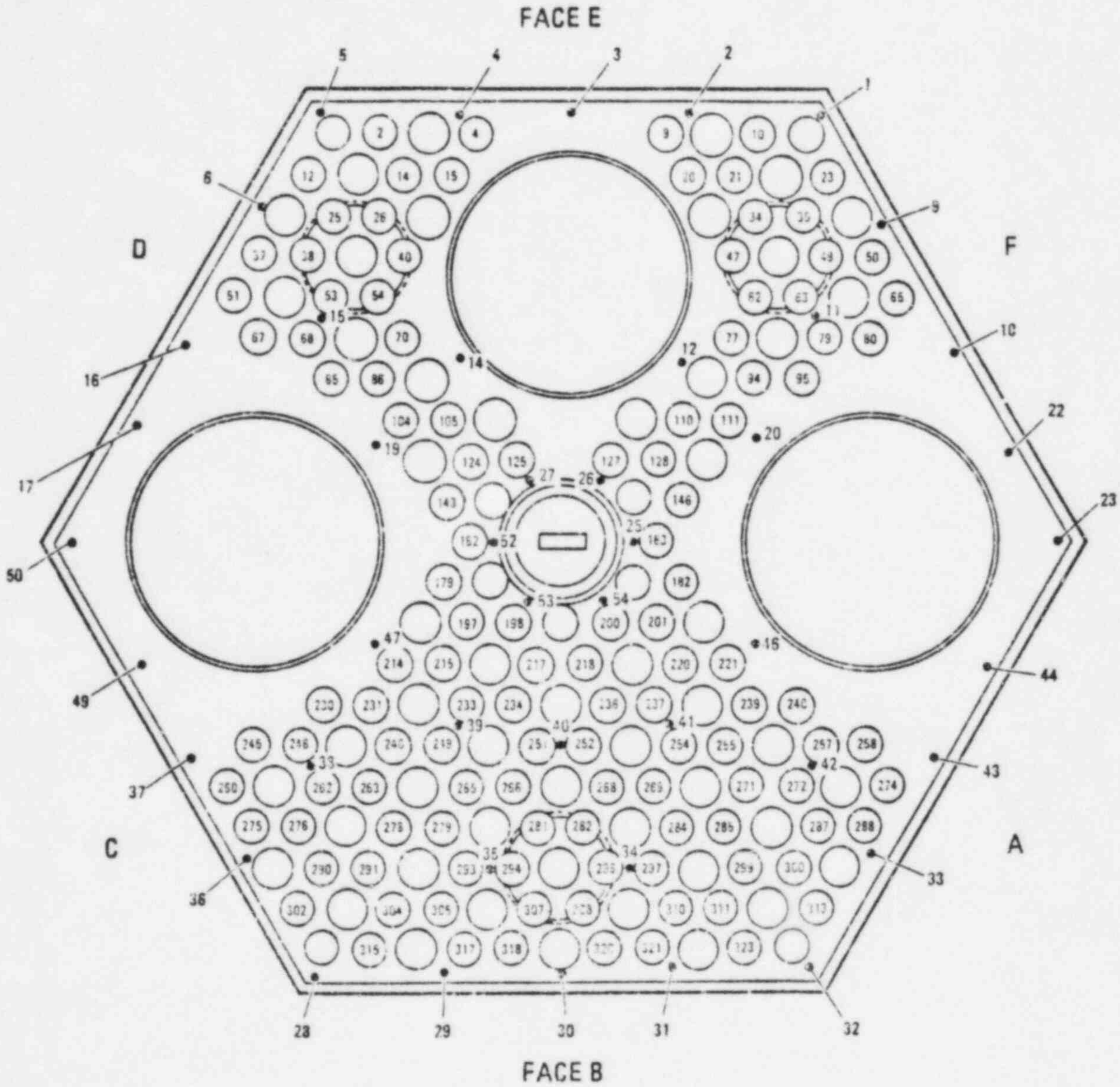
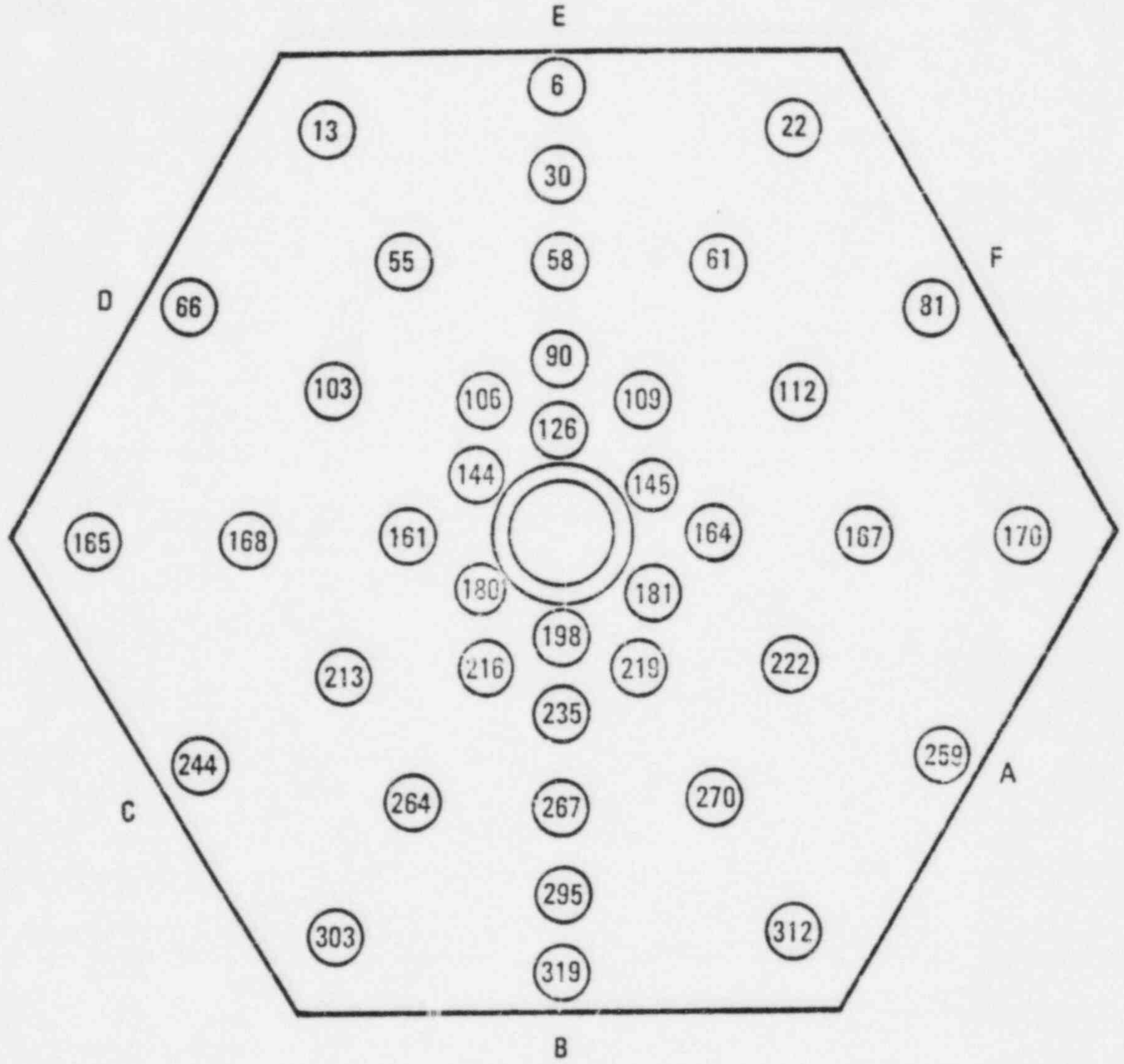


(b) CONTROL-ROD FUEL ELEMENT; FULL-LENGTH AND ABBREVIATED INSPECTIONS

Fig. 3-6 Top surface measurements (Sheet 2 of 2)



FULL LENGTH INSPECTION – REGULAR FUEL ELEMENT

NOTE: COOLANT HOLES 66, 81, 103, 112. 144, 145, 180, 181, 213, 222, 244, AND 259 OMITTED FOR ABBREVIATED INSPECTION OF REGULAR FUEL ELEMENT. COOLANT HOLES 312, 270, 219, 181, 198, 235, 180, 216, 264, 303, 319, 295, 267, 13, 106, 144, 145, 109, AND 22 MEASURED FOR CONTROL-ROD ELEMENTS.

Fig. 3-7 Coolant hole measurements

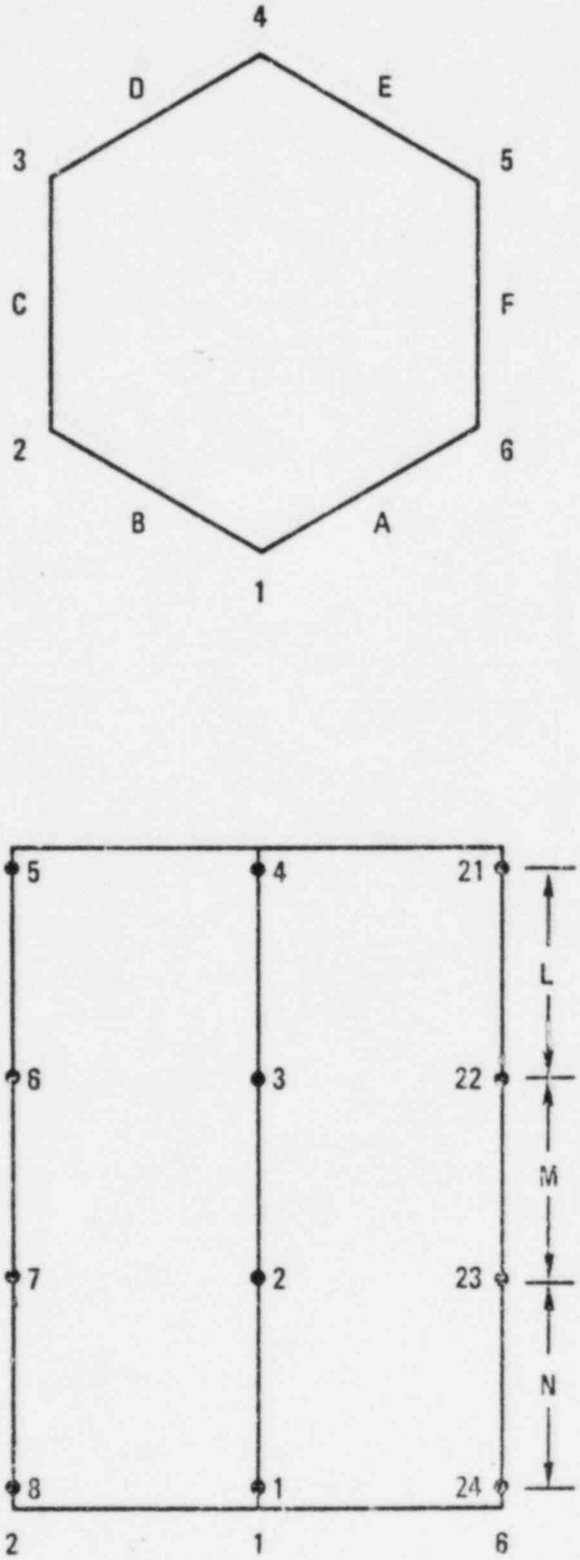


Fig. 8 Fiducial hole measurements

Table 3-1

RESULTS OF DIMENSIONAL INSPECTIONS OF FSV SEGMENT 3
CORE COMPONENTS AXIAL STRAIN AND BOW

Element Serial Number	Core Location	Irrad. Conditions[(a)]		Axial Strain[(b)] (%)				Bow (mm)	
		Temp. (°C)	Fast Fluence ($\times 10^{25} n/m^2$)	Measured		Calc.[(c)] $(E_Z)_c$	Difference $(E_Z)_c-(E_Z)_m$	Meas.	Calc.[(d)]
				$(E_Z)_m$	±1σ				
02-1707	18.01.F.03	387	1.67	−0.410	±.012	−0.349	0.061	0.30	0.002
01-0684	18.02.F.04	381	1.71	−0.401	±.012	−0.380	0.021	0.25	0.15
04-0463	18.03.F.04	386	1.69	−0.412	±.015	−0.363	0.049	0.28	0.10
01-1018	18.04.F.04	398	1.87	−0.457	±.008	−0.368	0.089	0.43	0.07
01-2282	18.05.F.04	396	1.88	−0.465	±.008	−0.376	0.089	0.36	0.09
01-0647	18.06.F.04	384	1.72	−0.416	±.012	−0.368	0.048	0.33	0.12
01-1612	18.07.F.04	379	1.67	−0.392	±.008	−0.374	0.018	0.25	0.13
02-2815	18.01.F.04	457	2.20	−0.537	±.008	−0.277	0.260	0.31	0.01
01-1990	18.02.F.05	448	2.37	−0.647	±.008	−0.315	0.332	0.43	0.18
01-0192	18.03.F.05	457	2.42	−0.648	±.008	−0.312	0.336	0.46	0.13
01-0305	18.04.F.05	482	2.62	−0.711	±.008	−0.297	0.414	0.43	0.06
01-1555	18.05.F.05	476	2.59	−0.731	±.007	−0.307	0.424	0.41	0.13
01-1410	18.06.F.05	456	2.45	−0.700	±.008	−0.321	0.379	0.48	0.16
01-0974	18.07.F.05	446	2.36	−0.639	±.008	−0.323	0.316	0.41	0.19
02-1120	18.01.F.05	517	2.25	−0.428	±.008	−0.191	0.237	0.23	0.03
01-2447	18.02.F.06	506	2.50	−0.580	±.012	−0.210	0.370	0.25	0.11
01-1228	18.03.F.06	519	2.60	−0.571	±.012	−0.205	0.366	0.33	0.10
01-2351	18.04.F.06	554	2.76	−0.561	±.012	−0.186	0.375	0.25	0.06
01-1397	18.05.F.06	546	2.74	−0.639	±.008	−0.192	0.447	0.30	0.10
01-0873	18.06.F.06	518	2.63	−0.596	±.008	−0.211	0.385	0.41	0.11
01-1918	18.07.F.06	504	2.51	−0.560	±.008	−0.216	0.344	0.36	0.14
02-0265	18.01.F.06	557	1.80	−0.216	±.008	−0.146	0.070	0.08	0.04
01-0443	18.02.F.07	545	2.03	−0.325	±.008	−0.157	0.168	0.13	0.06
01-1817	18.03.F.07	562	2.11	−0.323	±.008	−0.147	0.176	0.18	0.05
01-2939	18.04.F.07	602	2.24	−0.350	±.015	−0.133	0.217	0.25	0.06

[(a)] Temperatures and fast fluences were obtained from SURVEY code calculations based on the GAUGE code depletion analysis of FSV cycles 1, 2, and 3. Temperatures are time and volume averaged. The temperature uncertainty (1σ) is estimated by 10% of the difference between the temperature and the gas-inlet temperature (~335°C, time averaged). The fast neutron fluences $(E > 29\ fJ)_{HTGR}$ are volume averaged. The uncertainty in the fast fluence is ±10% (1σ).

[(b)] Axial strains are element averages.

[(c)] The calculated axial strains were obtained by subtracting the thermal strain at 177°C (350°F) (0.027×10^{-2} mm/mm) from the end-of-life shutdown strains.

[(d)] Bow calculated at the element midplane by SURVEY/STRESS.

Table 3-1

RESULTS OF DIMENSIONAL INSPECTIONS OF FSV SEGMENT 3 CORE COMPONENTS AXIAL STRAIN AND BOW

Element Serial Number	Core Location	Irrad. Conditions(a)		Axial Strain(b) (%)				Bow (mm)	
		Temp. (°C)	Fast Fluence ($x10^{25}n/m^2$)	Measured		Calc.(c) $(E_Z)_c$	Difference $(E_Z)_c-(E_Z)_m$	Meas.	Calc.(d)
				$(E_Z)_m$	±1σ				
01-4304	18.05.F.07	592	2.21	−0.349	±.008	−0.130	0.219	0.20	0.04
01-5217	18.06.F.07	560	2.13	−0.375	±.015	−0.145	0.230	0.25	0.05
01-1773	18.07.F.07	543	2.04	−0.342	±.008	−0.156	0.186	0.13	0.07
02-1950	18.01.F.07	596	1.46	−0.184	±.008	−0.119	0.065	0.05	0.04
01-1621	18.02.F.08	583	1.64	−0.220	±.007	−0.130	0.090	0.20	0.02
01-0091	18.03.F.08	602	1.72	−0.223	±.008	−0.121	0.102	0.20	0.02
01-2396	18.04.F.08	649	1.82	−0.204	±.012	−0.124	C.080	0.20	0.13
01-1796	18.05.F.08	638	1.79	−0.228	±.008	−0.112	0.116	0.23	0.07
01-1337	18.06.F.08	602	1.71	−0.237	±.007	−0.112	0.125	0.20	0.03
01-0536	18.07.F.08	582	1.63	−0.220	±.007	−0.172	0.048	0.13	0.03
03-0787	18.01.F.08	613	0.96	−0.052	±.012	−0.087	−0.035	0.08	0.03
01-2563	18.02.F.09	601	1.08	−0.106	±.012	−0.100	0.006	0.08	0.02
01-1049	18.03.F.09	621	1.14	−0.103	±.008	−0.093	0.010	0.15	0.03
01-0530	18.04.F.09	671	1.21	−0.096	±.015	−0.101	−0.005	0.15	0.15
01-2640	18.05.F.09	639	1.19	−0.129	±.008	−0.090	0.039	0.15	0.08
01-1805	18.06.F.09	621	1.13	−0.095	±.012	−0.086	0.009	0.10	0.02
01-0715	18.07.F.09	598	1.07	−0.106	±.015	−0.097	0.009	0.08	0.02
08-0206 (FTE-2)	22.06.F.06	512	2.07	−0.262	±.005	−0.280	−0.018	0.10	0.05
05-2191	22.03.F.06	484	1.54	−0.244	±.008	−0.187	0.057	0.61	0.38
05-0751	22.04.F.06	497	1.92	−0.361	±.012	−0.199	0.162	0.69	0.36
05-2104	22.04.F.06	493	2.07	−0.373	±.008	−0.217	0.156	0.53	0.27
01-2943	3.06.F.09	639	1.42	−0.122	±.007	−0.096	0.026	0.18	0.03
02-2781	13.01.F.03	380	1.63	−0.376	±.008	−0.350	0.026	0.18	0.01
01-2606	13.03.F.06	535	2.82	−0.637	±.011	−0.233	0.404	0.46	0.06
01-0335	13.03.F.09	644	1.20	−0.108	±.011	−0.085	0.023	0.25	0.06

(a) Temperatures and fast fluences were obtained from SURVEY code calculations based on the GAUGE code depletion analysis of FSV cycles 1, 2, and 3. Temperatures are time and volume averaged. The temperature uncertainty (1σ) is estimated by 10% of the difference between the temperature and the gas-inlet temperature (~335°C, time averaged). The fast neutron fluences $(E > 29\ fJ)_{HTGR}$ are volume averaged. The uncertainty in the fast fluence is ±10% (1σ).

(b) Axial strains are element averages.

(c) The calculated axial strains were obtained by subtracting the thermal strain at 177°C (350°F) (0.027×10^{-2} mm/mm) from the end-of-life shutdown strains.

(d) Bow calculated at the element midplane by SURVEY/STRESS.

Table 3-1

RESULTS OF DIMENSIONAL INSPECTIONS OF FSV SEGMENT 3
CORE COMPONENTS AXIAL STRAIN AND BOW

Element Serial Number	Core Location	Irrad. Conditions(a)		Axial Strain(b) (%)				Bow (mm)	
		Temp. (°C)	Fast Fluence ($x10^{25} n/m^2$)	Measured		Calc.(c) $(E_Z)_c$	Difference $(E_Z)_c-(E_Z)_m$	Meas.	Calc.(d)
				$(E_Z)_m$	±1σ				
41-1004	22.10.R.06	NC(e)	NC	0.024	±.008	NC	NA	0.20	NC
17-1394	18.04.R.03	NC	NC	0.070	±.020	NC	NA	-0.05	NC
17-1270	18.04.R.10	NC	NC	0.043	±.020	NC	NA	NM	NC

(a) Temperatures and fast fluences were obtained from SURVEY code calculations based on the GAUGE code depletion analysis of FSV cycles 1, 2, and 3. Temperatures are time and volume averaged. The temperature uncertainty (1σ) is estimated by 10% of the difference between the temperature and the gas-inlet temperature (~335°C, time averaged). The fast neutron fluences (E > 29 fJ)$_{HTGR}$ are volume averaged. The uncertainty in the fast fluence is ±10% (1σ).

(b) Axial strains are element averages.

(c) The calculated axial strains were obtained by subtracting the thermal strain at 177°C (350°F) (0.027×10^{-2} mm/mm) from the end-of-life shutdown strains.

(d) Bow calculated at the element midplane by SURVEY/STRESS.

(e) NC = Not Calculated NA = Not Available; NM = Not Measured

TITLE: NONDESTRUCTIVE EXAMINATION OF 62 FUEL AND REFLECTOR ELEMENTS FROM FORT ST. VRAIN CORE SEGMENT 3

DOCUMENT NO. 907785 | **ISSUE NO./LTR.** N/C

Table 3-2

RESULTS OF DIMENSIONAL INSPECTIONS OF FSV SEGMENT 3 CORE COMPONENTS, RADIAL STRAIN

Element Serial Number	Core Location	Irradiation Conditions(a)		Radial Strain(b) (%)			
		Temperature (^{o}C)	Fast Fluence ($x10^{25}$ n/m^2)	Measured		Calculated(e) $(E_X)_c$	Difference $(E_X)_c-E_X)_m$
				$(E_X)_m$	$\pm 1\sigma$		
02-1707	18.01.F.03	387	1.67	−0.274	0.046	−0.208	0.066
01-0684	18.02.F.04	381	1.71	−0.271	0.014	−0.220	0.051
04-0463	18.03.F.04	386	1.69	−0.334	0.008	−0.219	0.115
01-1018	18.04.F.04	398	1.87	−0.357	0.016	−0.244	0.113
01-2282	18.05.F.04	396	1.88	−0.303	0.017	−0.249	0.054
01-0647	18.06.F.04	384	1.72	−0.311	0.013	−0.227	0.084
01-1612	18.07.F.04	379	1.67	−0.241	0.025	−0.217	0.024
02-2815	18.01.F.04	457	2.20	−0.420	0.081	−0.189	0.231
01-1990	18.02.F.05	448	2.37	−0.480	0.008	−0.211	0.269
01-0192	18.03.F.05	457	2.42	−0.479	0.039	−0.220	0.259
01-0305	18.04.F.05	482	2.62	−0.491	0.006	−0.221	0.270
01-1555	18.05.F.05	476	2.59	−0.513	0.014	−0.227	0.286
01-1410	18.06.F.05	456	2.45	−0.569	0.042	−0.230	0.339
01-0974	18.07.F.05	446	2.36	−0.502	0.061	−0.220	0.282
02-1120	18.01.F.05	517	2.25	−0.325	0.030	−0.121	0.204
01-2447	18.02.F.06	506	2.50	−0.344	0.013	−0.140	0.204
01-1228	18.03.F.06	519	2.60	−0.401	0.068	−0.144	0.257
01-2351	18.04.f.06	554	2.76	−0.336	0.023	−0.125	0.211
01-1397	18.05.F.06	546	2.74	−0.425	0.027	−0.130	0.295
01-0873	18.06.F.06	518	2.63	−0.406	0.013	−0.152	0.254
01-1918	18.07.F.06	504	2.51	−0.356	0.021	−0.150	0.206

(a) Temperatures and fast fluences were obtained from SURVEY code calculations based on the GAUGE code depletion analysis of FSV cycles 1, 2, and 3. They are time- and volume-averaged temperatures for axial point 3, the mid-plane of the block. The temperature uncertainty (1σ) is estimated by 10% of the difference between the tempreature and the gas-inlet temperature (~335^{o}C), time averaged).

(b) Radial strains are element-averaged strains at the mid-plane of the elements.

(c) The radial strains were obtained by subtracting the thermal strain at 177^{o}C (350^{o}F) (0.056×10^{-2} mm/mm) from the end-of-life shutdown strain calculated by SURVEY/STRESS for axial point 3, the mid-plane of the element.

Table 3-2

RESULTS OF DIMENSIONAL INSPECTIONS OF FSV SEGMENT 3 CORE COMPONENTS, RADIAL STRAIN

		Irradiation Conditions[a]		Radial Strain[b] (%)			
				Measured			
Element Serial Number	Core Location	Temperature (°C)	Fast Fluence ($x10^{25}$ n/m^2)	$(E_X)_m$	±1σ	Calculated[e] $(E_X)_c$	Difference $(E_X)_c-E_X)_m$
02-0265	18.01.F.06	557	1.80	-0.135	0.021	-0.073	0.062
01-0443	18.02.F.07	545	2.03	-0.164	0.015	-0.084	0.080
01-1817	18.03.F.07	562	2.11	-0.182	0.002	-0.080	0.102
01-2939	18.04.F.07	602	2.24	-0.201	0.014	-0.057	0.144
01-4304	18.05.F.07	592	2.21	-0.164	0.019	-0.057	0.107
01-5217	18.06.F.07	560	2.13	-0.231	0.011	-0.081	0.150
01-1773	18.07.F.07	543	2.04	-0.210	0.011	-0.089	0.121
02-1950	18.01.F.07	596	1.46	-0.119	0.003	-0.042	0.077
01-1621	18.02.F.08	583	1.64	-0.137	0.026	-0.049	0.088
01-0091	18.03.f.08	602	1.72	-0.104	0.028	-0.042	0.062
01-2396	18.04.F.08	649	1.82	-0.060	0.020	-0.024	0.036
01-1796	18.05.F.08	638	1.79	-0.074	0.012	-0.019	0.055
01-1337	18.06.F.08	602	1.71	-0.113	0.013	-0.037	0.076
01-0536	18.07.F.08	582	1.63	-0.109	0.014	-0.050	0.059
03-0787	18.01.F.08	613	0.96	-0.011	0.019	-0.021	-0.010
01-2563	18.02.F.09	601	1.08	-0.041	0.029	-0.025	0.016
01-1049	18.03.F.09	621	1.14	-0.005	0.014	-0.018	-0.013
01-0530	18.04.F.09	671	1.21	-0.028	0.023	-0.003	0.025
01-2640	18.05.F.09	659	1.19	-0.052	0.017	-0.000	0.052
01-1805	18.06.F.09	621	1.13	-0.047	0.007	-0.014	0.033
01-0715	18.07.F.09	598	1.07	0.009	0.015	-0.026	-0.035
08-0206 (FTE-2)	22.06.F.06	512	2.07	-0.099	0.012	-0.211	-0.112

[a] Temperatures and fast fluences were obtained from SURVEY code calculations based on the GAUGE code depletion analysis of FSV cycles 1, 2, and 3. They are time- and volume-averaged temperatures for axial point 3, the mid-plane of the block. The temperature uncertainty (1σ) is estimated by 10% of the difference between the temperature and the gas-inlet temperature (~335°C), time averaged).

[b] Radial strains are element-averaged strains at the mid-plane of the elements.

[c] The radial strains were obtained by subtracting the thermal strain at 177°C (350°F) (0.056×10^{-2} mm/mm) from the end-of-life shutdown strain calculated by SURVEY/STRESS for axial point 3, the mid-plane of the element.

Table 3-2

RESULTS OF DIMENSIONAL INSPECTIONS OF FSV SEGMENT 3
CORE COMPONENTS, RADIAL STRAIN

Element Serial Number	Core Location	Irradiation Conditions(a)		Radial Strain(b) (%)			
		Temperature (°C)	Fast Fluence ($x10^{25}$ n/m^2)	Measured		Calculated(e) $(E_X)_c$	Difference $(E_X)_c-E_X)_m$
				$(E_X)_m$	$\pm 1\sigma$		
05-2191	22.03.F.06	484	1.54	−0.186	0.024	−0.148	0.038
05-0751	22.02.F.06	497	1.92	−0.243	0.032	−0.155	0.088
05-2104	22.04.F.06	493	2.07	−0.311	0.032	−0.165	0.146
01-2943	03.06.F.09	639	1.42	−0.082	0.022	−0.025	0.057
02-2781	13.01.F.03	380	1.63	−0.298	0.034	−0.228	0.070
01-2606	13.03.F.06	535	2.82	−0.455	0.019	−0.180	0.275
01-0335	13.03.F.09	644	1.20	−0.048	0.024	−0.013	0.035
41-1004	22.10.R.06	NC(d)	NC	−0.038	0.018	NC	NC
17-1394	18.04.R.03	NC	NC	0.016	0.092	NC	NC
17-1270	18.04.R.10	NC	NC	0.071	0.026	NC	NC

(a) Temperatures and fast fluences were obtained from SURVEY code calculations based on the GAUGE code depletion analysis of FSV cycles 1, 2, and 3. They are time- and volume-averaged temperatures for axial point 3, the mid-plane of the block. The temperature uncertainty (1σ) is estimated by 10% of the difference between the tempreature and the gas-inlet temperature (~335°C), time averaged).

(b) Radial strains are element-averaged strains at the mid-plane of the elements.

(c) The radial strains were obtained by subtracting the thermal strain at 177°C (350°F) (0.056×10^{-2} mm/mm) from the end-of-life shutdown strain calculated by SURVEY/STRESS for axial point 3, the mid-plane of the element.

(d) NC = Not Calculated.

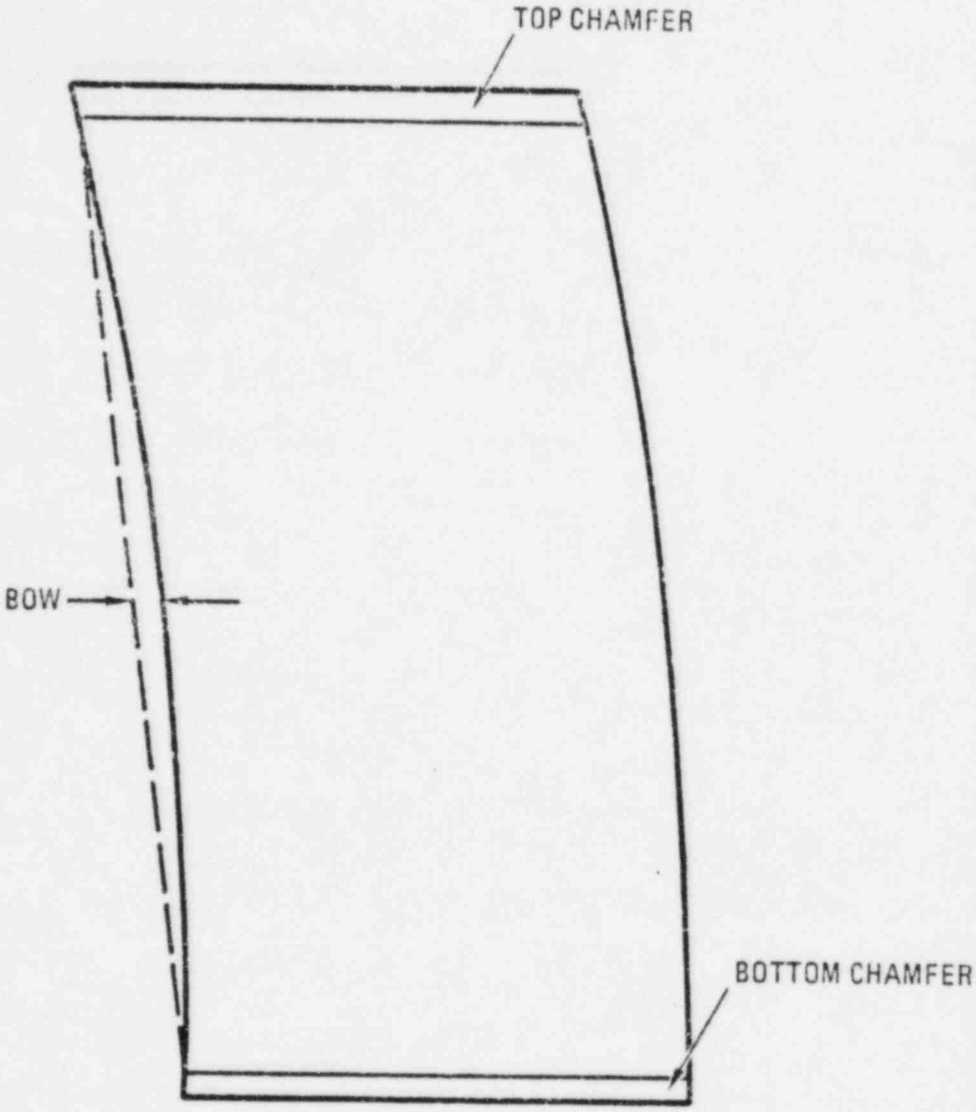


Fig. 3-9 Bow of FSV core components. Bow is defined as the displacement of the side face relative to a straight line connecting the top and bottom (below and above the chamfers) of the side face

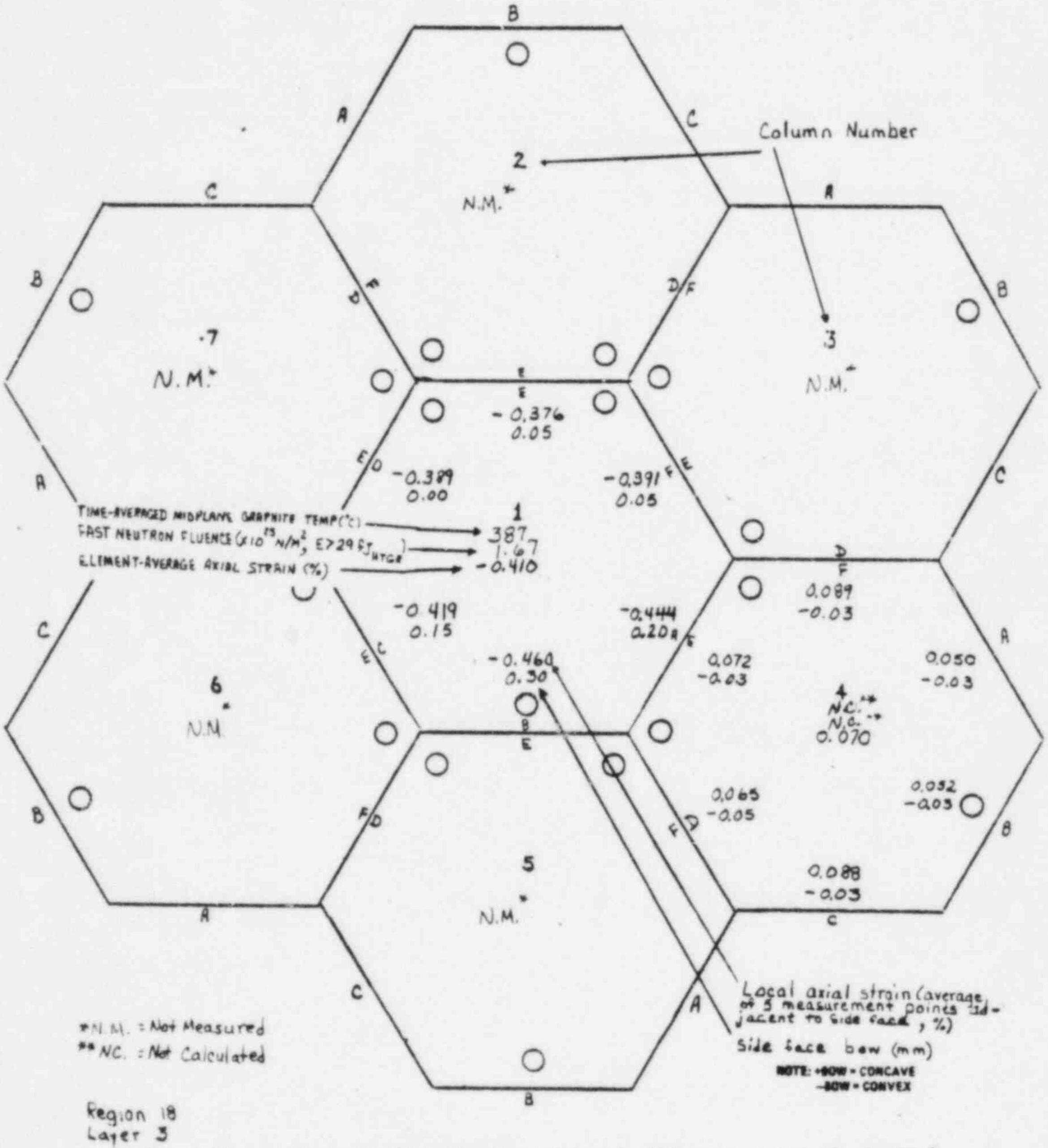


Fig. 3-10 Axial strain distribution and bow in FSV core region 18, layer 3
(1 of 8 sheets)

TITLE: NONDESTRUCTIVE EXAMINATION OF 62 FUEL AND REFLECTOR ELEMENTS FROM FORT ST. VRAIN CORE SEGMENT 3

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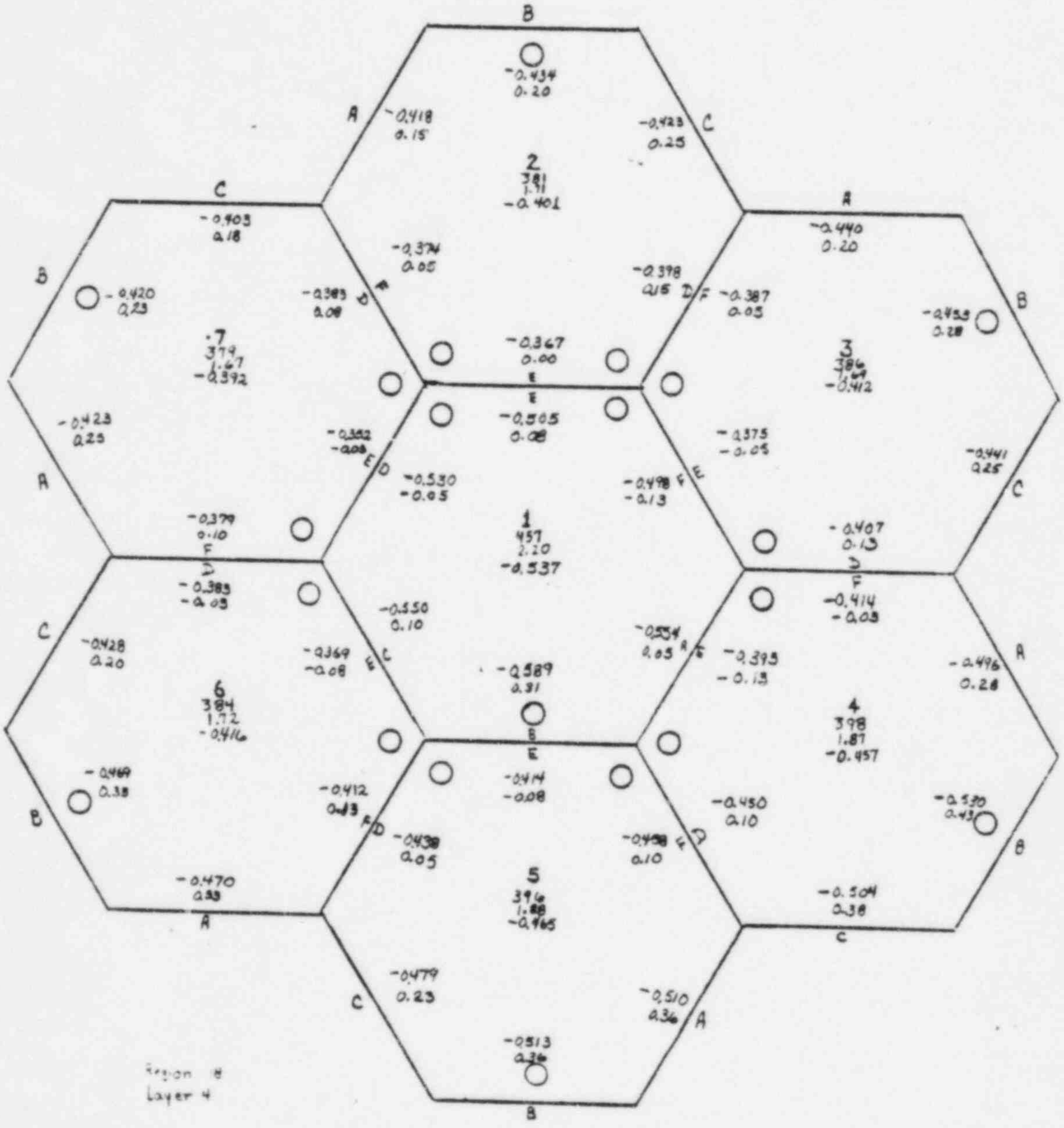


Fig. 3-10 Axial strain distribution and bow in FSV core region 18, layer 4 (2 of 8 sheets)

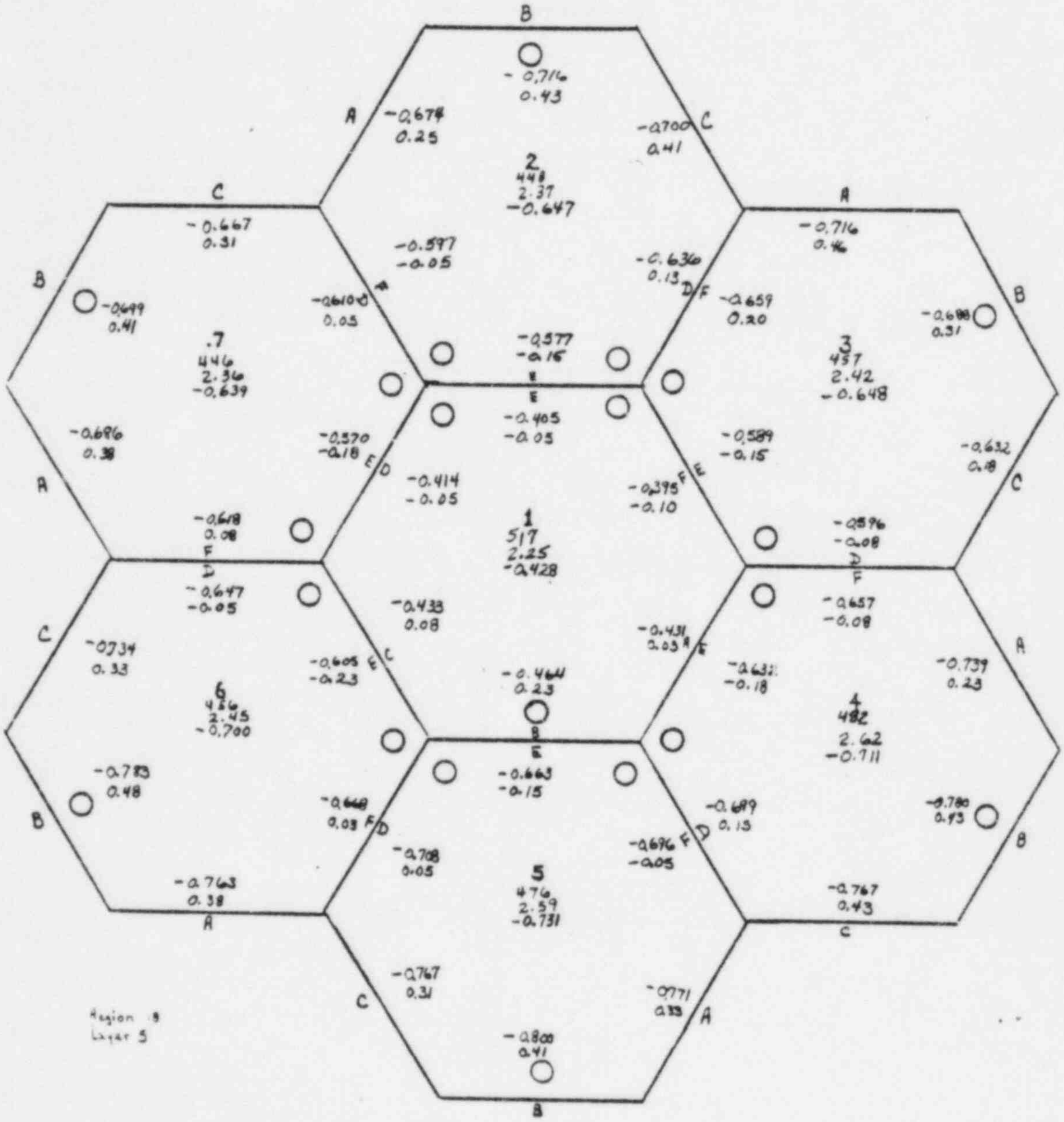


Fig. 3-10 Axial strain distribution and bow in FSV core region 18, layer 5 (3 of 8 sheets)

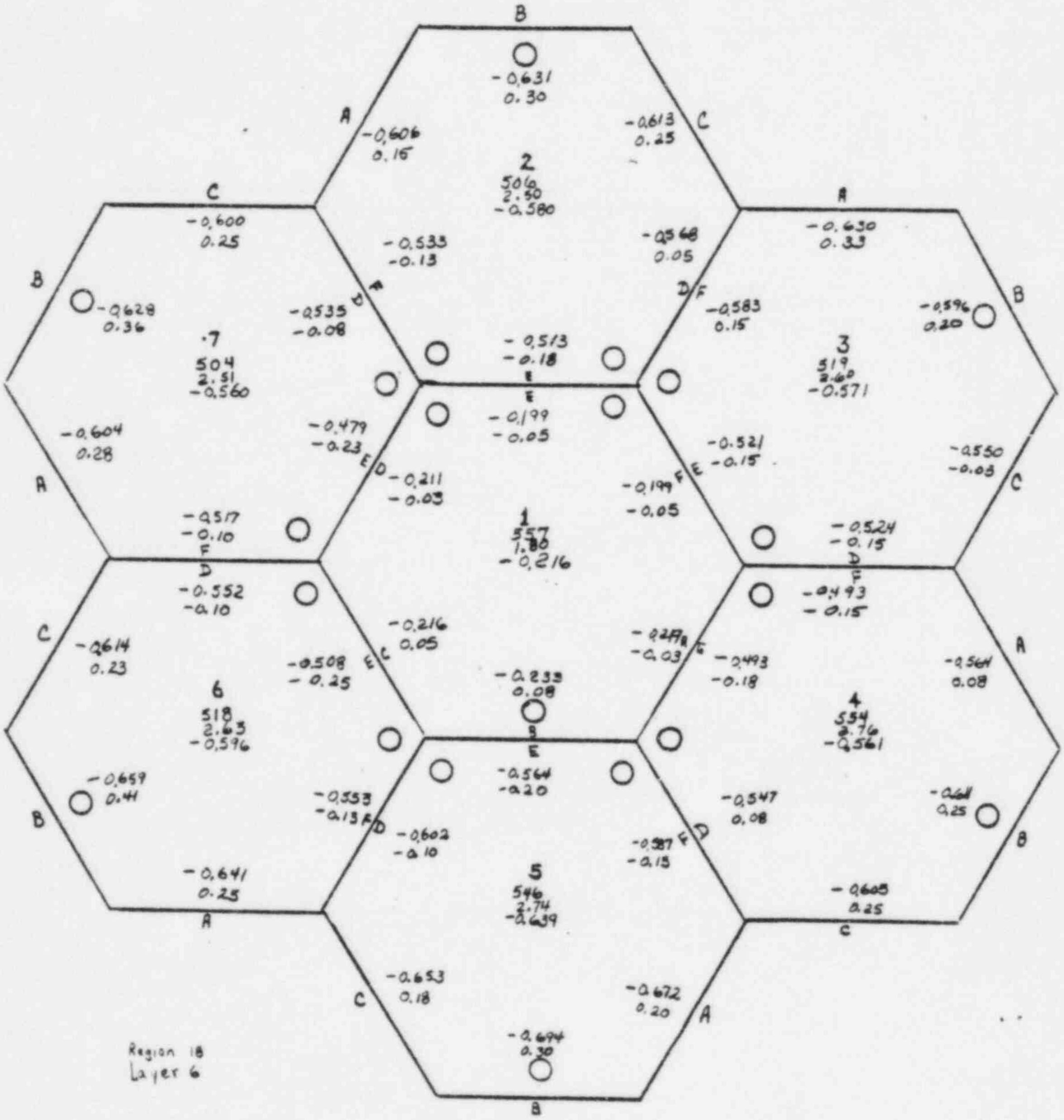


Fig. 3-10 Axial strain distribution and bow in FSV core region 18, layer 6 (4 of 8 sheets)

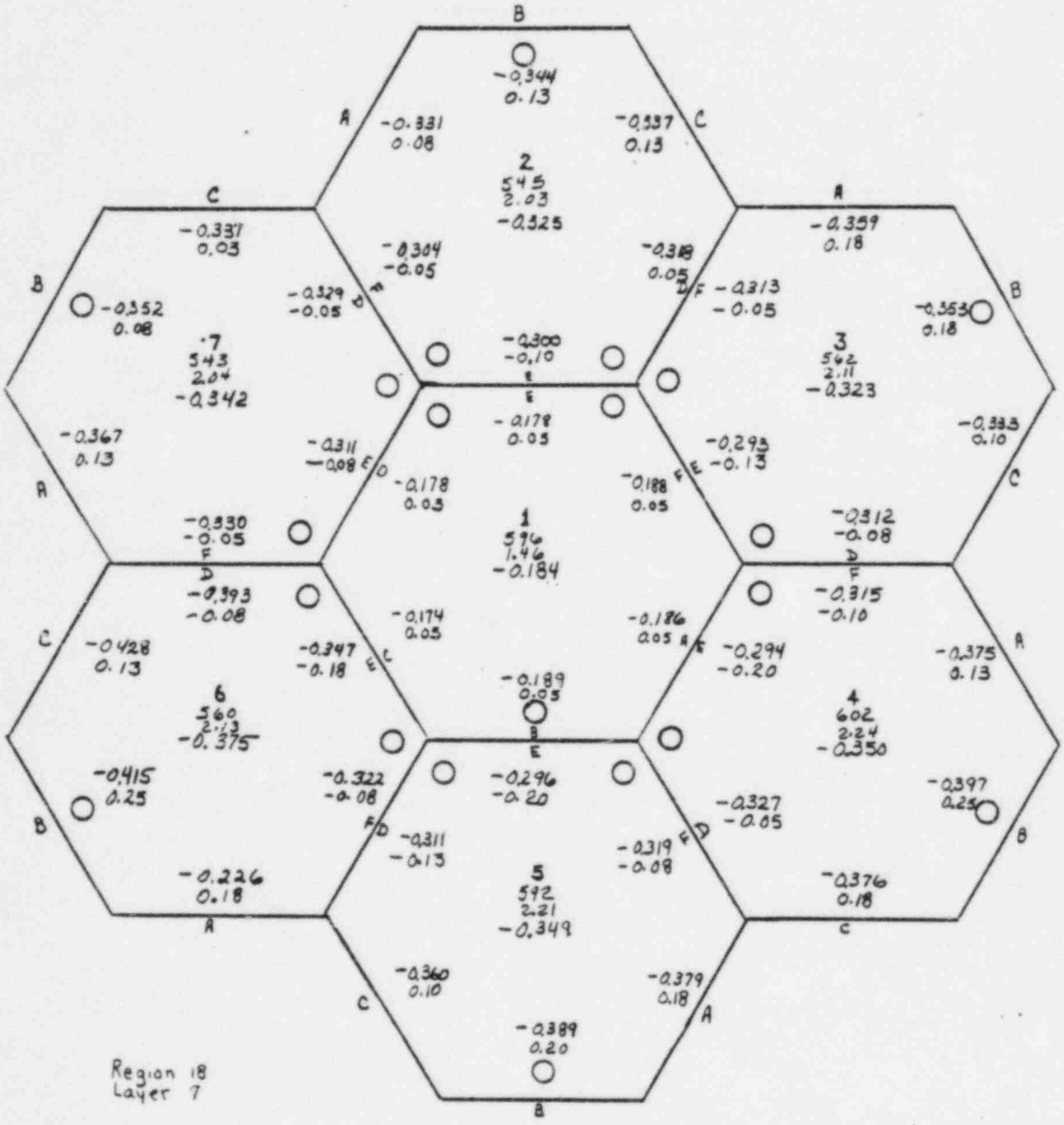


Fig. 3-10 Axial strain distribution and bow in FSV core region 18, Layer 7
(5 of 8 sheets)

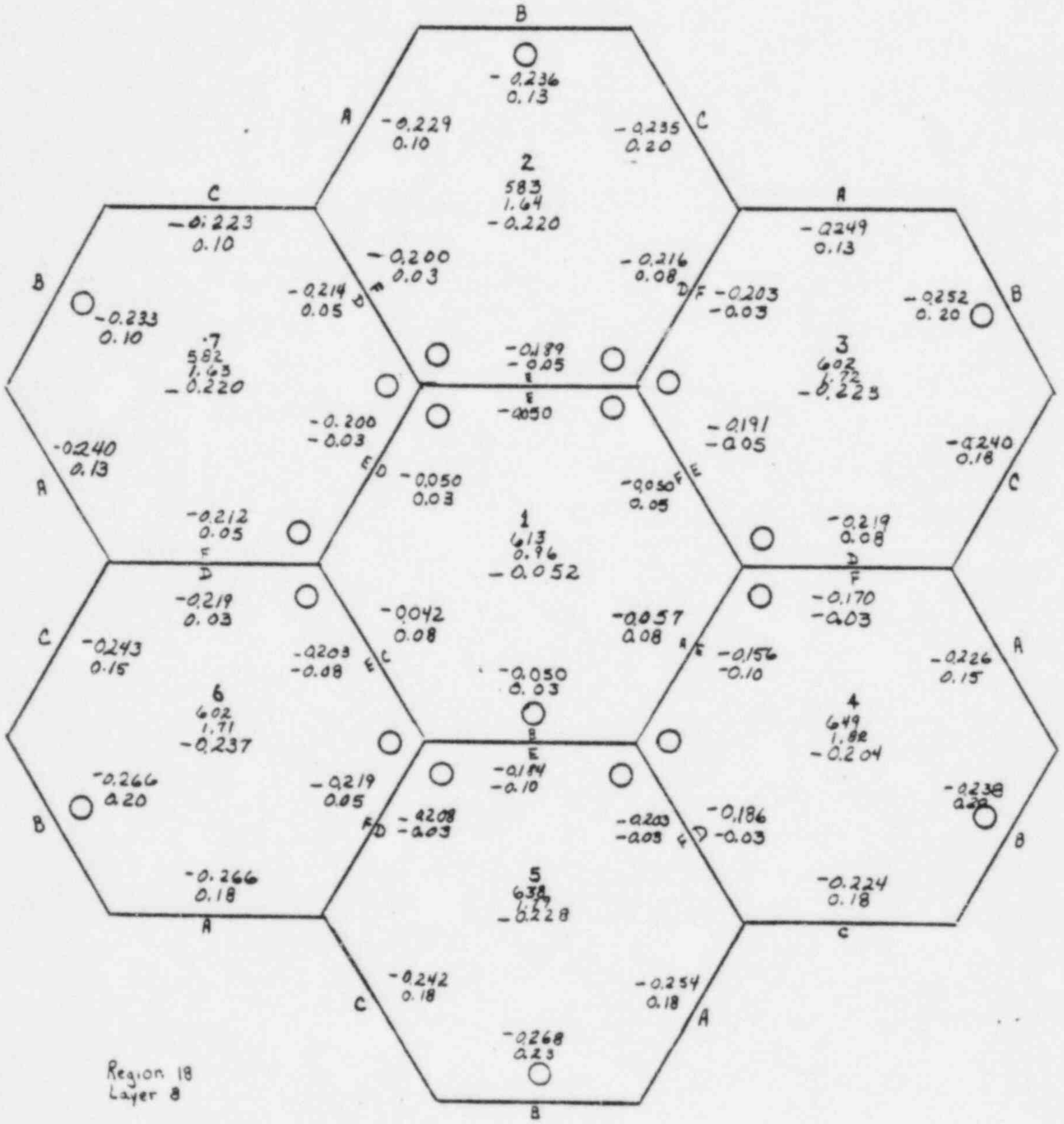


Fig. 3-10 Axial strain distribution and bow in FSV core region 18, layer 8
(6 of 8 sheets)

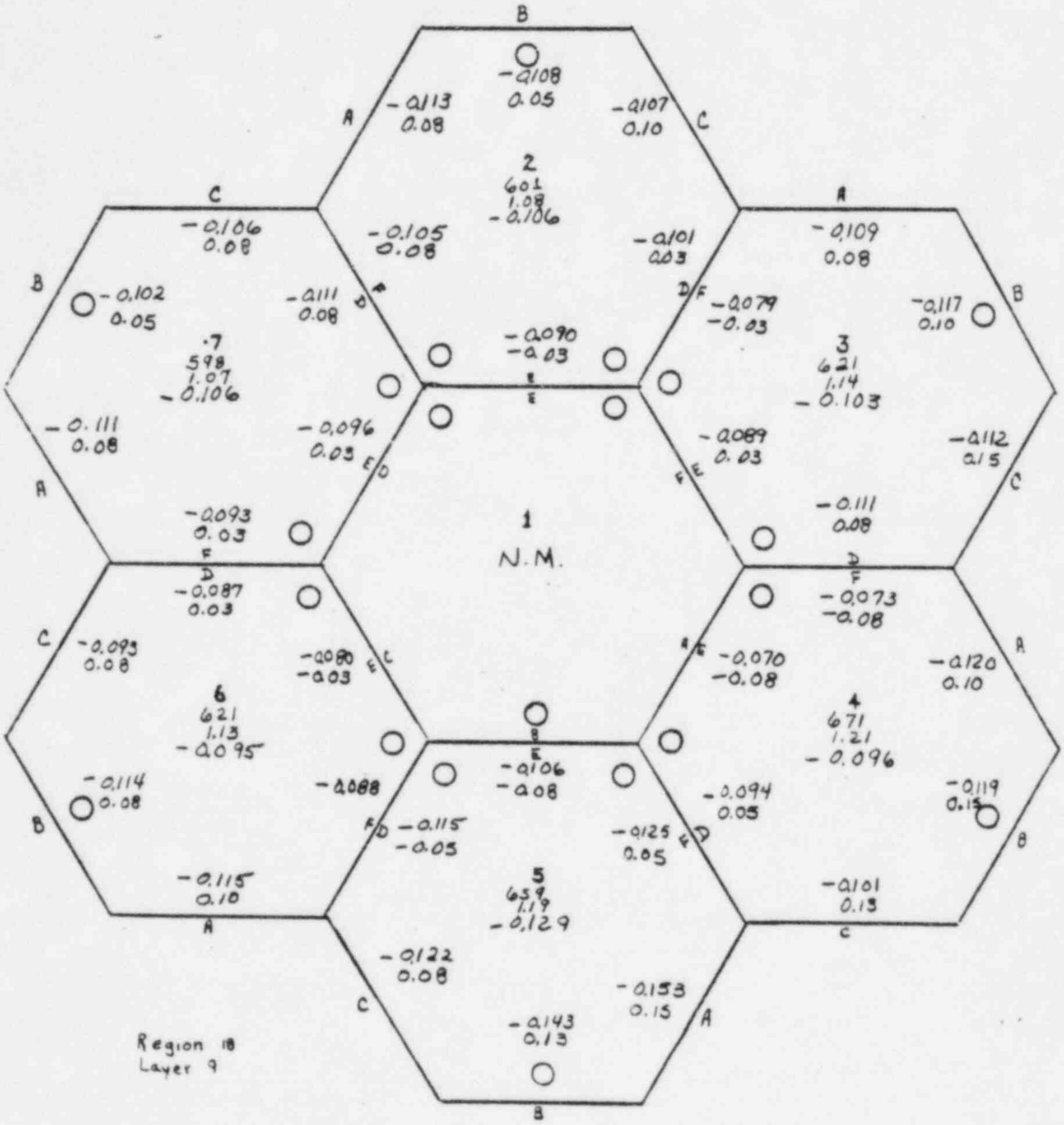
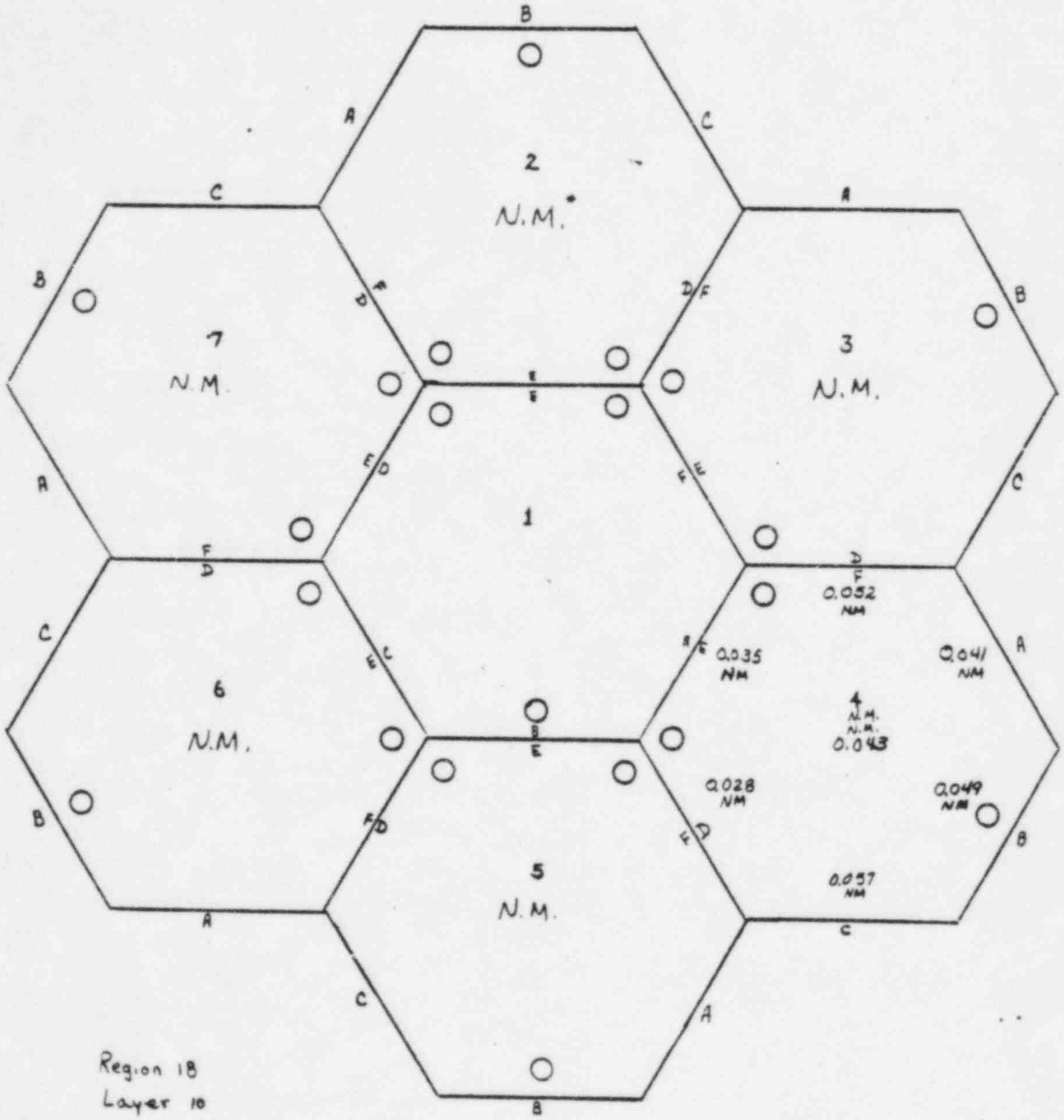


Fig. 3-10 Axial strain distribution and bow in FSV core region 18, layer 9
7 of 8 sheets)



Region 18
Layer 10
*NM : Not Measured

Fig. 3-10 Axial strain distribution and bow in FSV core region 18, Layer 10 (8 of 8 sheets)

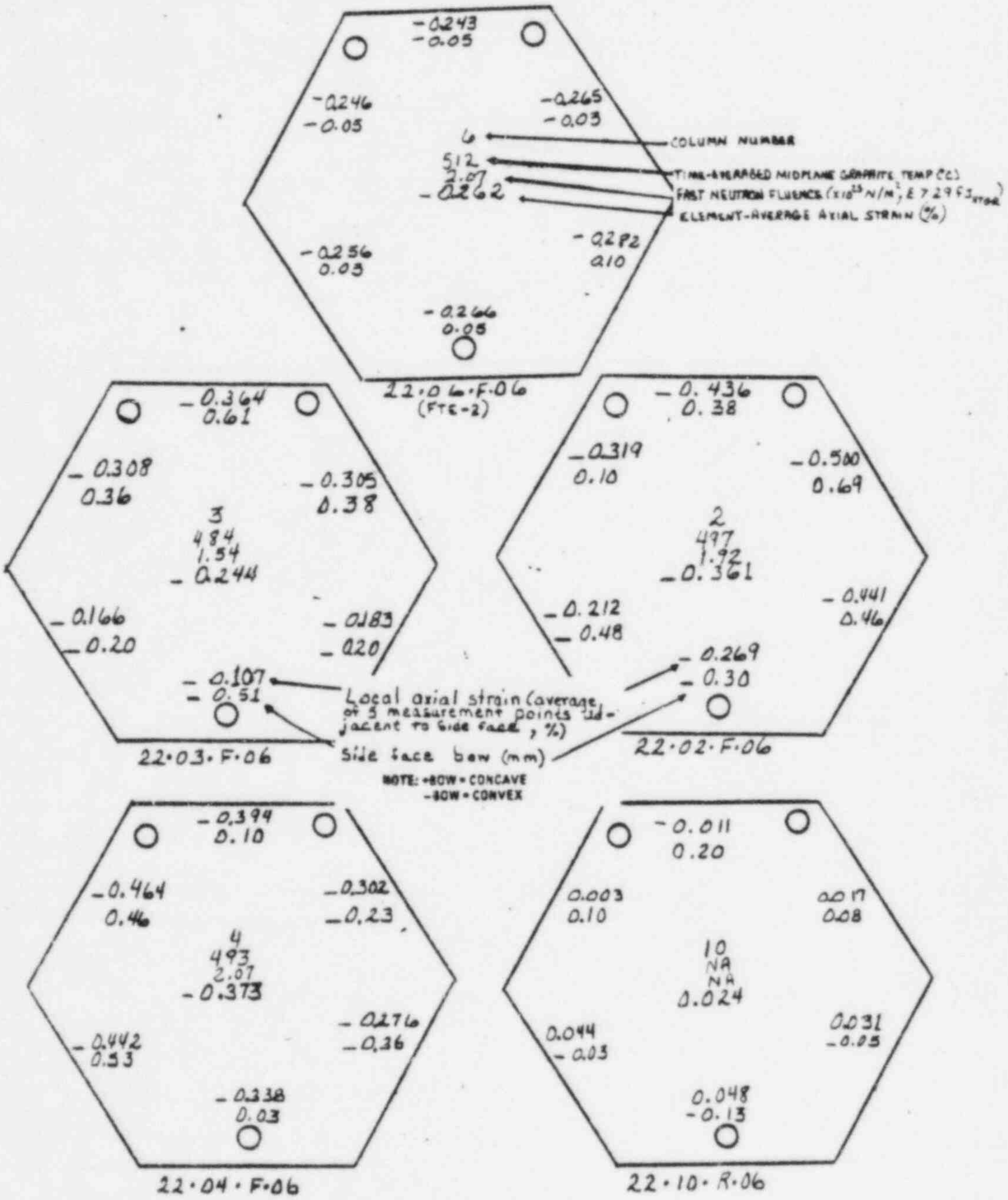


Fig. 3-11 Axial strain and bow distribution in examined elements from FSV core region 22

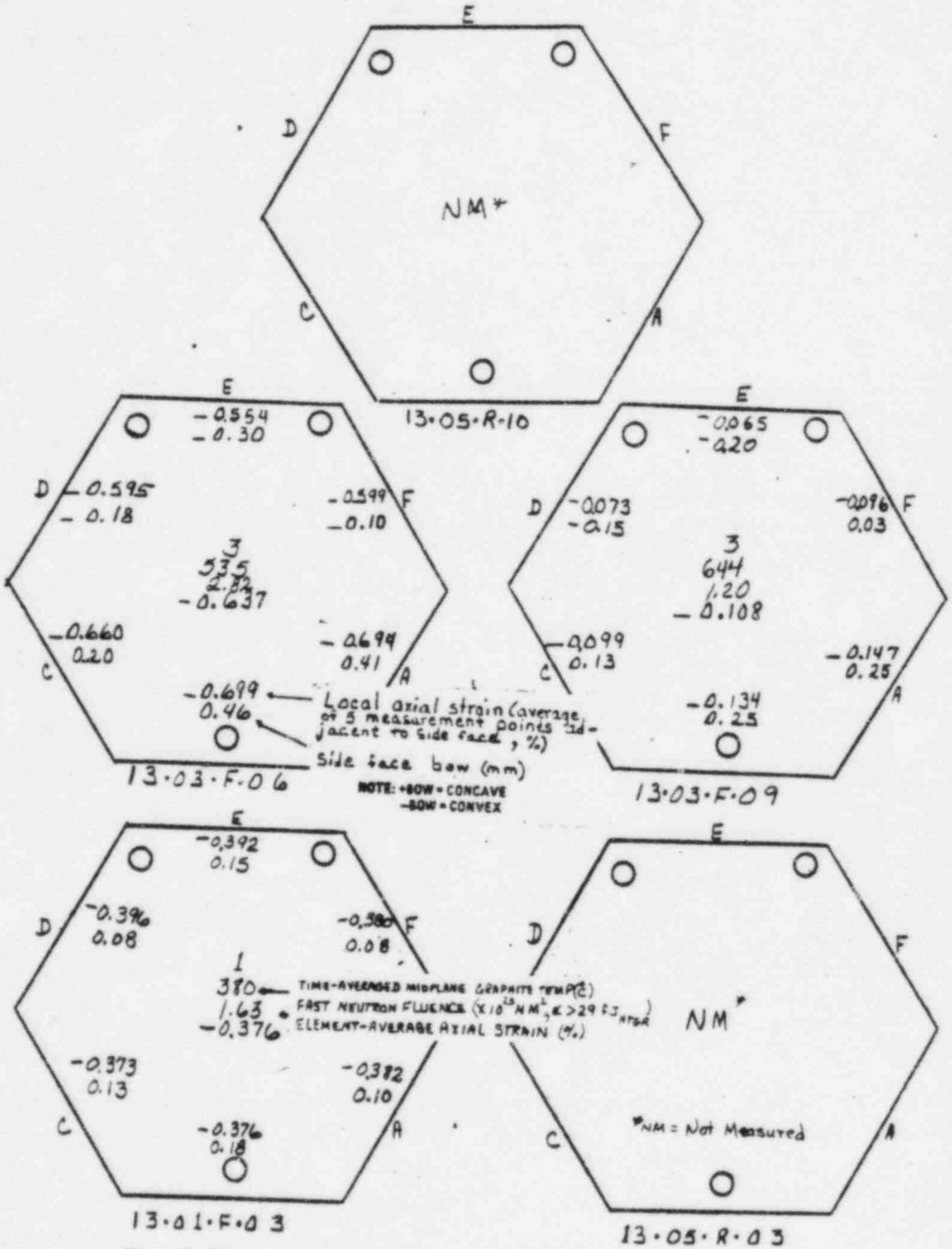


Fig. 3-12 Axial strain and bow in examined elements from FSV core region 13

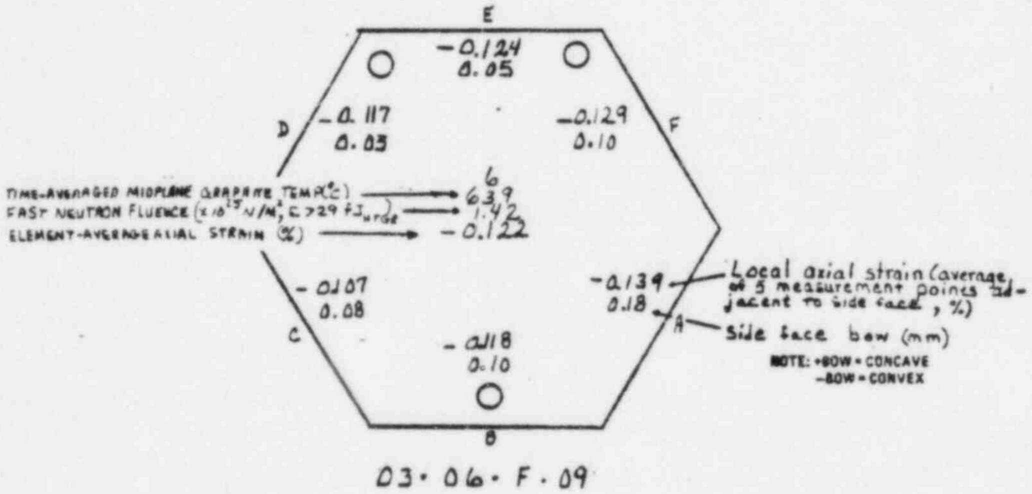
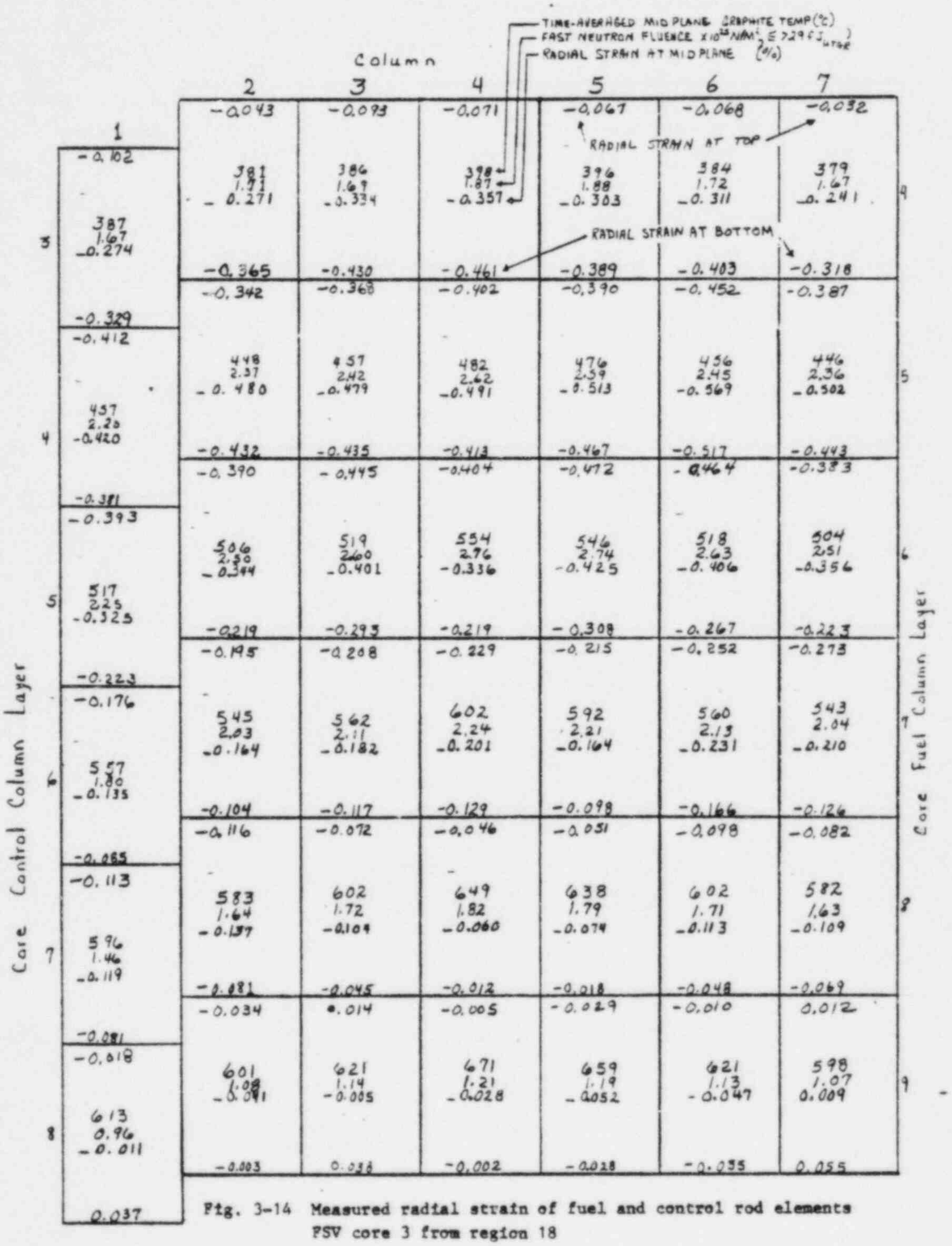


Fig. 3-13 Axial strain and bow from element 03·06·F·09



Core Fuel Column Layer	2	3	4	5	6	7
4	-0.043 381 1.71 -0.271 -0.365	-0.093 386 1.69 -0.334 -0.430	-0.071 398 1.87 -0.357 -0.461	-0.067 396 1.88 -0.303 -0.389	-0.068 384 1.72 -0.311 -0.403	-0.032 379 1.67 -0.241 -0.318
5	-0.342 448 2.37 -0.480 -0.432	-0.368 457 2.42 -0.479 -0.435	-0.402 482 2.62 -0.491 -0.413	-0.390 476 2.39 -0.513 -0.467	-0.452 456 2.45 -0.569 -0.517	-0.387 446 2.36 -0.502 -0.443
6	-0.390 506 2.50 -0.344 -0.219	-0.445 519 2.60 -0.401 -0.293	-0.404 554 2.76 -0.336 -0.219	-0.472 546 2.74 -0.425 -0.308	-0.464 518 2.63 -0.406 -0.267	-0.383 504 2.51 -0.356 -0.223
7	-0.195 545 2.03 -0.164 -0.104	-0.208 562 2.11 -0.182 -0.117	-0.229 602 2.24 -0.201 -0.129	-0.215 592 2.21 -0.164 -0.098	-0.252 560 2.13 -0.231 -0.166	-0.273 543 2.04 -0.210 -0.126
8	-0.116 583 1.64 -0.137 -0.081	-0.072 602 1.72 -0.104 -0.045	-0.046 649 1.82 -0.060 -0.012	-0.051 638 1.79 -0.074 -0.018	-0.098 602 1.71 -0.113 -0.048	-0.082 582 1.63 -0.109 -0.069
9	-0.034 601 1.08 -0.091 -0.003	.014 621 1.14 -0.005 0.038	-0.005 671 1.21 -0.028 -0.002	-0.029 659 1.19 -0.052 -0.028	-0.010 621 1.13 -0.047 -0.035	0.012 598 1.07 0.009 0.055

Core Control Column Layer	1
3	-0.102 387 1.67 -0.274 -0.329
4	-0.412 457 2.20 -0.420 -0.381
5	-0.393 517 2.25 -0.325 -0.223
6	-0.176 557 1.80 -0.135 -0.085
7	-0.113 596 1.46 -0.119 -0.081
8	-0.018 613 0.96 -0.011 0.037

Fig. 3-14 Measured radial strain of fuel and control rod elements FSV core 3 from region 18

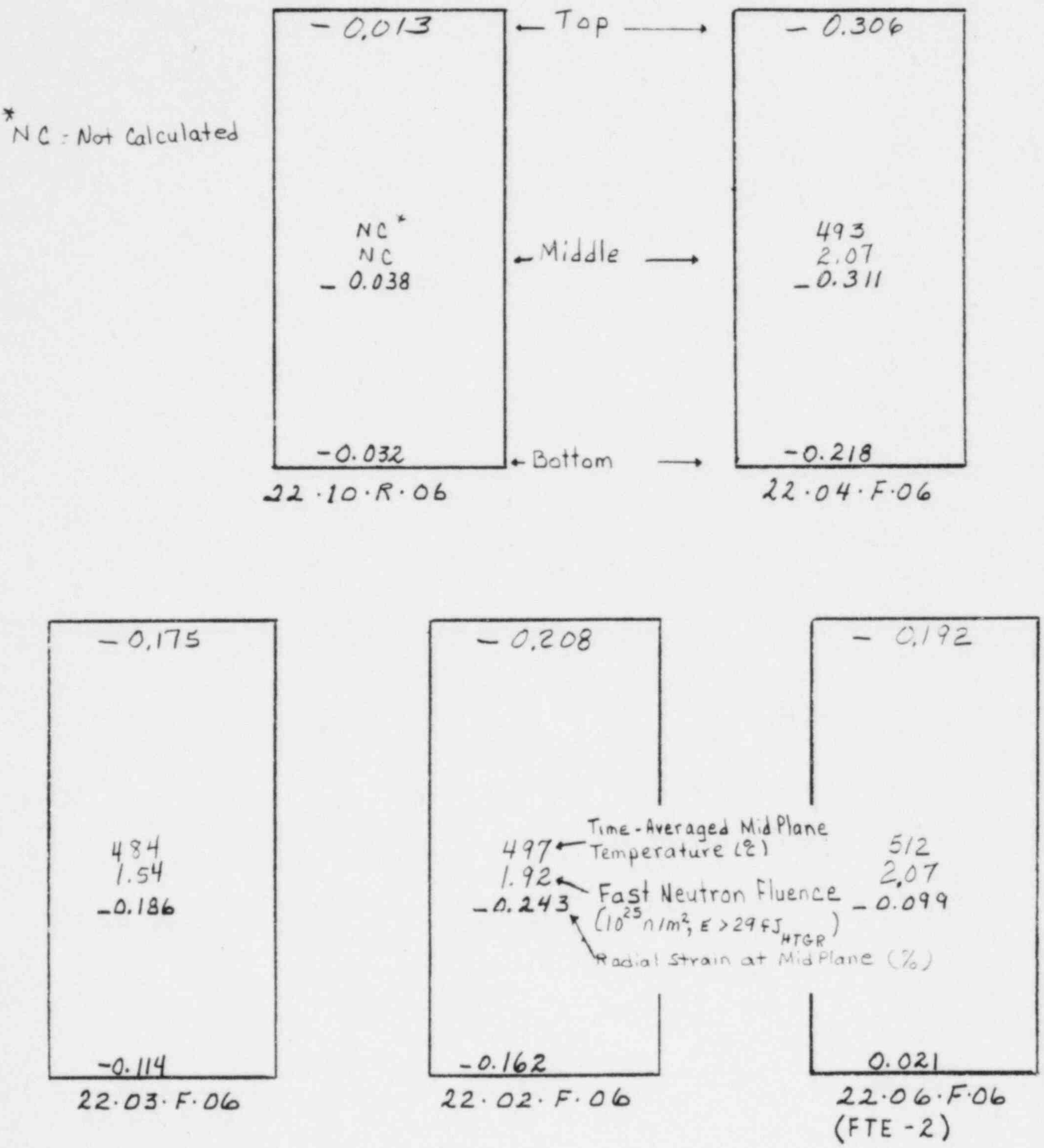


Fig 3-15 Measured radial strain of selected fuel elements and one side reflector from FSV core 3 region 22

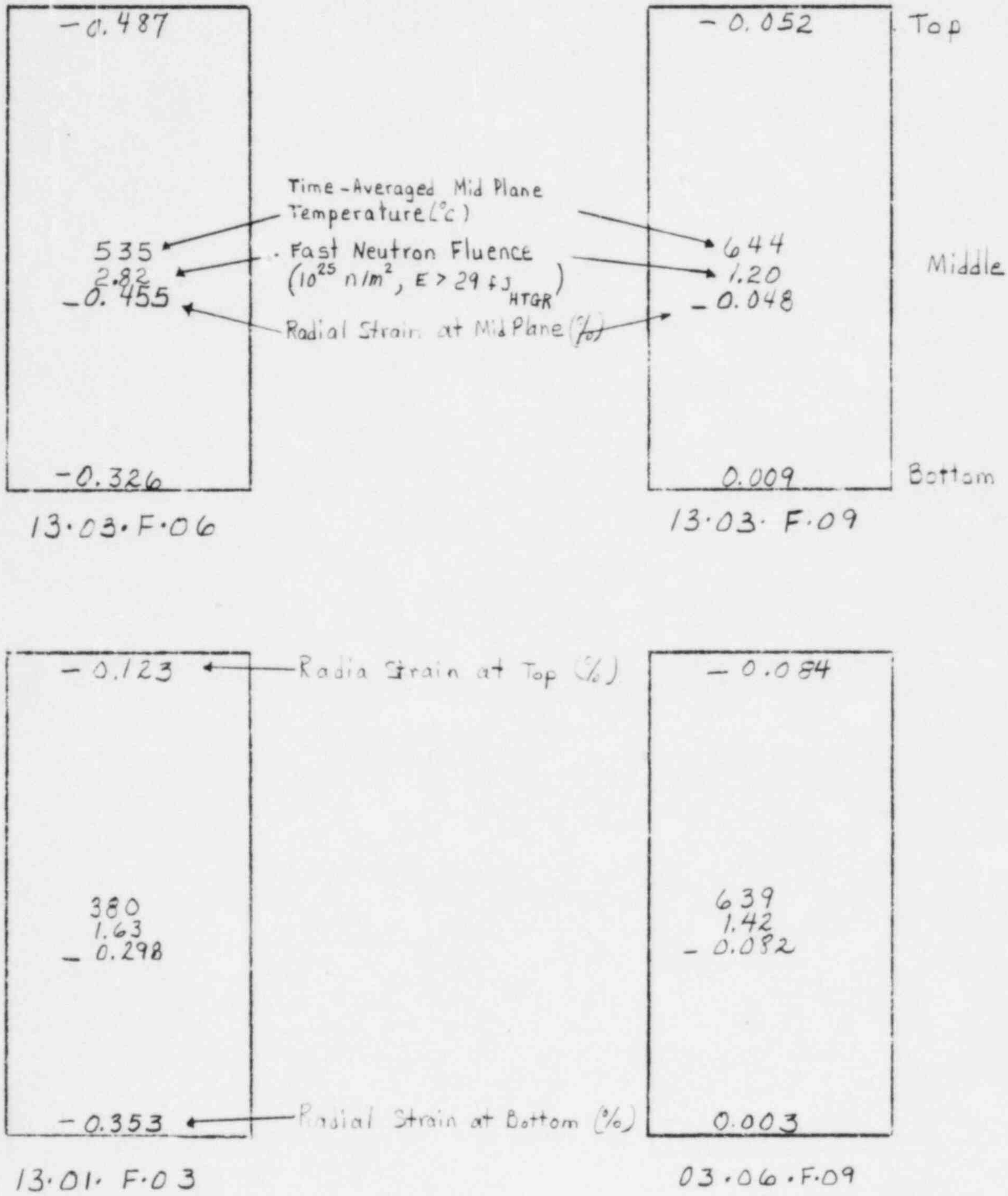


Fig. 3-16 Measured radial strain of selected fuel elements from FSV core 3 regions 13 and 3

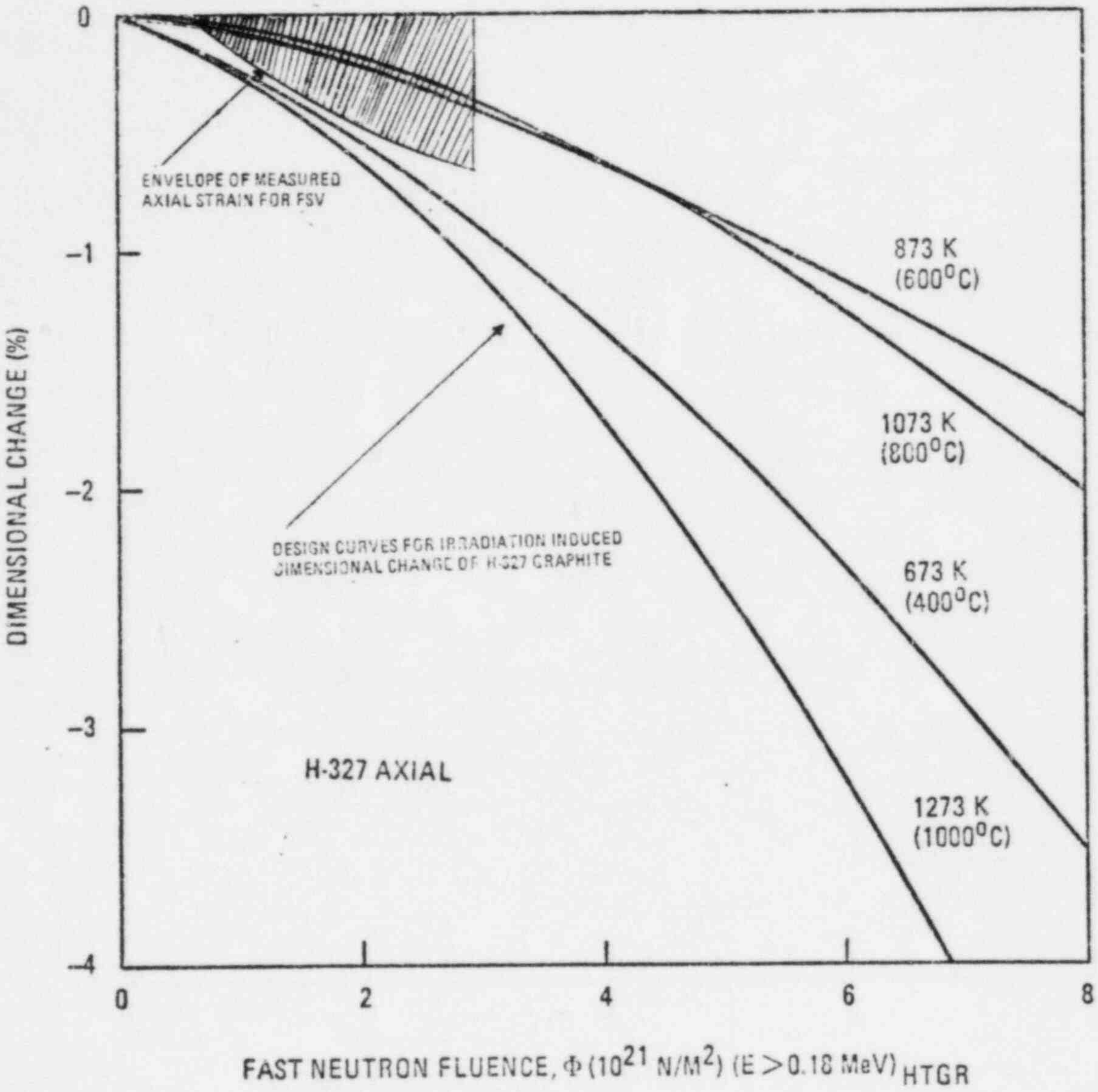


Fig. 3-17 Envelope of axial strains observed in FSV segments 1, 2, and 3 fuel elements

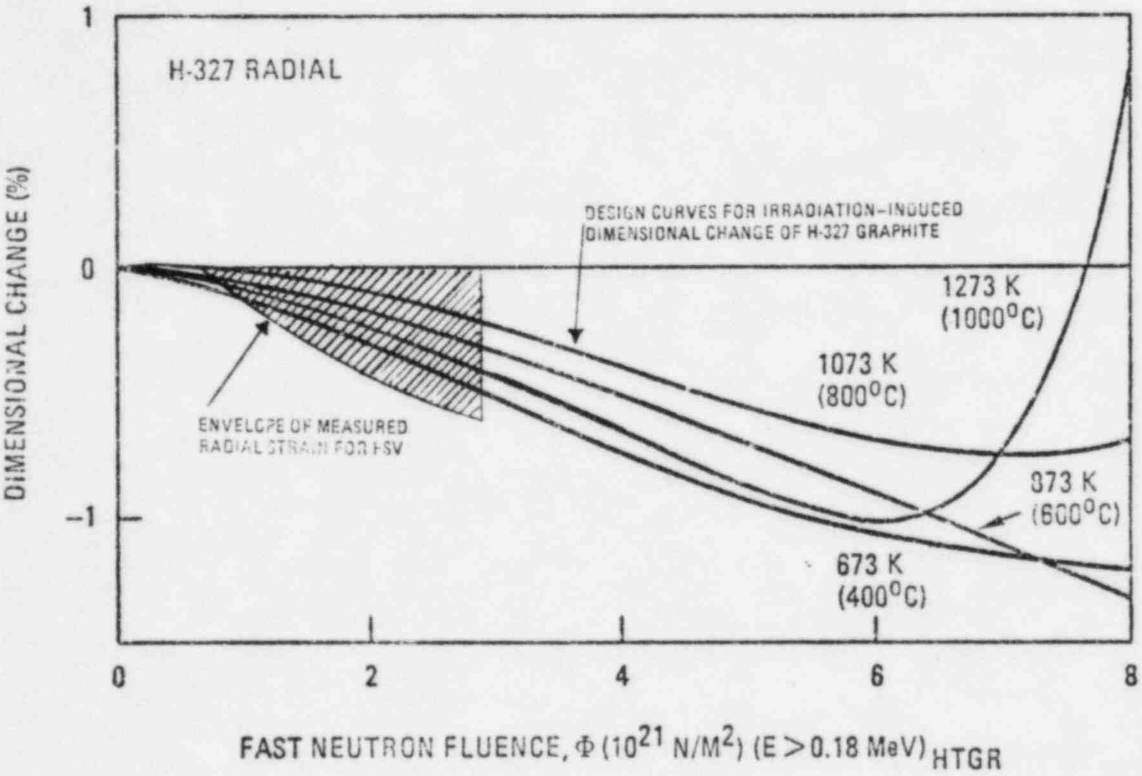


Fig. 3-18 Envelope of radial strains observed in FSV segments 1, 2, and 3 fuel elements

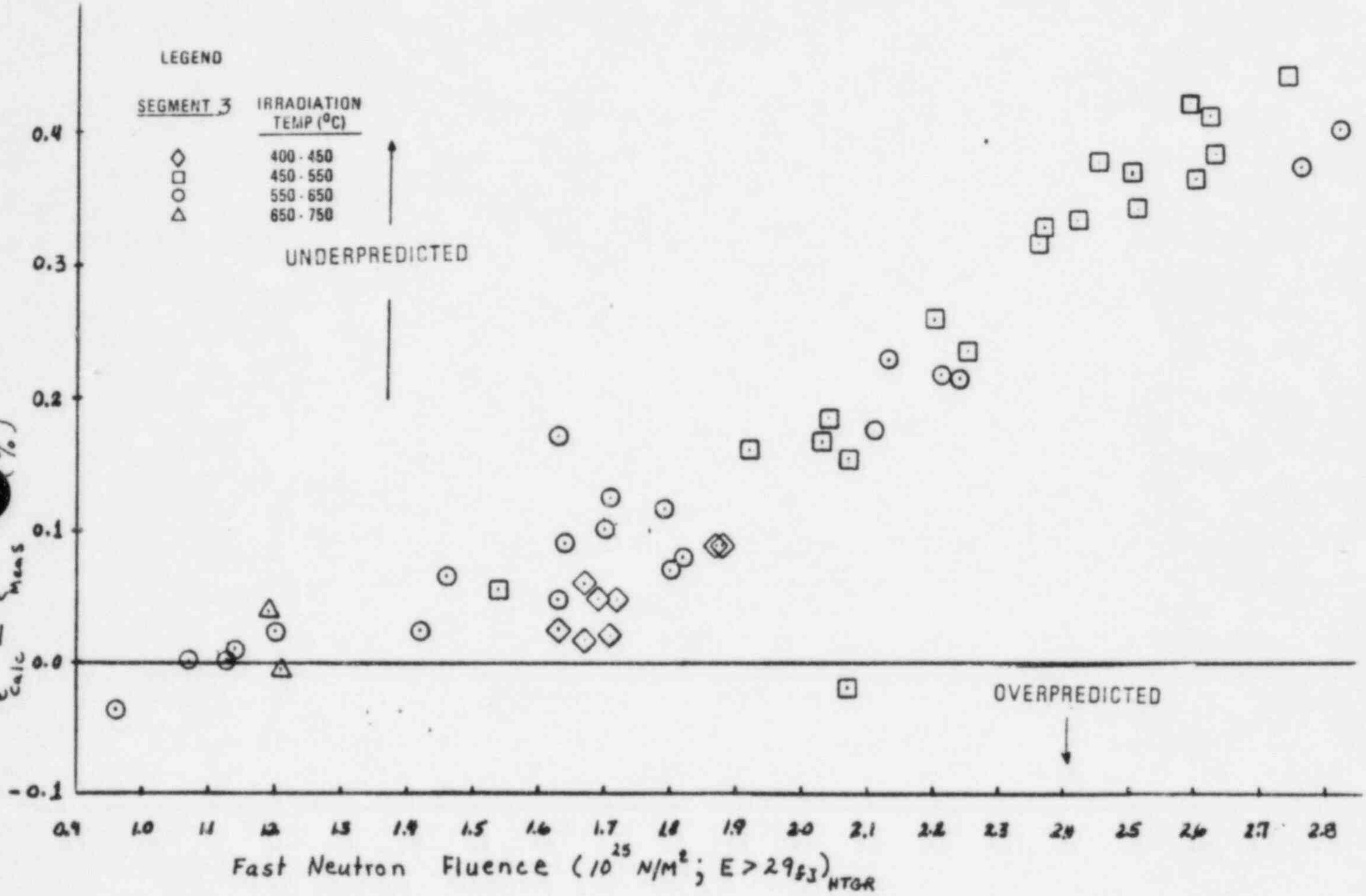


Fig. 3-19 Differences in calculated and measured axial strains for FSV segment 3 fuel elements

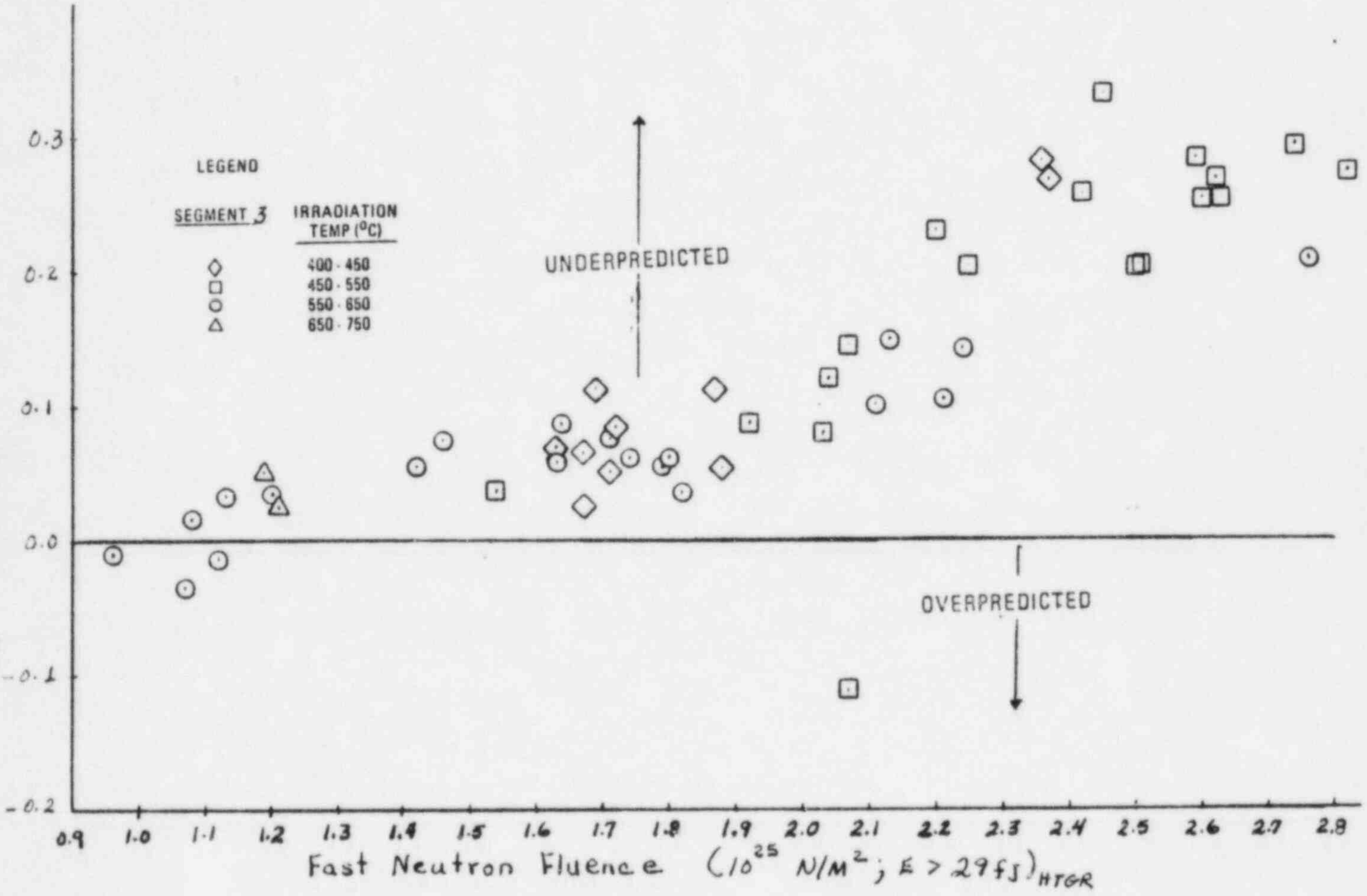


Fig. 3-20 Differences in calculated and measured radial strains for FSV segment 3 fuel elements

4. GAMMA AND NEUTRON ACTIVITY MEASUREMENTS

4.1 Gamma Dose Rates

Gamma dose rates at 91 cm (3 ft) and at 100 cm (39.5 in.) were measured for selected segment 2 elements with a Reuter-Stokes, Model RS-C4-1606-203, gamma ionization chamber.

Figure 4-1 shows the geometry for the gamma dose rate measurements.

The PATH (Ref. 11) gamma shielding code was used to calculate the gamma dose rate at the above specified distances. The PATH analysis calculated nuclide densities of the major gamma contributors. Dose rates calculated by the PATH model were then scaled according to the nuclide densities of the major gamma contributors to give the calculated dose rate for each fuel element.

Table 4-1 shows the results of the measured and calculated gamma dose rates. The measured gamma dose rate for a top reflector was 76 mR/h. The measured gamma dose rate for fuel elements ranged from 605 to 2815 R/h. The ratio of calculated to measured gamma dose rate for examined fuel elements ranged from 0.78 to 2.11 with an average of 1.04. If the worst case ratio of 2.11 is omitted (see Table 4-1), the average ratio of calculated to measured gamma dose rate is 0.99. The previous surveillance (Ref. 3) had an average calculated to measured gamma dose rate of 1.7. The better agreement for the core 3 segment can be attributed to more precise source terms used in the PATH calculations.

4.2 Neutron Count Rates

Neutron count rates for selected segment 3 fuel elements were measured using a SNOOPY-type detector system equipped with a Reuter-Stokes, model RS-

P6-085-134, fission counter. The measured counts are not believed to be correct because the detector indicated higher counting rates for the background than for a fuel element. The system is believed to have degraded due to electronic noise. Therefore, the neutron counts will not be presented in this report.

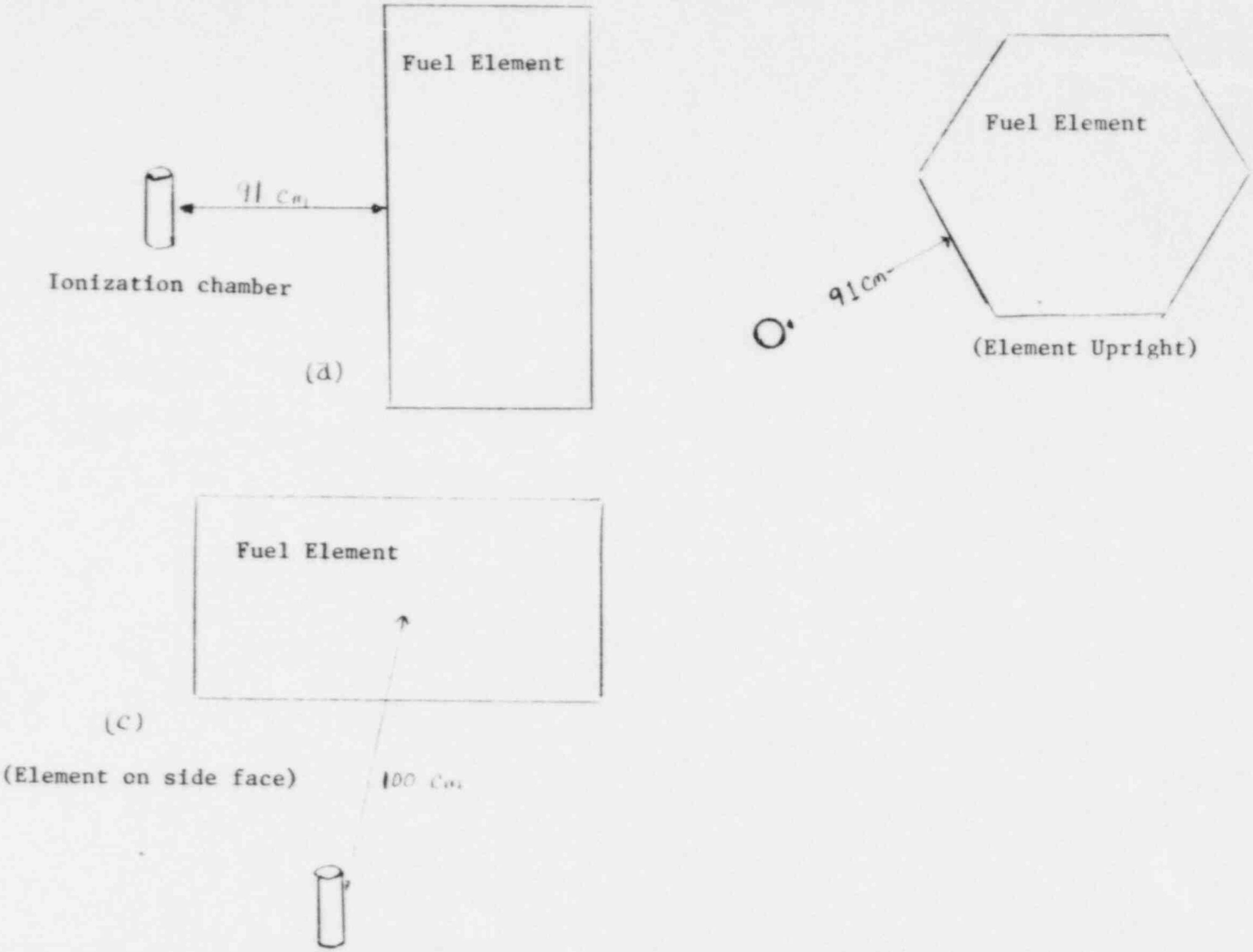


Fig. 4-1 Geometry for gamma dose rate measurements, (a) and (b) show the geometry for the measurements on the metrology robot, and (c) show the metrology for the measurements on the gamma robot.

Table 4-1

COMPARISONS OF CALCULATED AND MEASURED GAMMA DOSE RATES FOR FSV SEGMENT 3 ELEMENTS

Element Serial Number	Core Location	Distance from Center of Face (cm)	Gamma Dose (R/h)		Calc./ Meas.
			Calculated	Measured	
1-2606	13.03.F.06	91	2497	2664	0.94
		100	2141	2370	0.90
1-0335	13.03.F.09	100	1275	605	2.11
1-2943	3.06.F.09	91	1632	1227	1.33
		100	1398	1076	1.30
5-2104	22.04.F.06	91	2669	2462	1.08
8-0206	22.06.F.06	91	2924	2387	1.22
		100	2507	2462	1.02
5-0751	22.02.F.06	91	2895	2815	1.03
		100	2482	2521	0.98
1-0530	18.04.F.09	100	1285	1471	0.87
1-1018	18.04.F.04	100	1404	1630	0.86
1-2640	18.05.F.09	91	1438	1471	0.98
1 1397	18.05.F.06	100	2162	2546	0.85
1-2351	18.04.F.06	100	2223	2622	0.85
1-4304	18.05.F.07	91	2118	2303	0.92
1-0091	18.03.F.08	91	1948	2487	0.78
1-0873	18.06.F.06	91	2562	2555	1.00
2-0265	18.01.F.06	91	1566	1462	1.07
1-1990	18.02.F.05	91	2493	2479	1.01
1-0192	18.03.F.05	91	2286	2513	0.91
1-0305	18.04.F.05	91	2223	2345	0.95
		100**	1905	2311	0.82
17-1394	18.04.R.03	104	NC*	0.076	--
Average					1.04

*NC = Not Calculated

**Detector was moved

5. VISUAL EXAMINATION

The visual examinations were performed concurrently with the metrological examination. A core component (element) was lower into the HSF by the fuel handling machine (FHM). The element was placed on the turntable of the metrology robot. During the metrological examination, the turntable rotated the element so that each side face (Fig. 1-2) could be viewed through the HSF window and by the camera system.

The 62 segment 3 fuel and reflector elements were visually examined using four remotely controlled television cameras equipped with pan/tilt units and zoom lenses. Lighting was provided by the HSF lighting, by remotely controlled camera lights, and by three light banks. All surfaces of each element were thoroughly inspected and recorded on videotape. In addition the element side faces were photographed through the HSF window with a 35-mm camera equipped with a telephoto lens. Two photographs (the top half and bottom half) of each face were taken to give a composite picture of the entire face. Polaroid photographs were taken from the television monitors of features of interest.

The visual examinations were hampered by numerous camera and peripheral equipment malfunctions resulting from the high dose rates ($\leq$2900 R/h at 1 meter). The dose rate for segment 2 elements $\leq$ 500 R/h at 1 meter. However, all 62 elements were videotaped.

The inspected elements were in good condition. No cracks were detected. Three dowel pins on an element were damaged. Another element had exterior damage in one dowel socket. Little evidence was observed of graphite oxidation or erosion. Most blemishes observed on the elements were typical strains of scratches, scrapes, rub marks, interface marks and flow marks (Fig.

5-1). These were similar to the observations of the first two segments (Refs. 2 and 3) and of the inspection of core region 35 in March of 1979 (Ref. 12). The results of the visual examinations of the regular and surveillance fuel and reflector elements are discussed in more detail below. The fuel test element, FTE-2, is also discussed below in a separate subsection.

5.1 Regular and Surveillance Elements Visual Results

The regular and surveillance fuel and reflector elements were fabricated from H-327 graphite. The observed blemishes are discussed below.

5.1.1 Stains

Dark stains were observed on many side faces of the elements. However, stains were seen most frequently on the control rod elements (column 1) and on the E face of elements (Fig. 5-2). The E face was always toward the control column. The general appearance of a typical stain was as if liquid had trickled down the element face leaving a dark residue. In general, there was no consistent staining pattern. Some stains were very prominent; others were barely visible. Some stains could be traced down a column, while others started or ended abruptly. The paths of a few stains were disrupted by the top edge of the adjacent element leaning against it which caused the staining liquid to run horizontally and disperse or continue downward at an offset (Fig. 5-3).

Similar stains were observed on the fuel and reflector elements during previous inspections. During the inspection of region 35 (Ref. 12), samples of the staining material were collected and subjected to gamma spectroscopic analysis. A high concentration of iron and silicon and lesser amounts of aluminum, copper, and silver were detected. The presence of iron may have come from the unplanned water ingresses into the prestressed concrete reactor vessel (PCRV). The silicon and aluminum are believed to have come from the Kaowool insulation used in the core. The copper apparently came from alloys used for reactor or water system components. These material were apparently carried down the elements by the water, and was left behind as a residue.

Figure 5-4 shows another observed stain. These localized stains were seen on several elements. The appearance is circular with a darker central area which may contain contaminants.

5.1.2 Scratches and Scrapes

Numerous scratches and scrapes were observed on the surfaces of many of the elements. Most of these markings were insignificant; however, some are notable and are listed below.

- A continuous (sometimes discontinuous) vertical scratch of some depth down the center of face C of an element (Fig. 5-5).

  Four of the core segment 3 elements were observed to have this scratch. This scratch was also noted during the previous two inspections, but is not believed to be of a depth to cause any structural problems.

- Vertical scrapes and scratches on the left and/or right sides of face D of the element (Figs. 5-6).

  This type of marking varied in length and degree of scraping and scratching. Some elements only had a scrape or scratch for only a few vertical inches on the left or right side, while other had marking extending the length of the block. Forty-five elements were observed to exhibit these markings on face D. Elements from the segment 2 surveillance were observed to have similar markings.

- Vertical scratch on right and/or left side on face F of an element (Fig. 5-7).

  Twenty one segment 3 elements exhibited this scratch on the right and some time left side of face F. This particular marking was noted only on one element during a previous surveillance.

Since the above mentioned scratches and/or scrapes were nearly identical in location and appearance, they are believed to have been made during handling and are not believed to be of sufficient consequence to cause any future structural problems.

5.1.3 Oxidation

Iron, which is a catalyst for graphite oxidation, was found on the residue of the evaporated stains (see Section 5.1.1). This suggests that oxidation may have occurred due to contamination by iron which seeped into the graphite. Therefore, darkened areas in the vicinity of stains or on control elements and face E of regular elements are possible sites for localized graphite oxidation. Figures (5-8, 9) show two suspicious darken areas which may have a little oxidation.

5.1.4 Rub Marks

Light vertical bands and/or columns of short, horizontal marks were observed near the left and/or right edges on some side faces (Fig. 5-10). Twenty of the examined elements showed this type of burnishing indicating some contact with adjacent elements. The rubbing highlighted the machining marks on the side faces, but did not removed them. Since the degree of abrasion appears to be about the same as observed in surveillances 1 and 2, the observed rub marks probably are the results of earlier core movement (Ref. 2, 3 and 12). This observation represents evidence that the core restraint devices installed at the start of cycle 3 were effective in reducing fuel element movement.

5.1.5 Flow Marks

Dark horizontal bands, approximately 45 mm wide, were observed on nearly all faces of the control-rod elements (Fig. 5-11) and on face E of the regular fuel elements (Fig. 5-12). Face E of the regular elements always faced the column of control-rod elements. In the FSV core, the control-rod columns are vertically offset from the surrounding columns of regular fuel elements by one-quarter of a block length. The dark bands appeared at the axial locations corresponding to the top and bottom chamfers of the adjacent fuel elements. Two chamfers are a total of 45 mm wide, the same width as the dark bands.

The dark appearance of these areas is indicative of surface roughening due to graphite erosion caused by particulates in the coolant flowing through the flow paths formed by the sides of elements and the top and bottom chamfers of the adjacent elements. The horizontal displacement of stains (Subsection 5.1.1) at these block interfaces suggests that substantial coolant flowed through these flow paths. On several blocks, there were dark areas above or below the dark bands (Fig. 5-13). These are thought to have been soot deposits formed by the graphite abraded from the elements.

5.1.6 Chips, Nicks and Debris

There were a few small nicks and chips on the elements. Most of these were very minor and insignificant. However, element serial number 1-1228 (core location 18.03.F.06) had minor damage to all three of its dowel pins. The two E face dowel pins were more chipped than the B face dowel pin. Figure 5-14 shows the damage to the E face dowel pins. The elements located above and below this element appeared to be free of dowel pin or socket damage.

Element serial number 2-1707 (core location 18.01.F.03) had damage to the B face dowel socket. A small chip of the graphite web between the dowel socket and the central coolant hole (319) on the B face edge was missing (Fig. 5-15). The element located above this element appeared to be free of dowel socket damage. The element located directly below element 2-1707 had debris around both E face dowel pins, but was free of debris near the B face dowel pin (Fig. 5-16). This indicates that probably all three dowel sockets of element 2-1707 had minor scaping and chipping. Since only the exterior of the E face dowel sockets of element 2-1707 could be viewed with the failing camera system, only the damage to the B face socket was observed.

A few dowel pins also had wear debris, which came to rest on the top of the dowels (Fig. 5-17). Apparently, material was shaved off dowel sockets in the bottom of one element by the dowel pins on the top of an element stacked below, and the shavings tended to accumulate on the upper dowel pin surface.

5.2 Fuel Test Element FTE-2 Visual Results

Fuel test element FTE-2, one of eight precharacterized elements with fuel test arrays (Ref. 13) was inserted in the FSV core during the first reload in March and April of 1979. Unlike the regular FSV fuel elements which were cured-in-bed, the fuel rods in FTE-2 were cured-in-place. Also, FTE-2 was fabricated from near isotropic H-451 grade graphite instead of the needle-coke H-327 grade graphite used in the initial core elements. Elements fabricated from H-451 grade graphite are designated for FSV refueling segments and advanced HTGR designs. The visual examinations of the test elements provide observable and concrete evidence of the H-451 graphite structural integrity and performance.

FTE-2 was in excellent condition. There were small scratches but no significant structural damage. No cracks were observed on any of the surfaces. There was no evidence of graphite oxidation.

The side faces of FTE-2 are shown in Figures 5-18 through 5-23. There was a discontinuous vertical scratch running nearly the length of face C (Fig. 5-20). Face D had vertical scrapes and scratches on the left side (Fig. 5-21). The upper right side of face F also had vertical scratches (Fig. 5-23). Similar markings were observed on the regular FSV elements during this and previous surveillances, and are believed to have been caused during handling.

The photographs and video tape of some of the side faces had darkened areas which had the appearance of build-up of some substance (Figs. 5-20, 21, 22, 23). However, the darkened areas disappeared when the element was rotated. A possible explanation is that particulate matter from the coolant flow or outgassing from the cure-in-place caused a change in the surface finish which altered the reflectivity. Some of the darkened areas on the E face did not disappear upon rotation and are thought to have been soot deposits formed by the graphite abraded from the elements (Fig. 5-22).

The top surface of FTE-2 is shown in Figure 5-24. A few dark markings (Fig. 5-25) were seen on this surface. These markings were located around fuel holes, coolant and adjacent burnable poison holes. These markings also were observed in FTE-1 where it was demonstrated that the darkened areas were not build-up of substances, but most probably stains caused by outgassing from the graphite cement used to cement the fuel hole plugs in place (Ref. 14). None of the observed regular FSV elements showed these types of markings.

The bottom surface of FTE-2 was in excellent condition and was relatively free of blemishes.

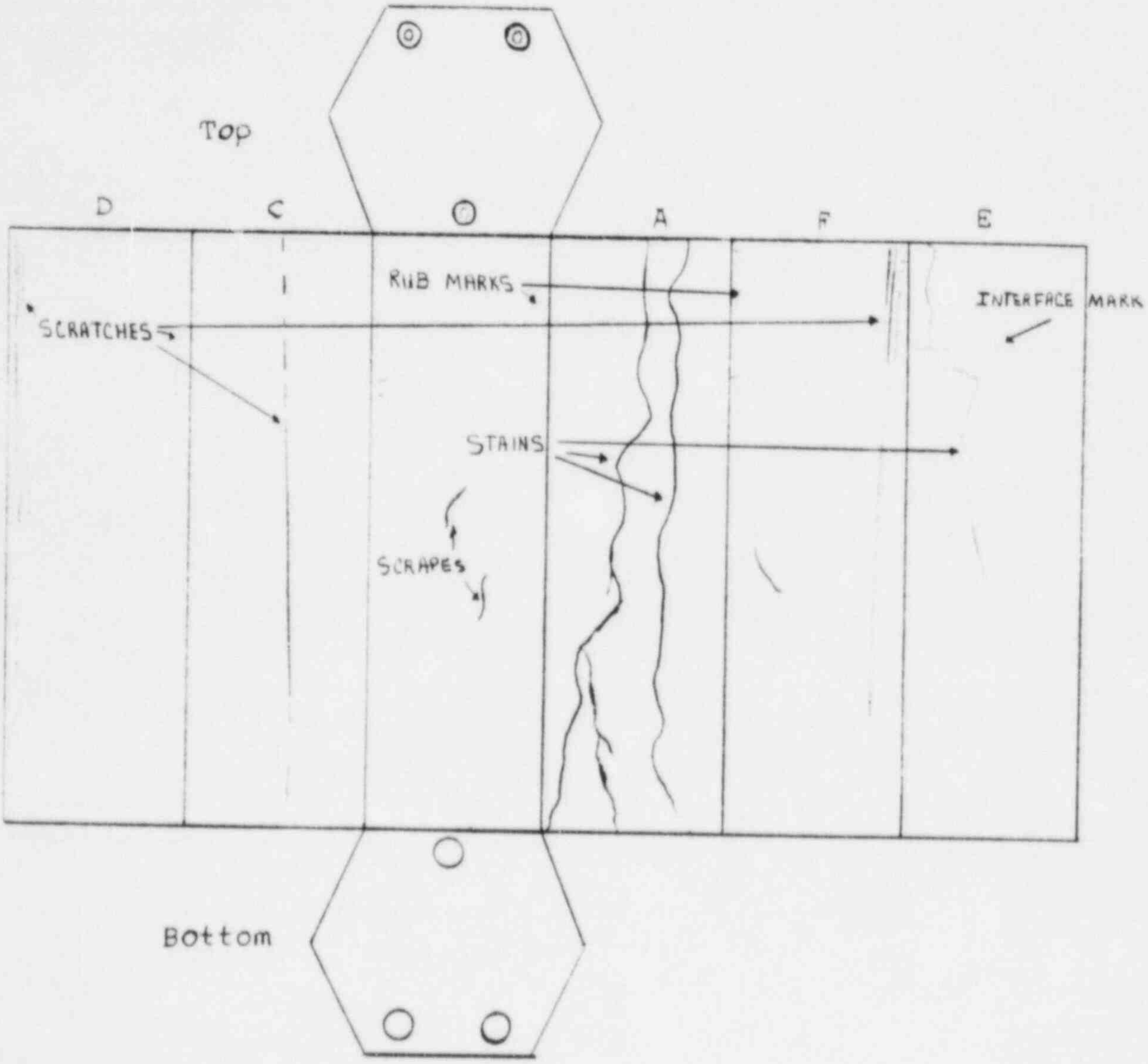


Fig. 5-1 Typical surface markings

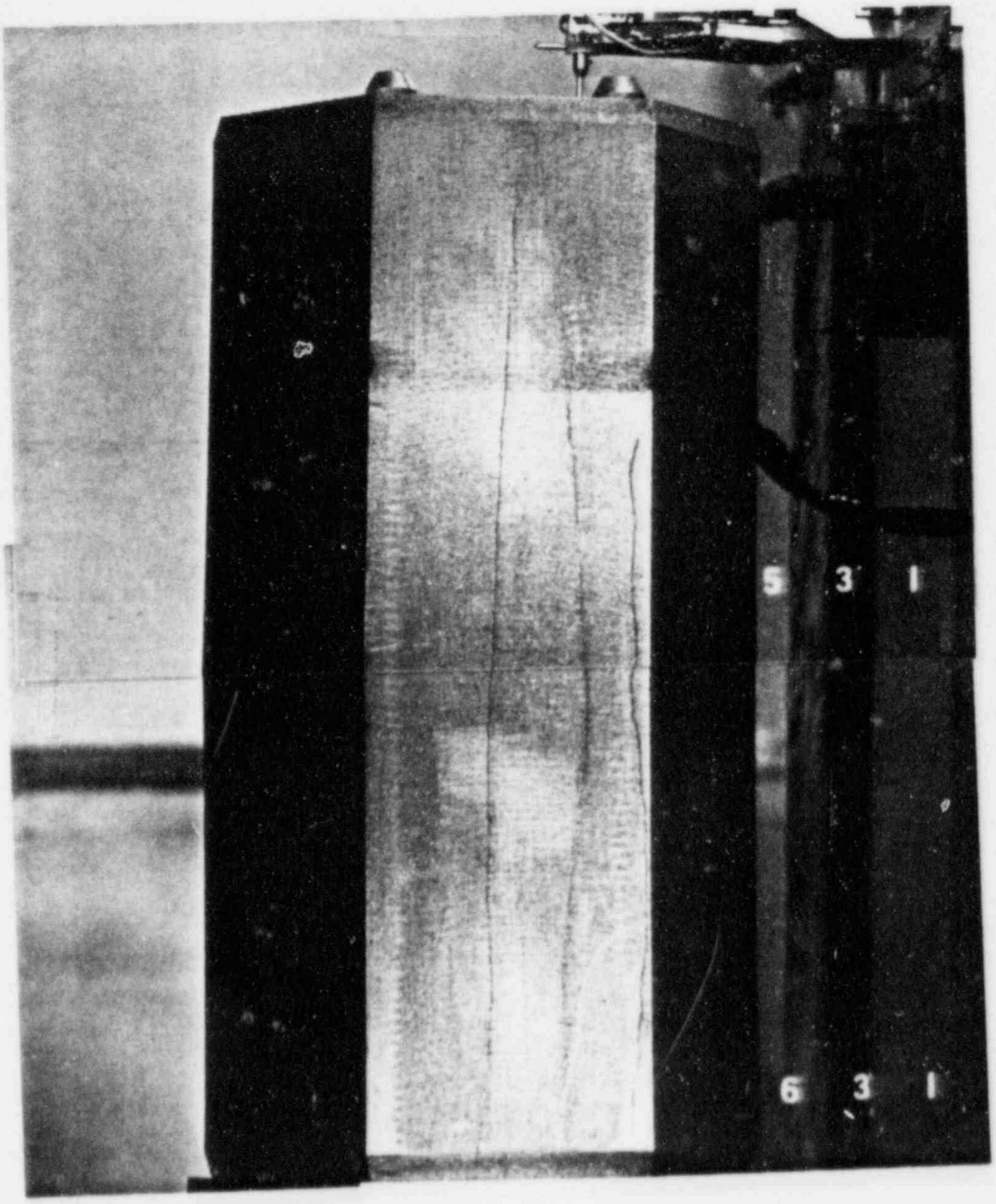


Fig. 5-2 Face E of element 1-0530: example of stains observed on the side faces of some elements

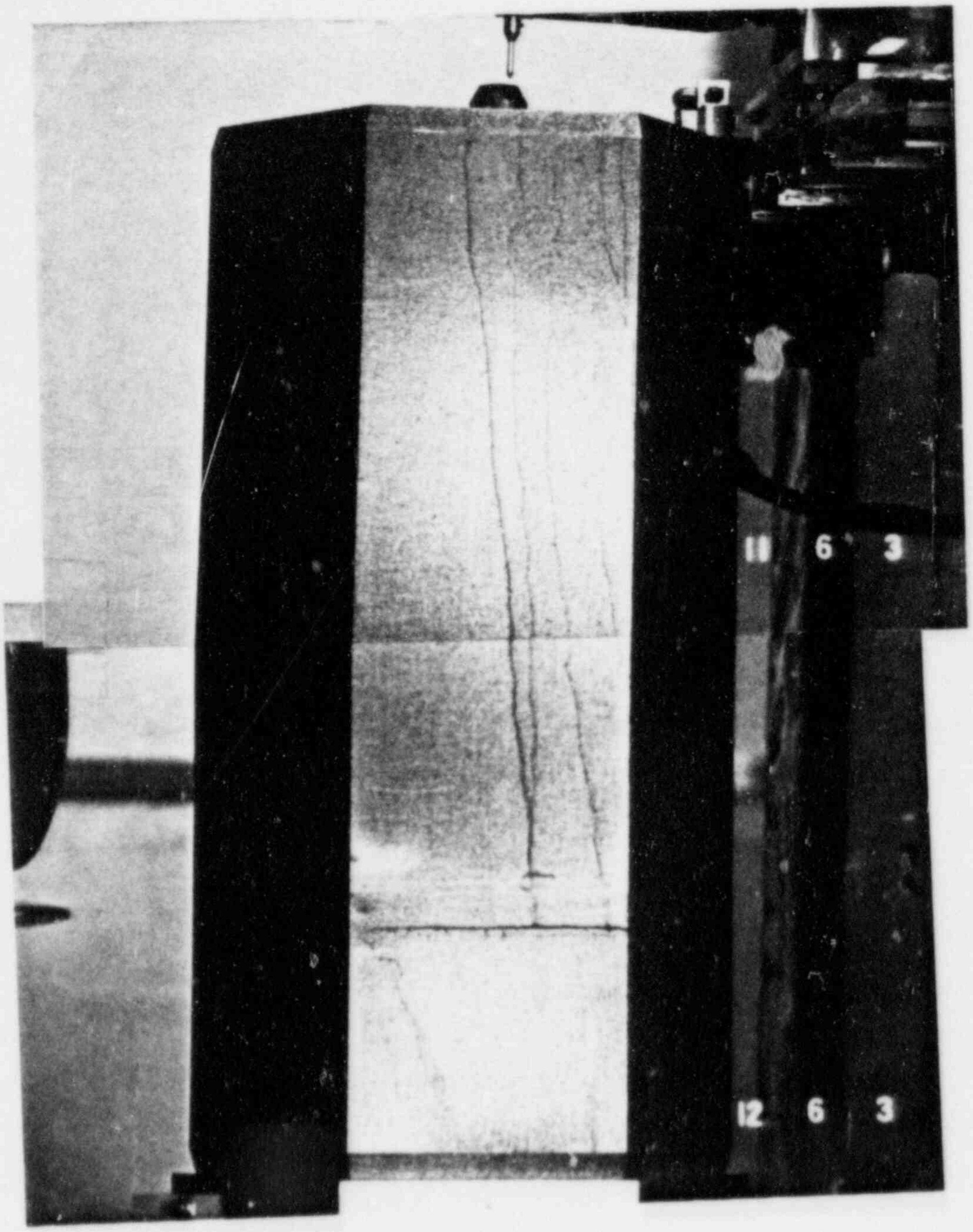
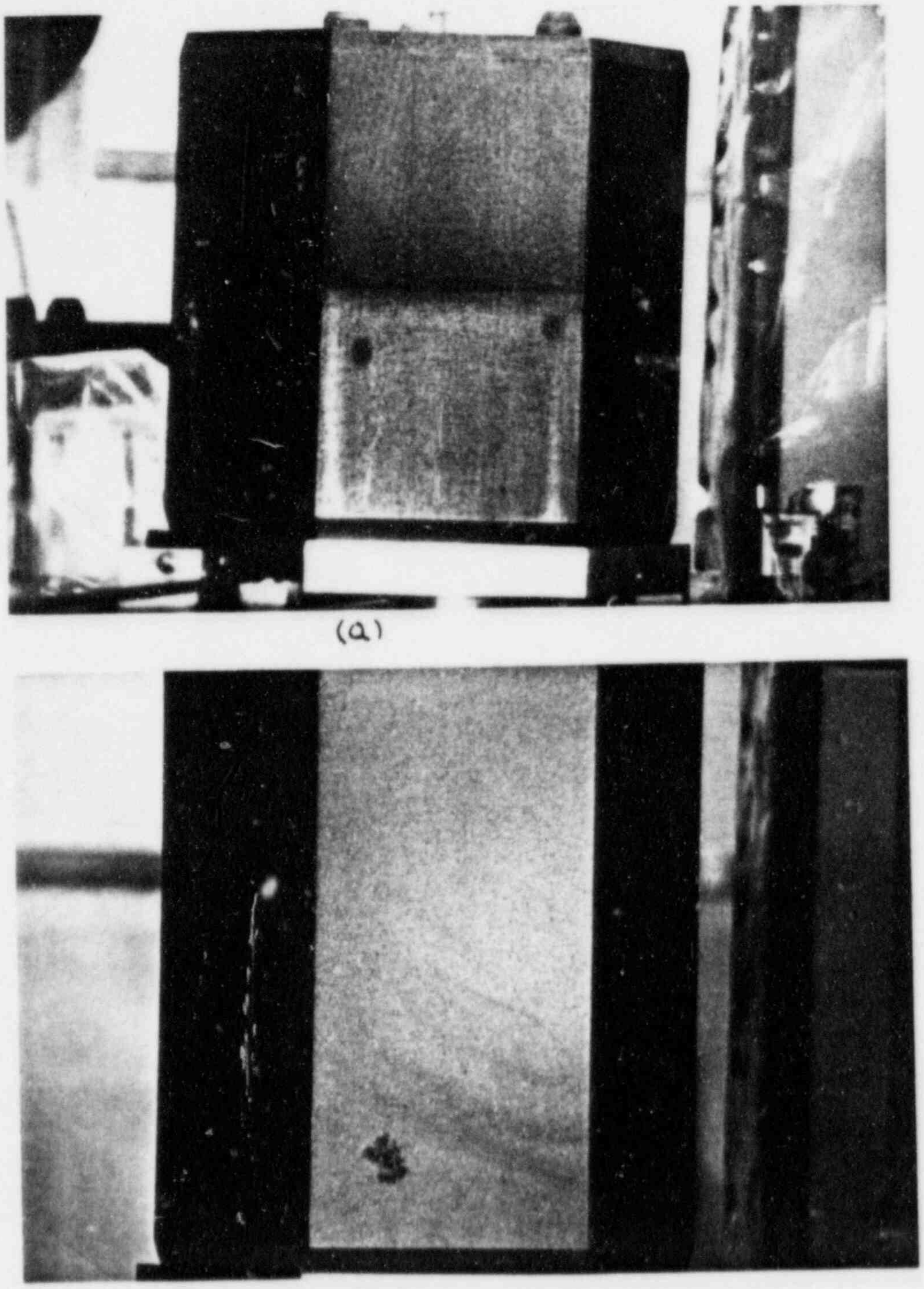


Fig. 5-3 Face B of element 2-1120: example of horizontal displacement of stains at the interface of two adjacent elements


(a)

(b)

Fig. 5-4 (a) Face E of reflector element 17-1128 and (b) bottom of face E of element 1-1805: examples of localized dark circular stains

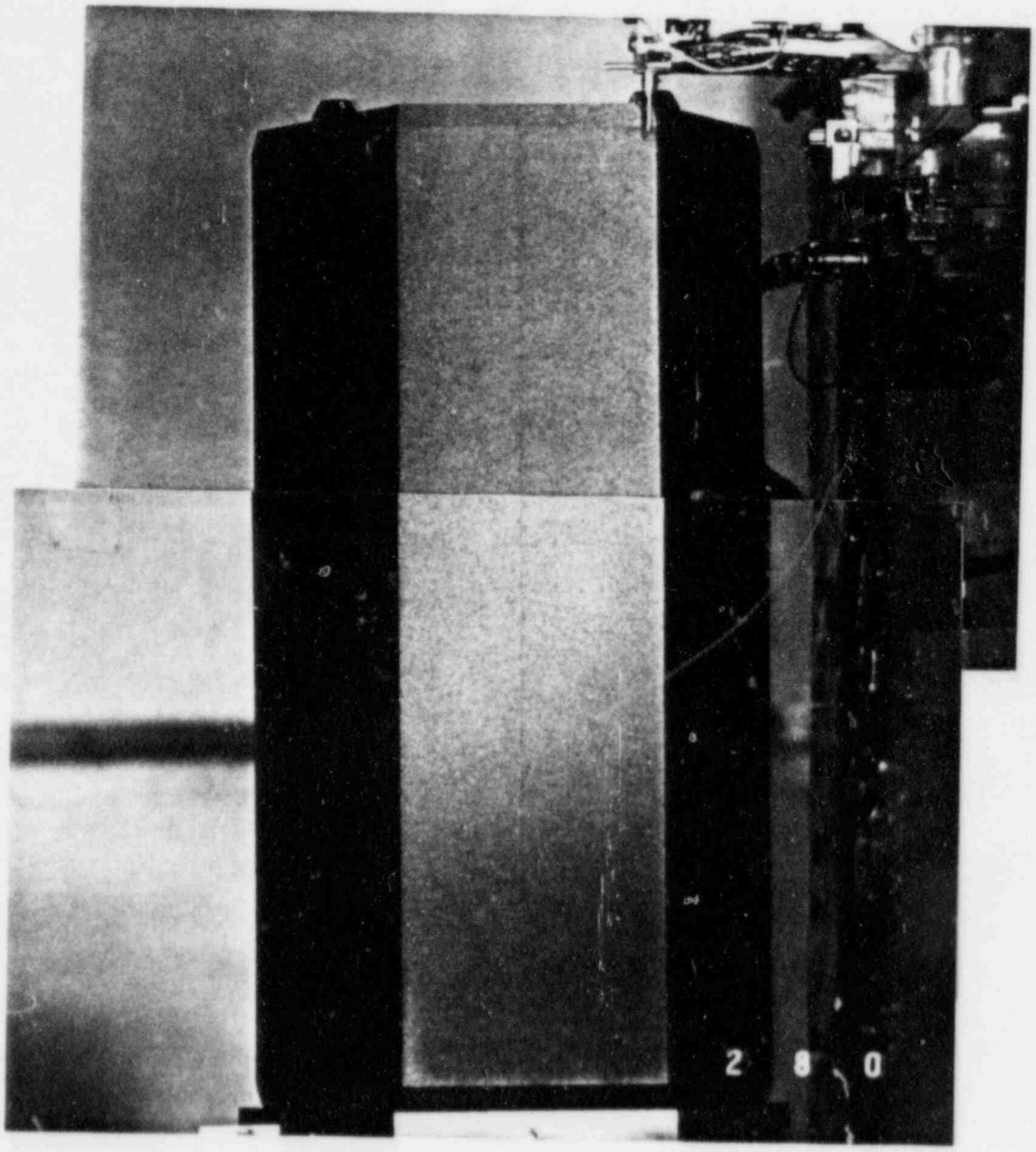
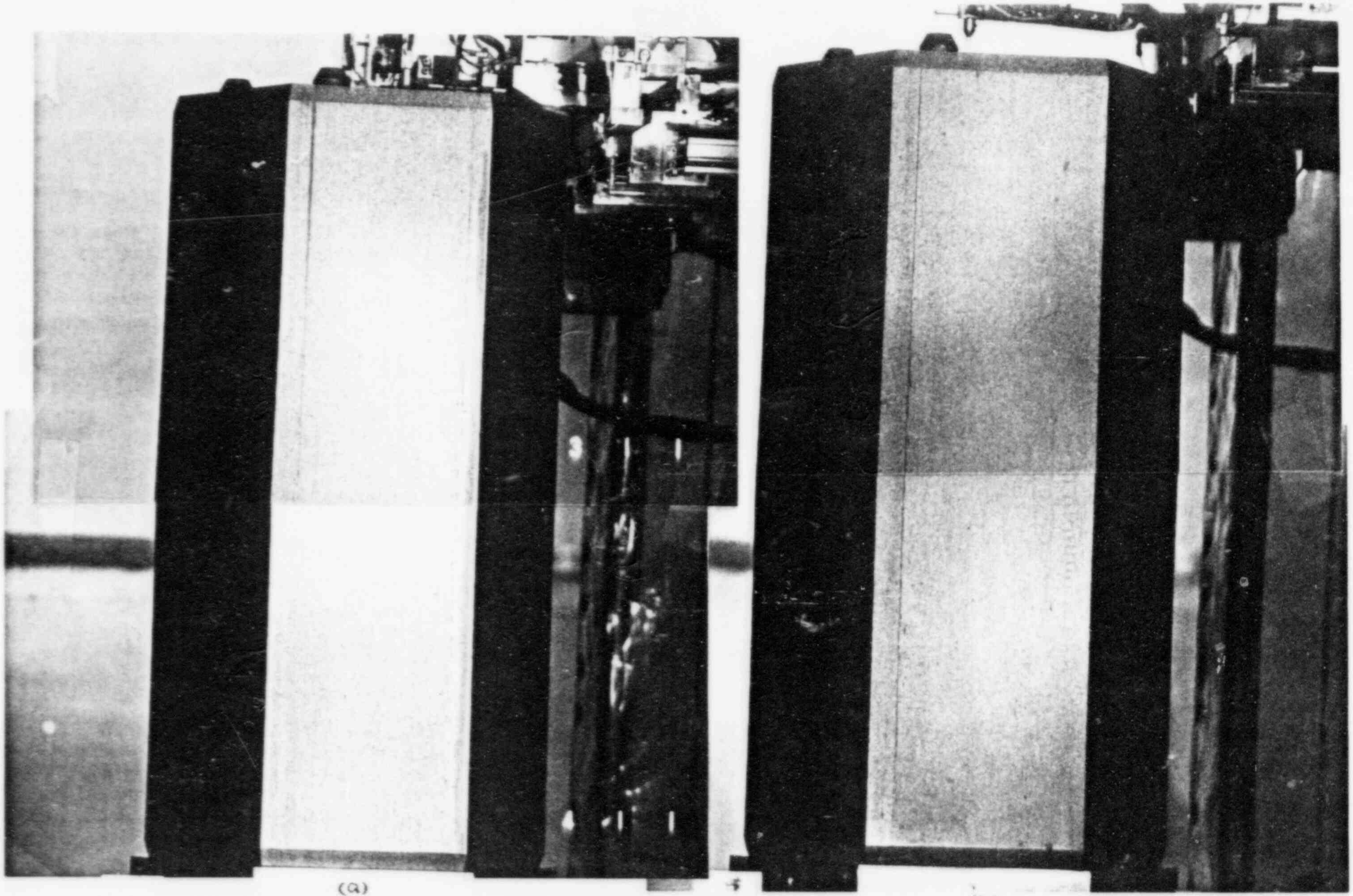


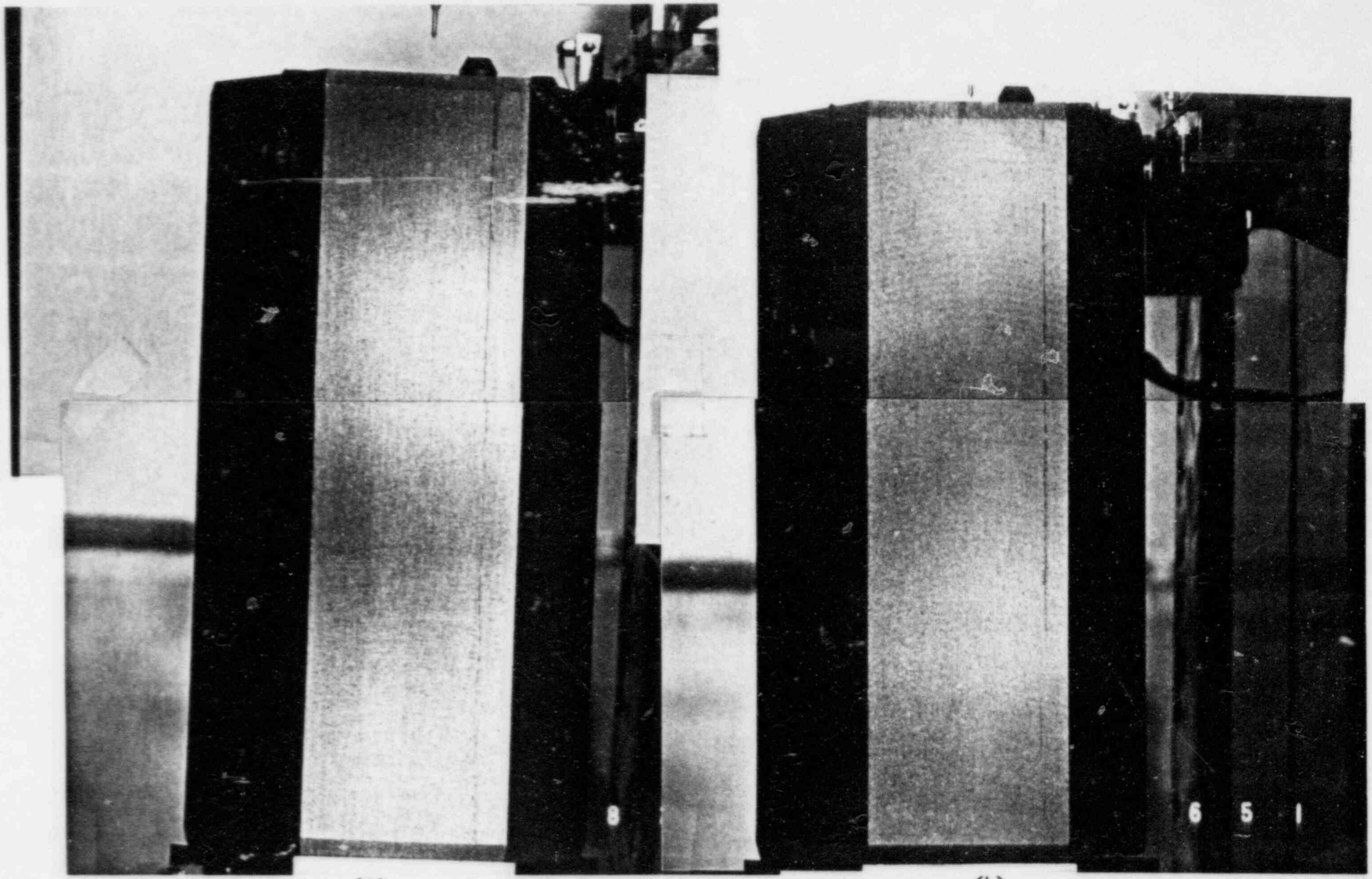
Fig. 5-5 Face C of element 5-2104: example of central vertical scratch observed on face C of several elements



(a)

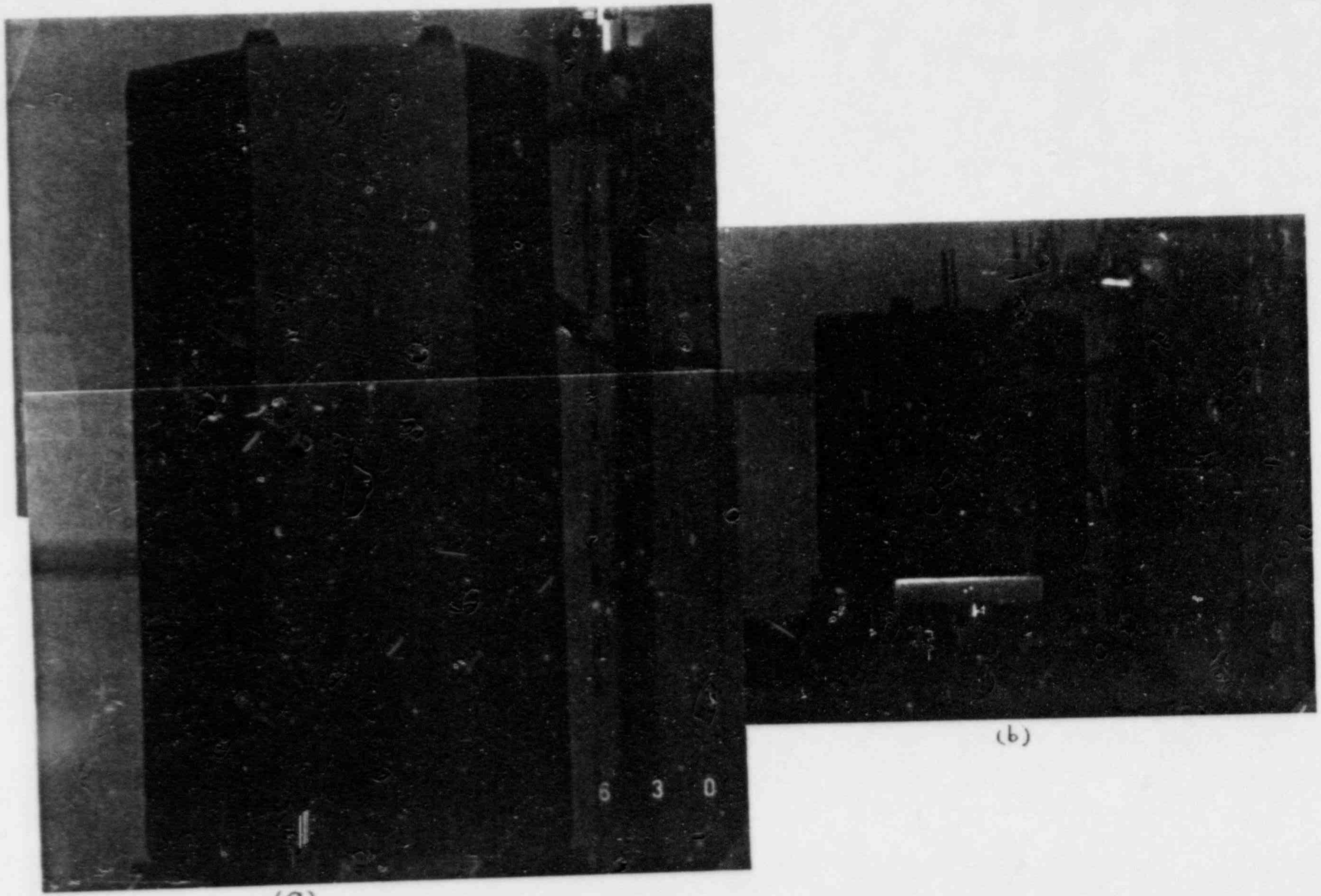
(b)

Fig. 5-6 (a) element 5-0751 and (b) element 1-1805: examples on vertical scratches and scrapes on left and/or right side of face D



(a) (b)

Fig. 5-7 Face F of (a) element 1-1228 and (b) element 1-2640: examples of scratches and scrapes on the F face



(a)

(b)

Fig. 5-8 Face E of (a) element 1-2606 and (b) reflector 42-1008· examples of possible oxidation

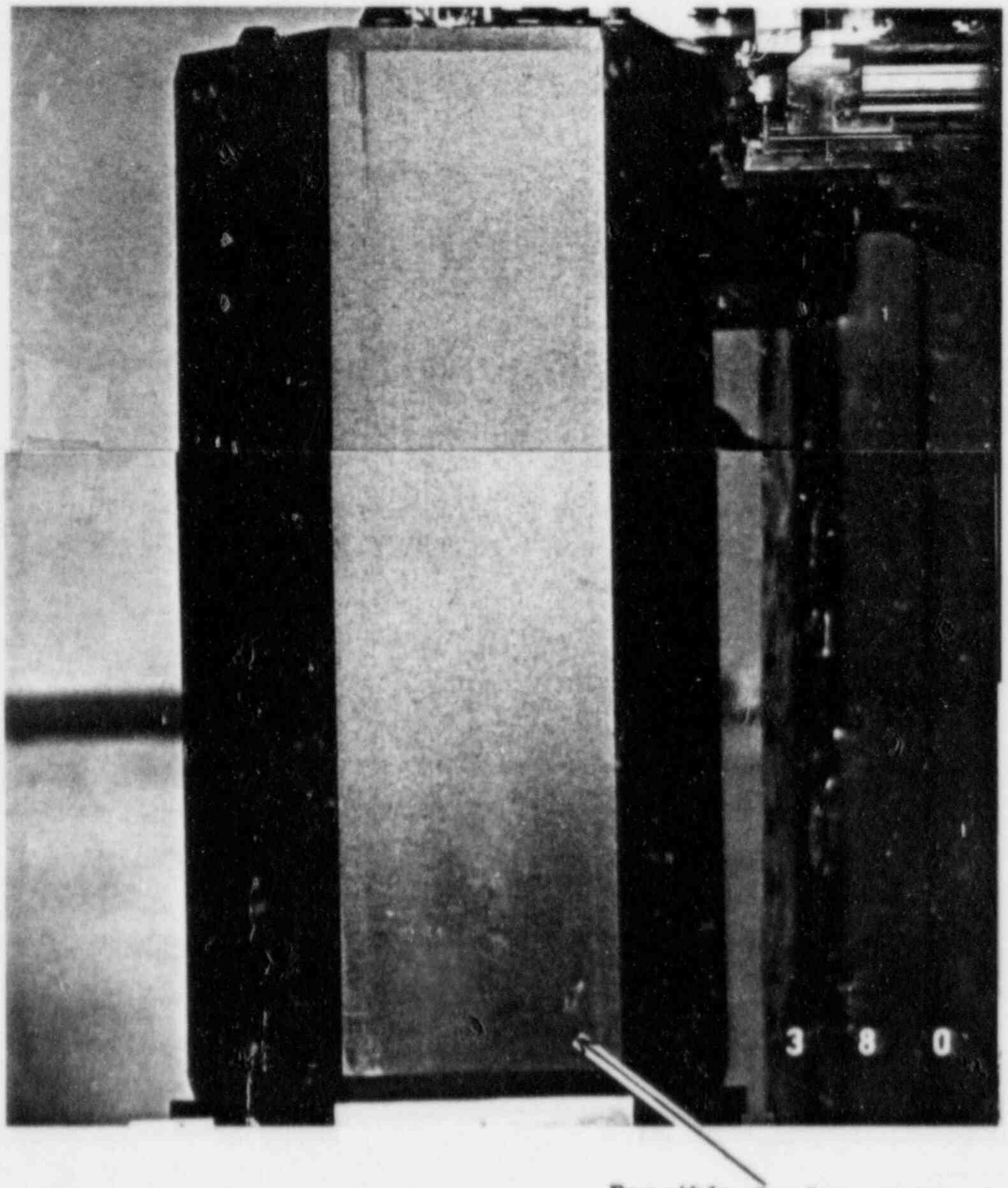
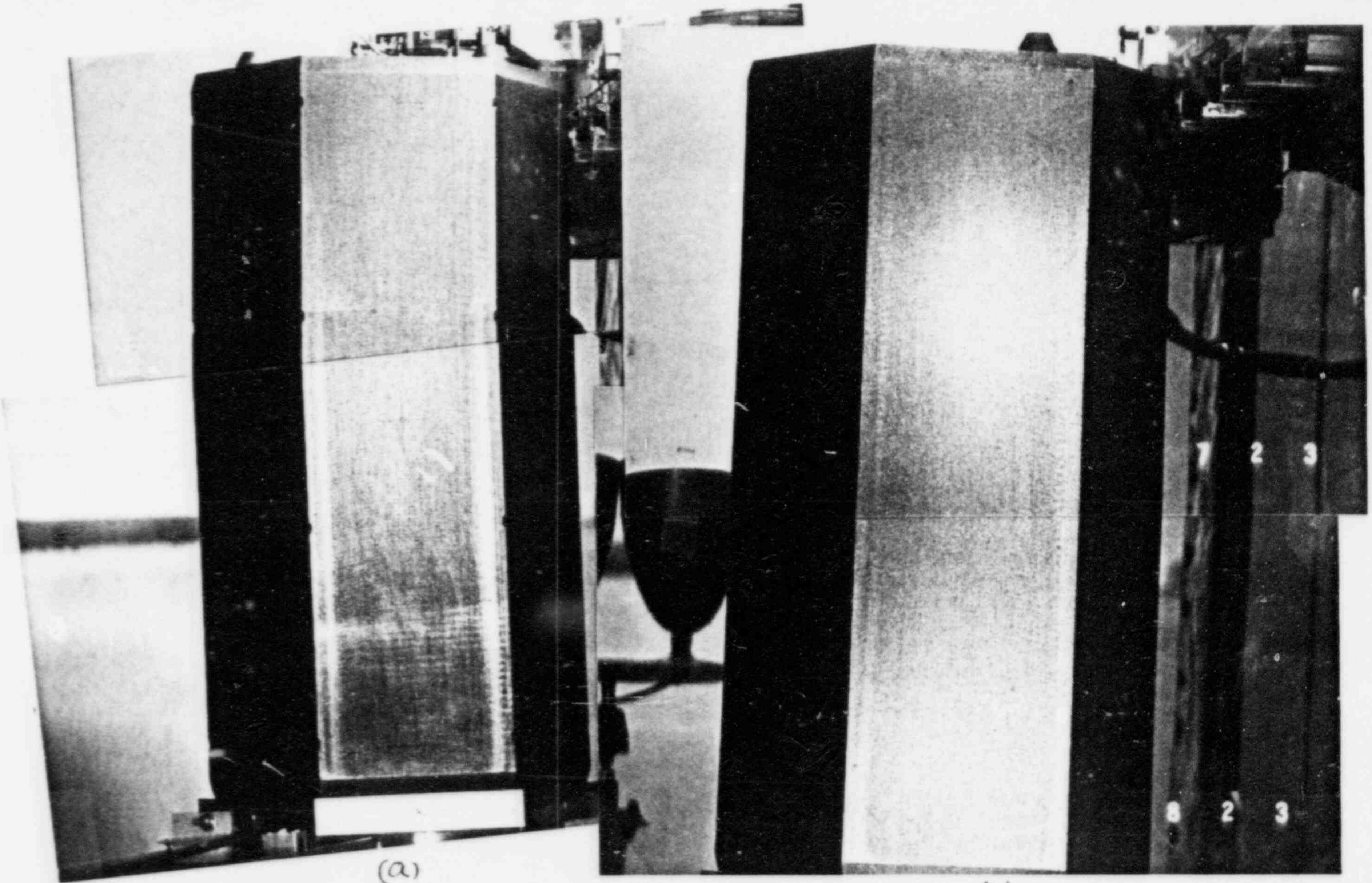


Fig. 5-9 Possible oxidation on face D of element 5-2104



(a)

(b)

Fig. 5-10 (a) face C of element 41-1004 (side reflector) and (b) face F of element 1-2396: examples of rubbing marks

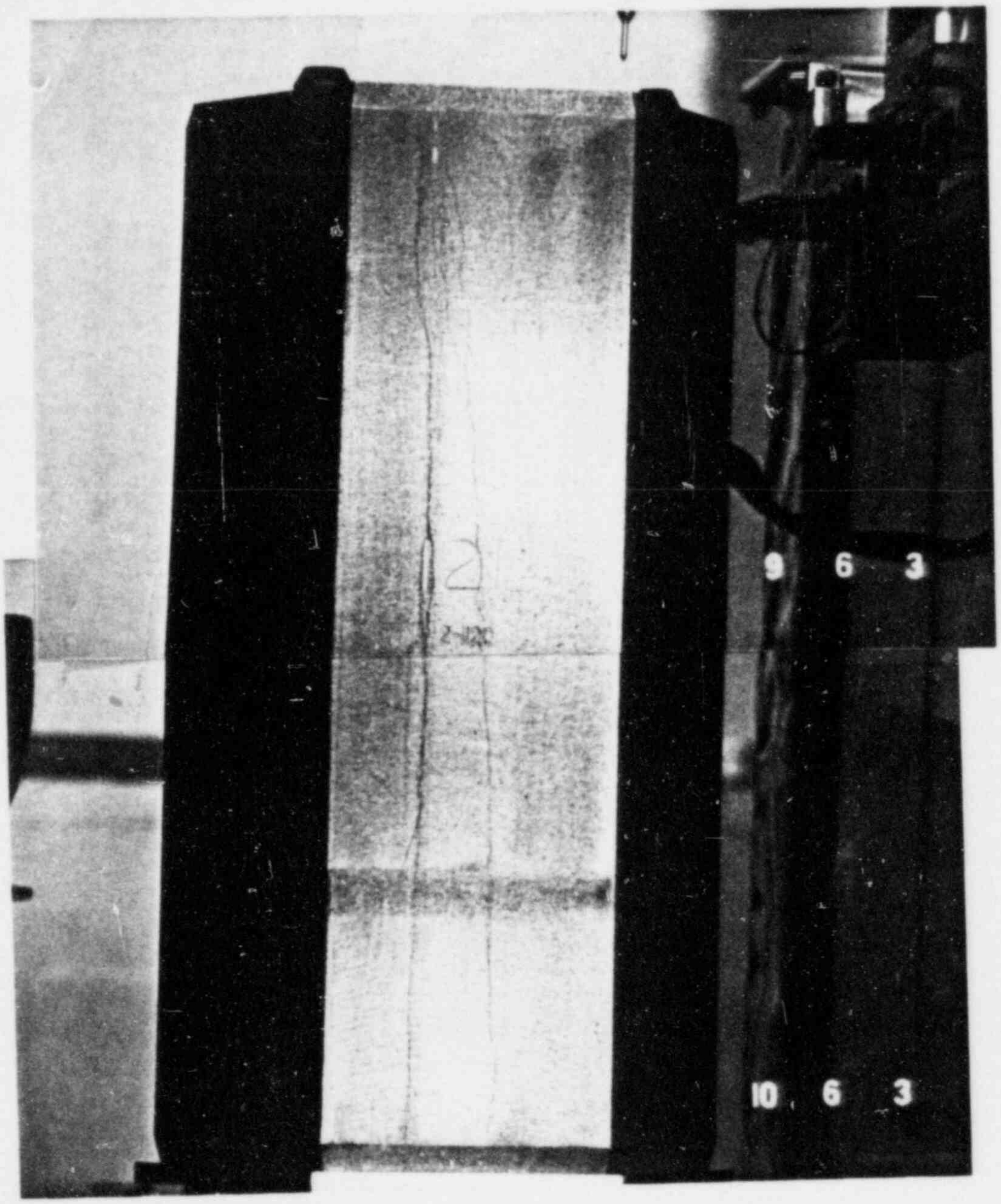


Fig. 5-11 Face A of control element 2-1120 showing dark 45 mm wide band

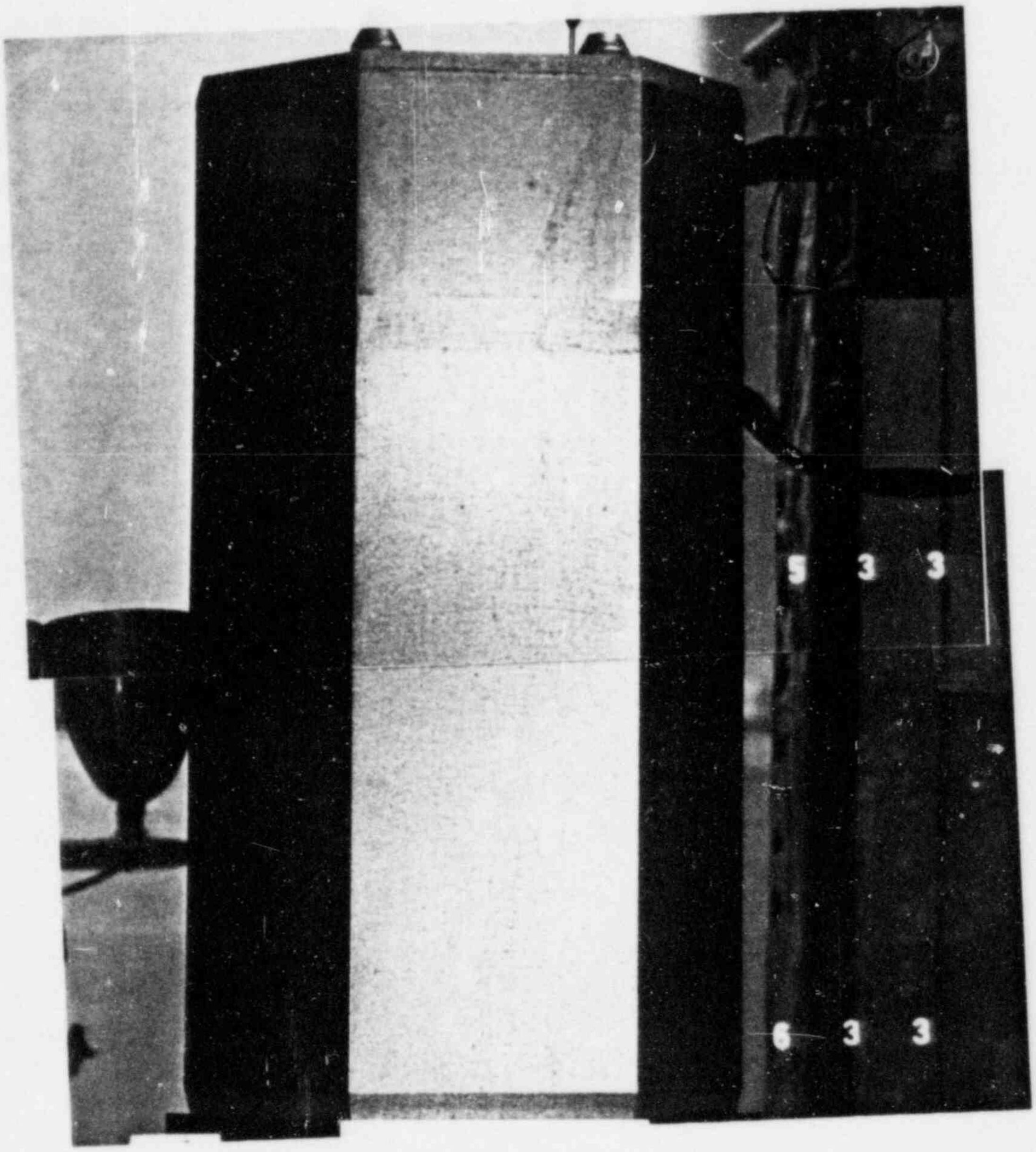


Fig. 5-12 Face E of element 1-4304 shows the 45 mm wide band

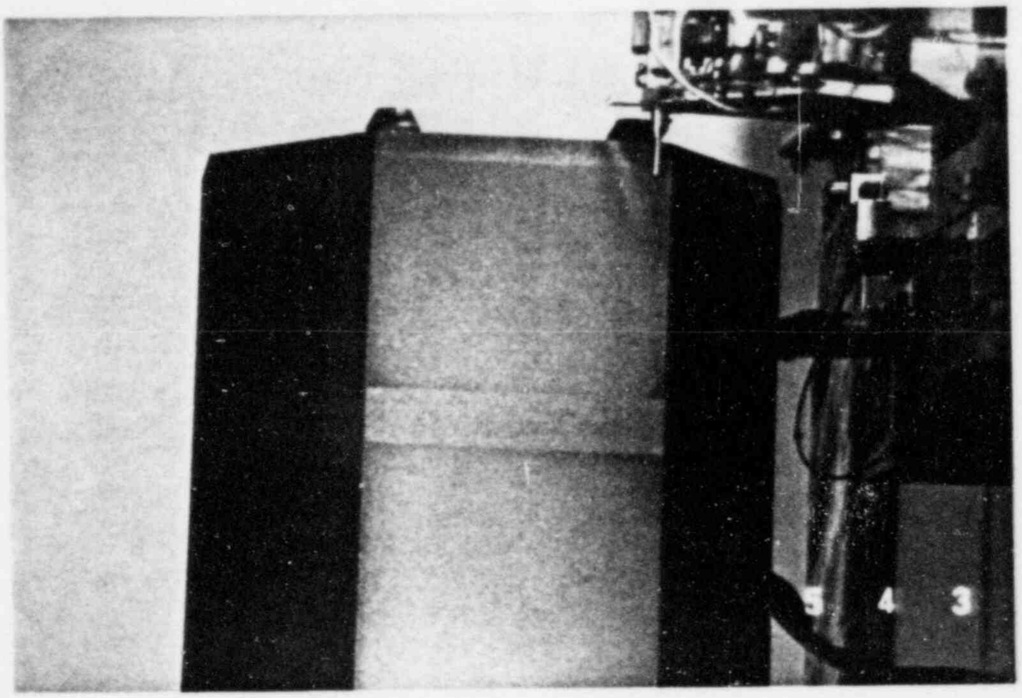
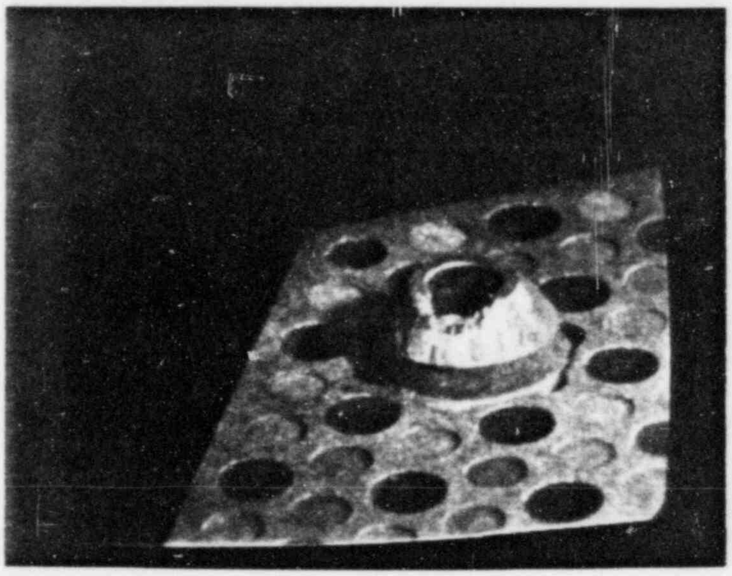


Fig. 5-13 Top half of face E of element 1-1817 showing dark areas above and below band



(a)

(b)

Fig. 5-14 Top surface of element 1-1228 showing damage to dowel pins: (a) E dowel pin located between faces D and E and (b) E dowel pin located between faces E and F

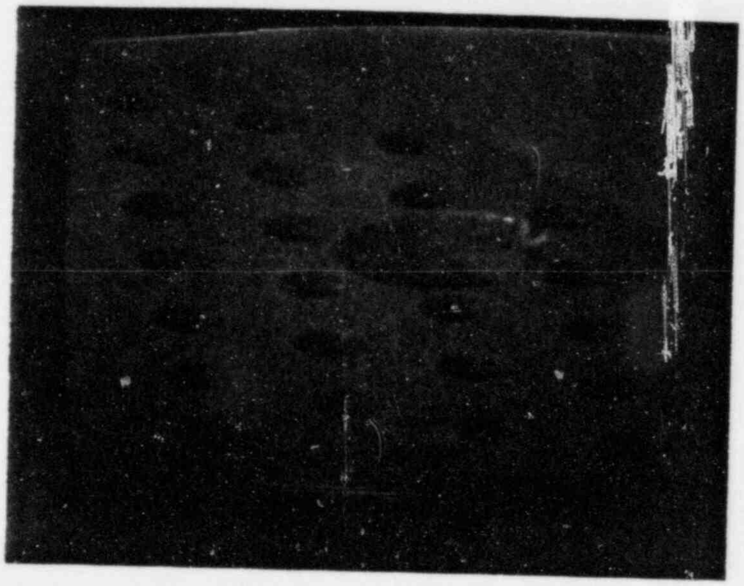
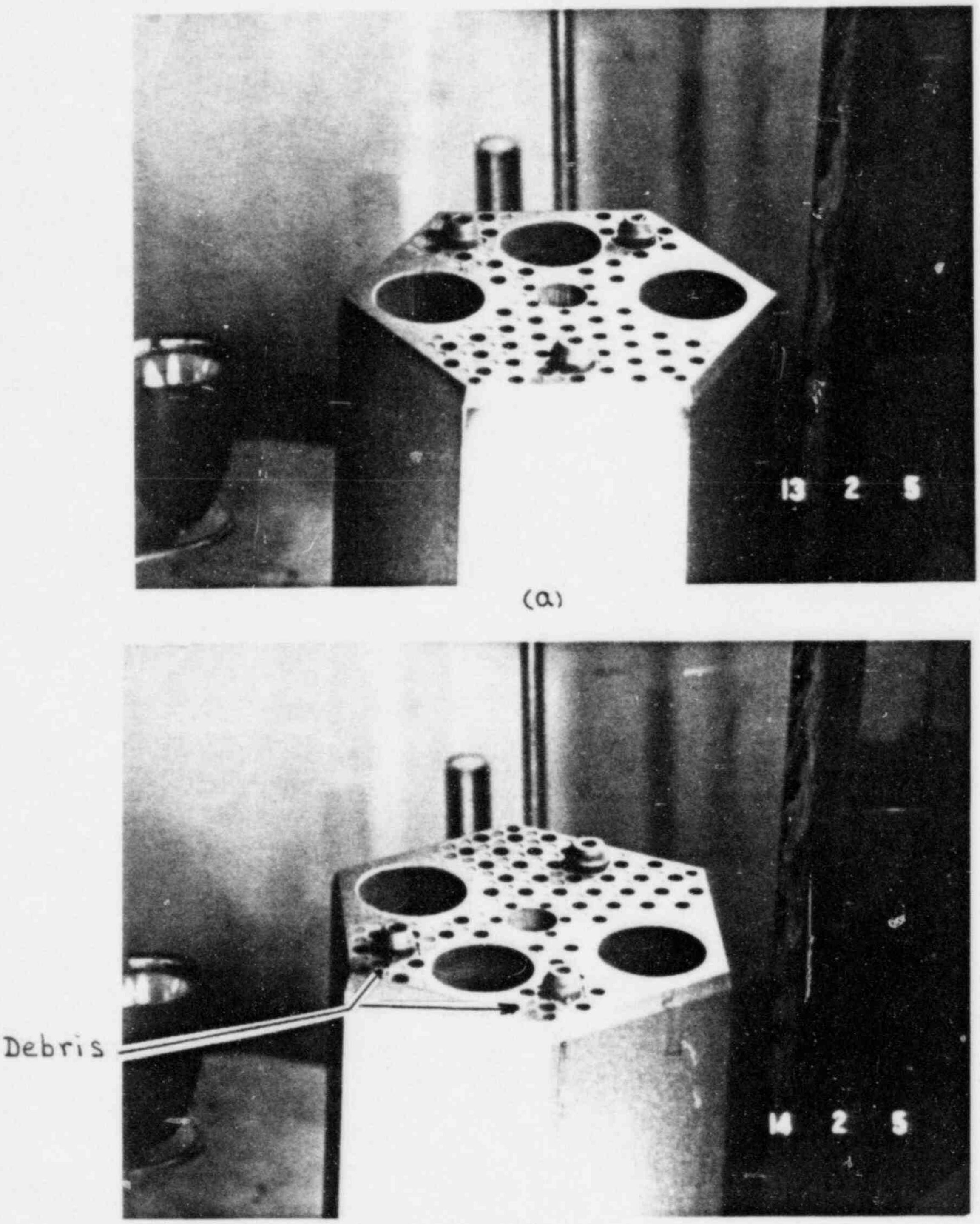


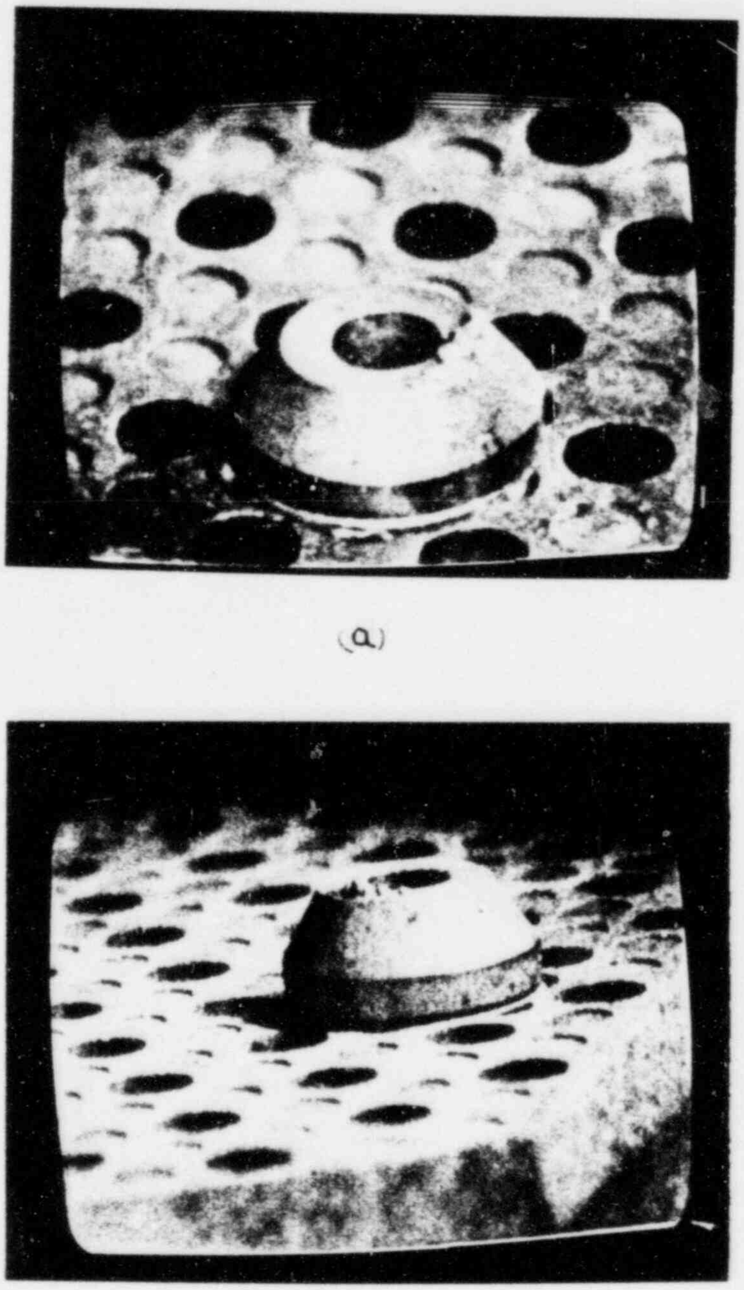
Fig. 5-15 Bottom surface near the B dowel socket of element 2-1707 showing a missing chip between the dowel socket and the central coolant hole (319) on the B face edge



(a)

(b)

Fig. 5-16 Top surface of element 2-2815 (located directly below element 2-1707) showing (a) B dowel pin free of debris and (b) both E dowel pins showing debris from the dowel sockets of element 2-1707



(a)

(b)

Fig. 5-17 Dowel pins of (a) element 1-2282 and (b) element 1-1337 both showing the wear debris of the element located directly above each

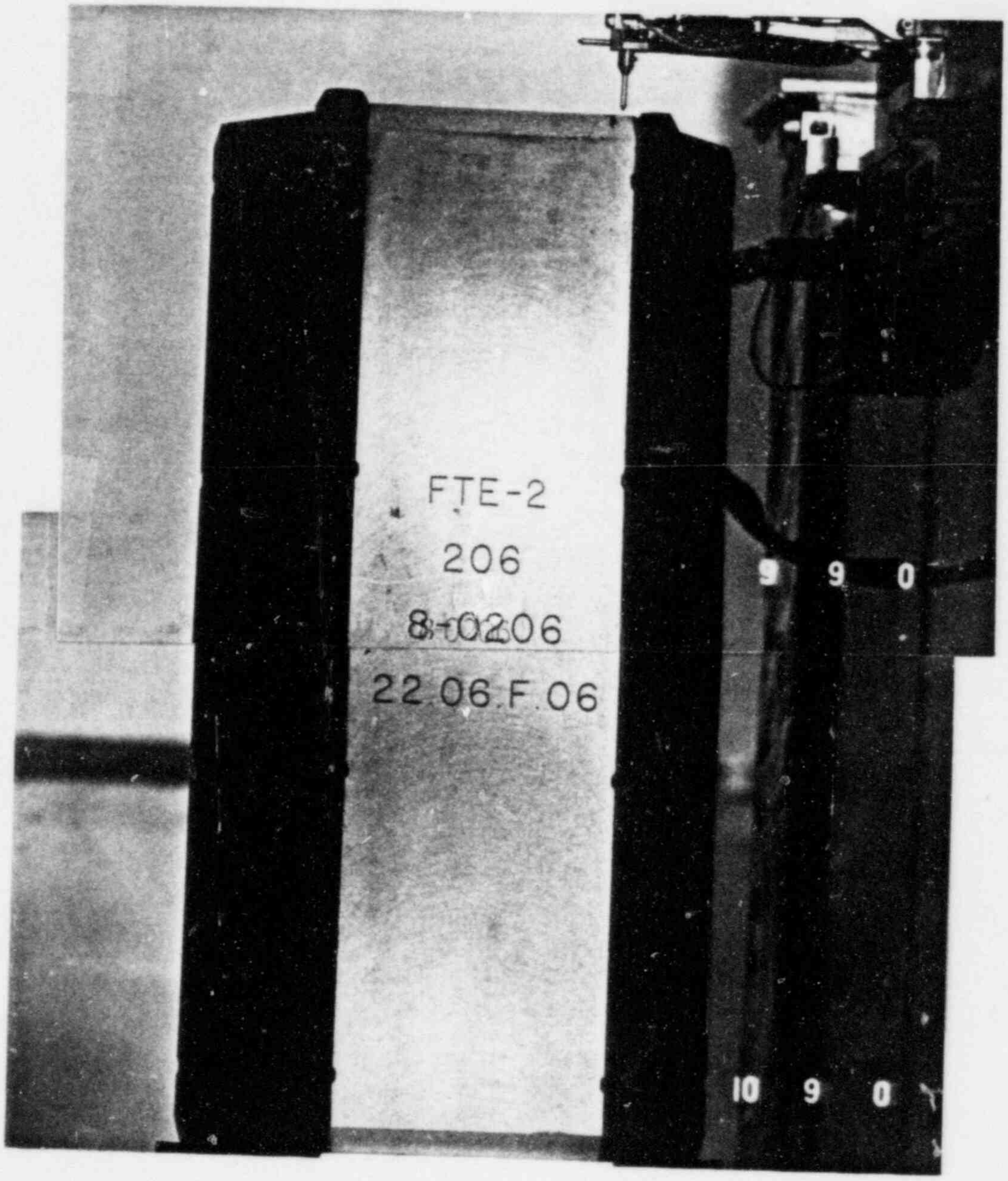


Fig. 5-18 Side face A of element 8-0206 (FTE-2)

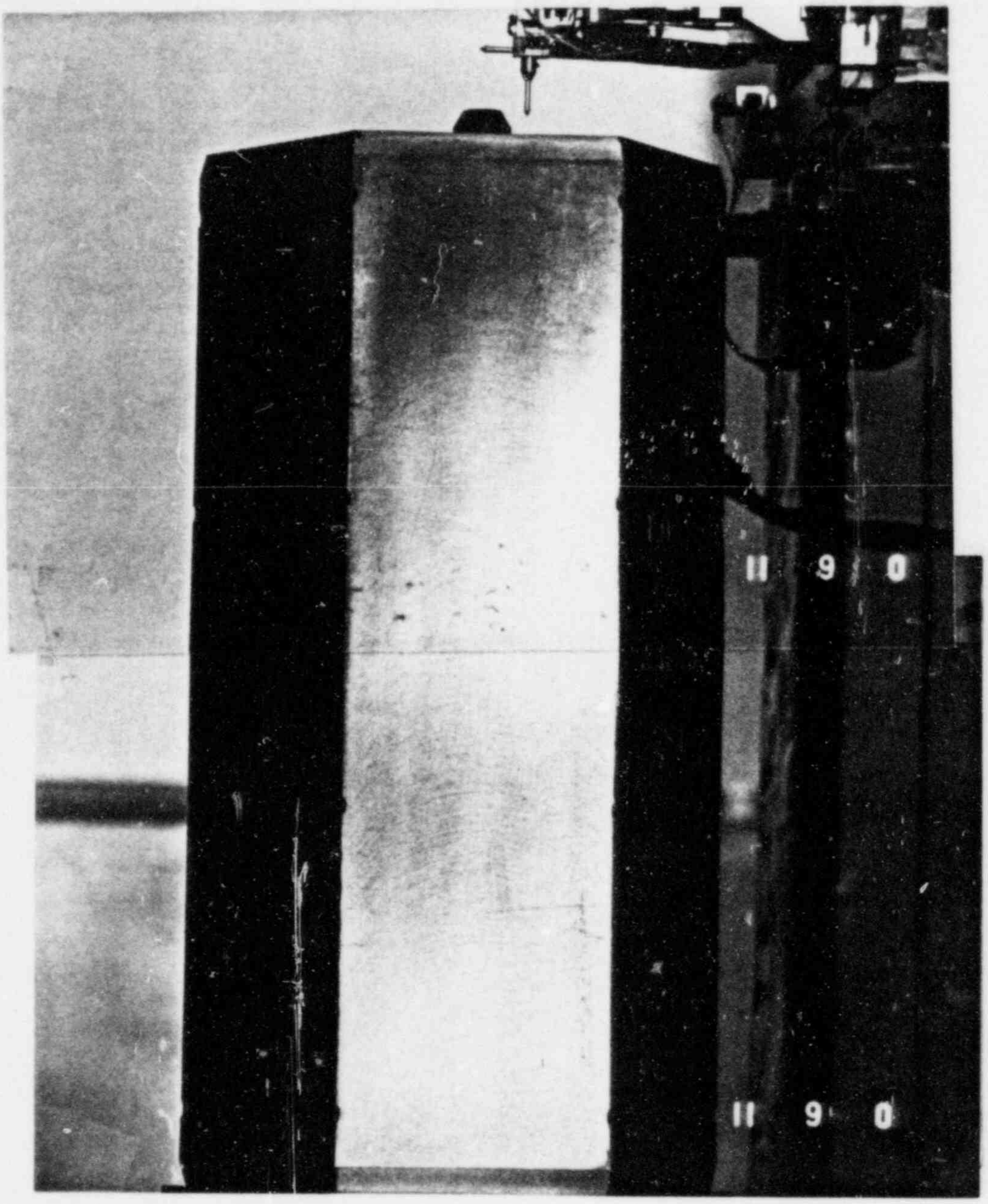


Fig. 5-19 Side face B of element 8-0206 (FTE-2)

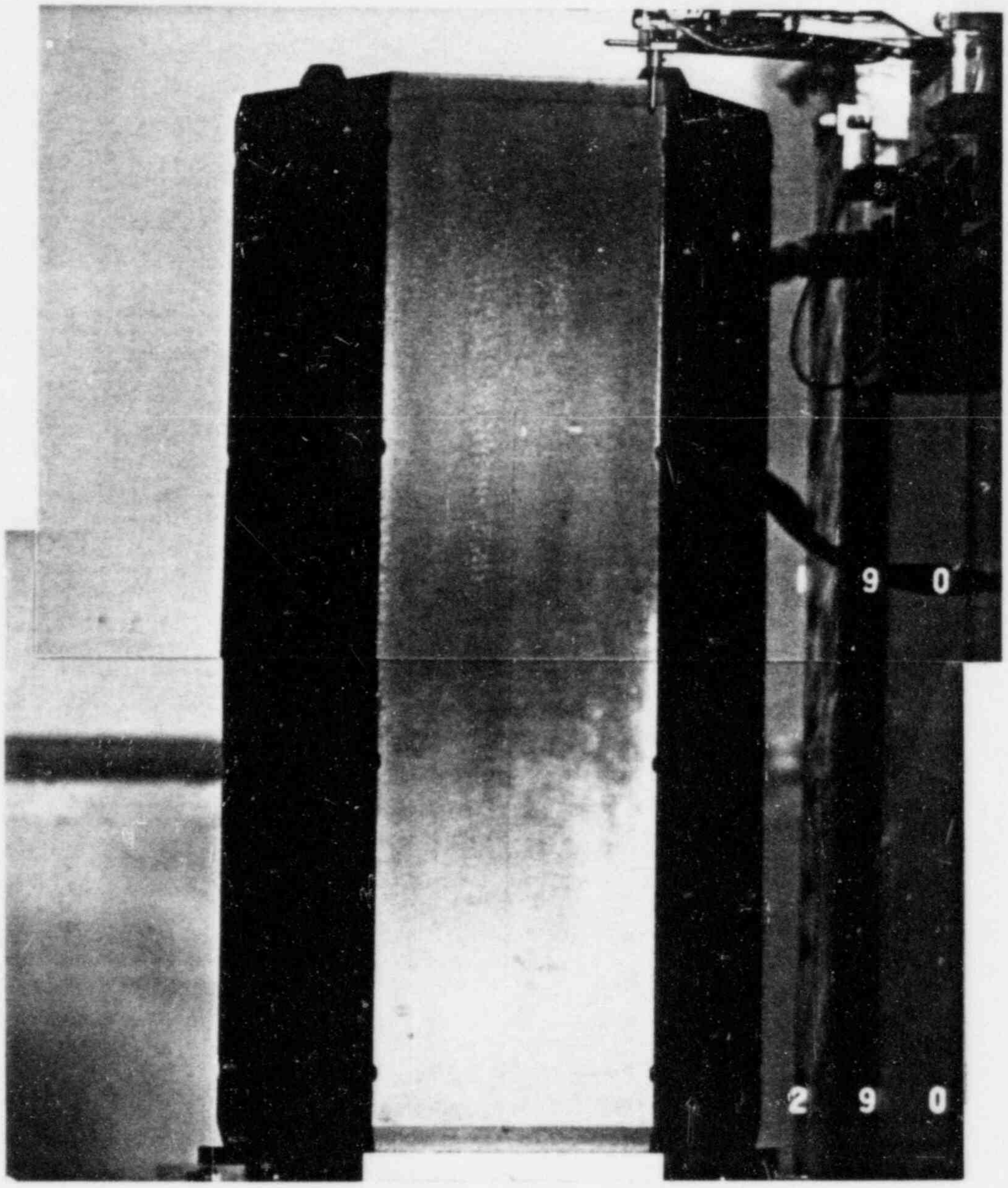


Fig. 5-20 Side face C of element 8-0206 (FTE-2). (Notice the central scratch).

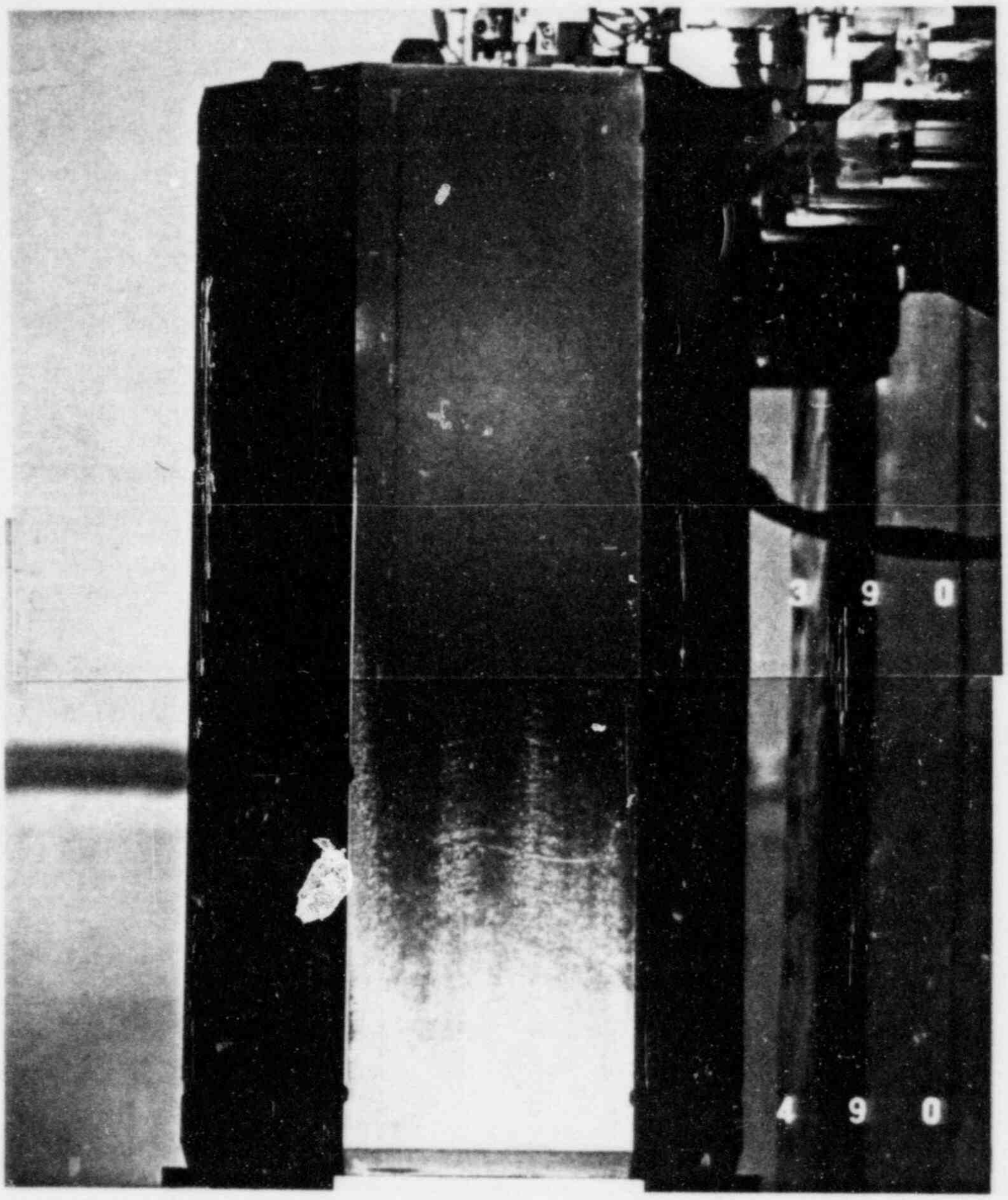


Fig. 5-21 Side face D of element 8-0206 (FTE-2). (Notice the scrapes and scratches on the left edge of the face)

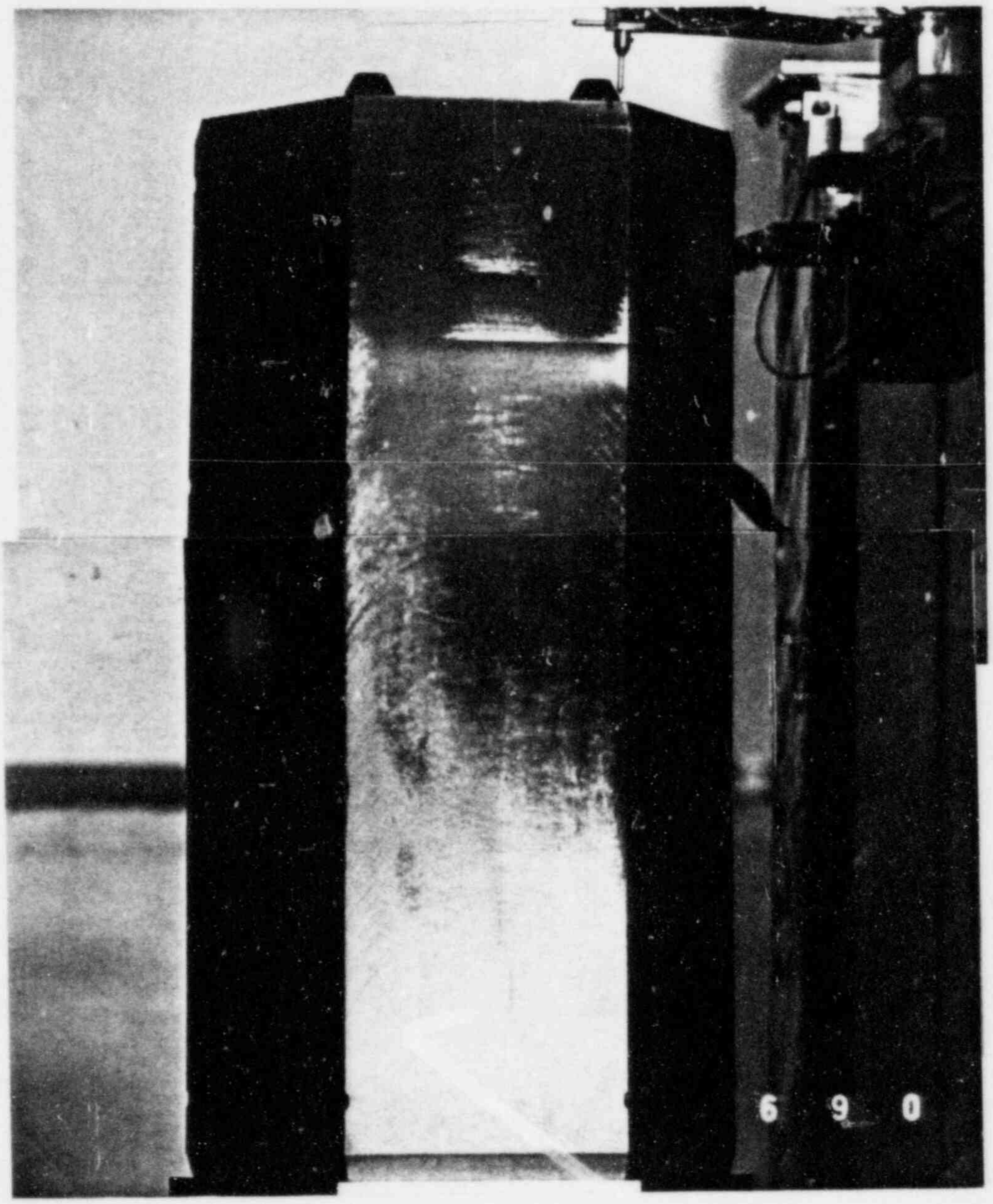


Fig. 5-22 Side face E of element 8-0206. (Notice the interface mark)

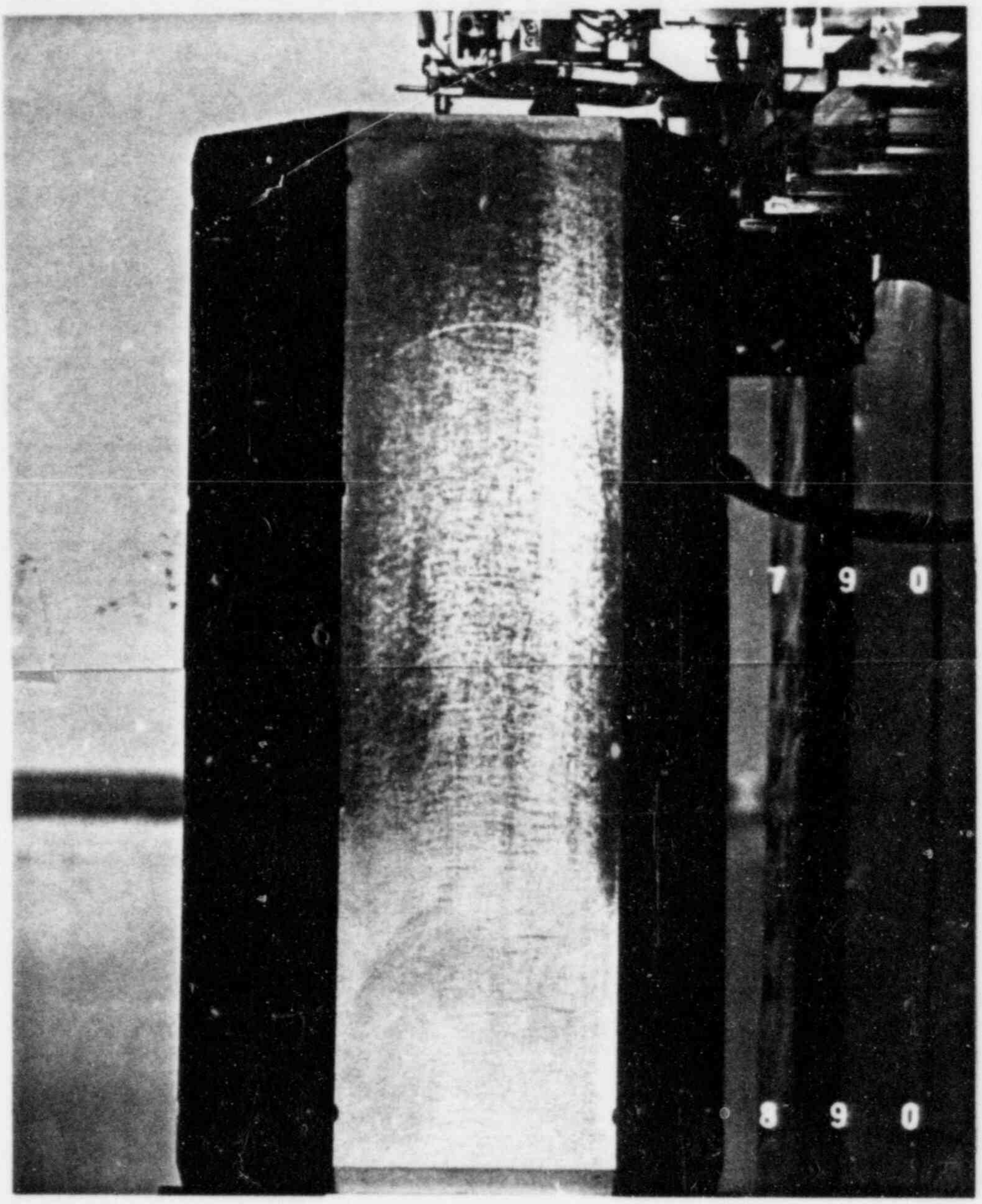


Fig. 5-23 Side face F of element 8-0206

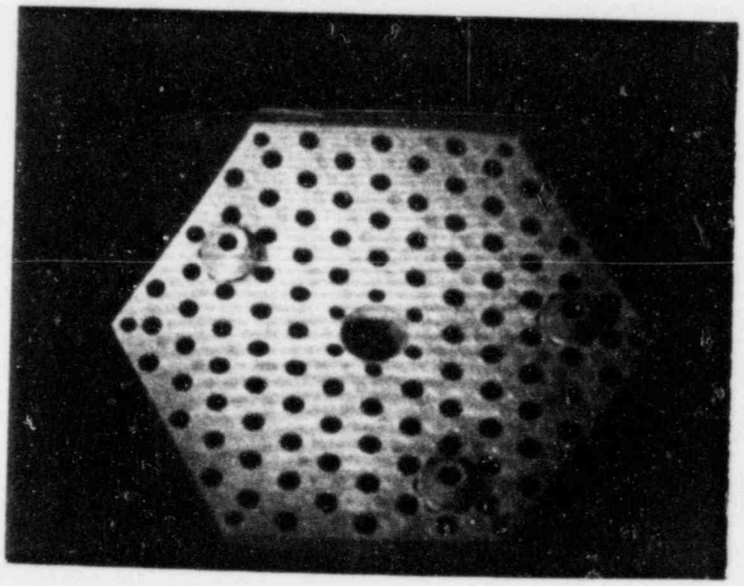


Fig. 5-24 Top surface of FTE-2 (element serial number 8-0206)

TITLE: NONDESTRUCTIVE EXAMINATION OF 62 FUEL AND REFLECTOR ELEMENTS FROM FORT ST. VRAIN CORE SEGMENT 3

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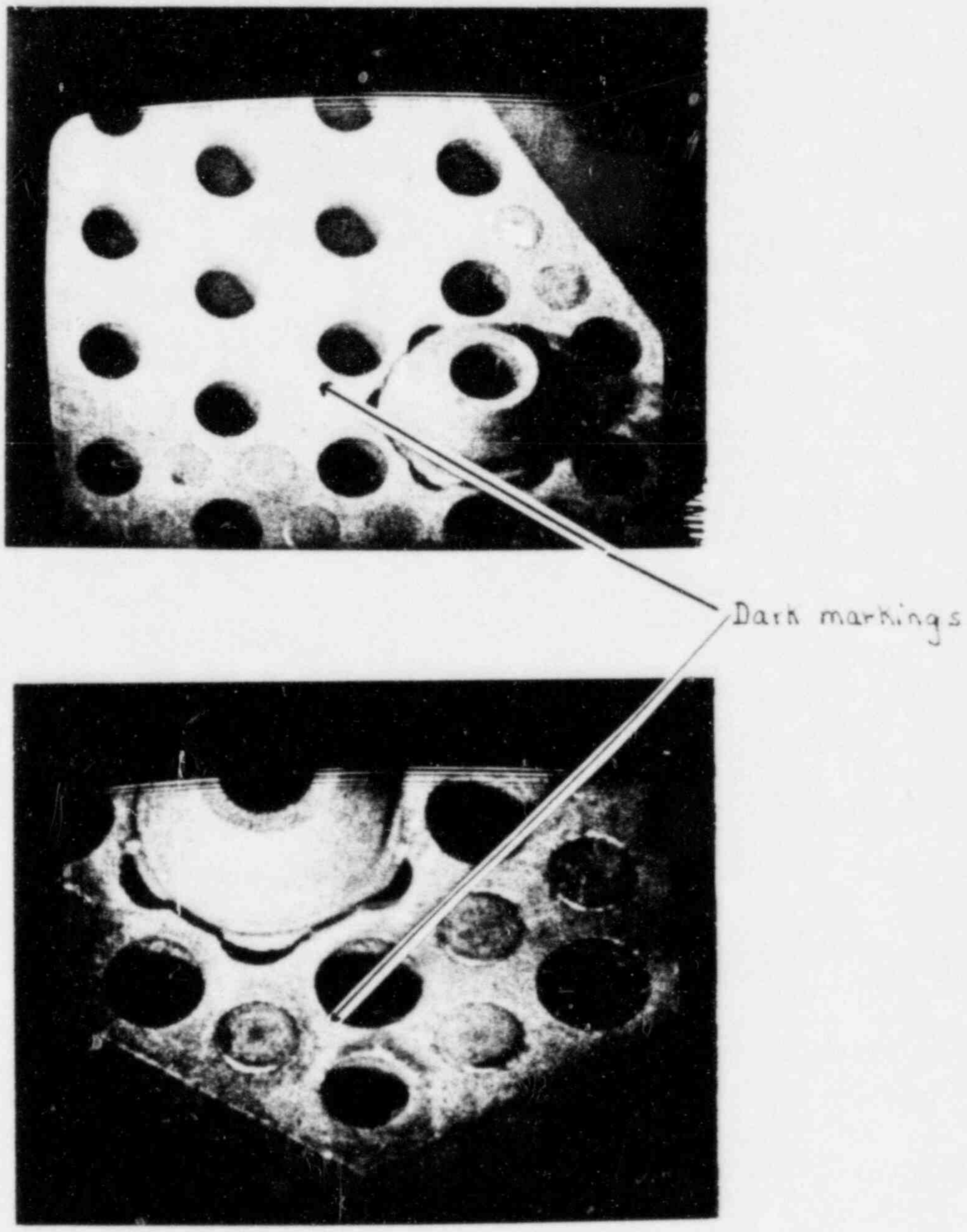

Fig. 5-25 Dark circular markings observed around fuel holes coolant and adjacent burnable poison holes on the top surface of FTE-2.

6. SUMMARY AND CONCLUSIONS

Sixty-two fuel and reflector elements from FSV core segment 3 were nondestructively examined in the HSF at FSV during June, 1984. These examinations were performed by GA at FSV as part of the DOE-sponsored surveillance program. The time- and volume-averaged graphite irradiation temperatures and volume-averaged fast neutron fluences for the elements ranged from approximately 380° to 670°C and from 0.96 to 2.82 x 10^{25} n/m^2, respectively. The examinations were intended to verify the structural integrity and dimensional stability of the elements and to obtain dimensional change data and gamma dose rates to verify HTGR design code calculations.

The results and conclusions of the nondestructive examinations are summarized below.

6.1 Core Component Performance

The axial and radial dimensions of nearly all the inspected H-327 graphite fuel elements shrank as a result of irradiation, but the dimensional changes were relatively small. The maximum element-average axial ($\Delta Z/Z$) and radial ($\Delta X/X$) strains were -0.73% and -0.57%, respectively. The maximum bow was 0.69 mm. The examined reflector elements underwent very little dimensional expansion (less than ±0.48 mm). The measured strains in segment 3 elements were reasonably close to or greater than the calculated dimensional changes. The measured bow was consistently higher than the calculated bow.

The visual examinations of the elements showed the elements to be in good condition. No cracks were observed. There was little evidence of graphite oxidation. The evidence of mechanical interactions (rub marks) was no more severe than in the two previous surveillances which suggested that the core movement was very minimal or had stopped. Minor dowel pin and dowel socket damage was observed on two elements, but the damaged areas did not affect the handling, storage nor core performance of the elements. A few chips, nicks and other handling scratches were noted, but these blemishes did not affect the performance of the core components.

6.2 Code Verification

Strain calculations were performed with the HTGR code SURVEY/STRESS and the results compared with measured strains. The results of the comparison showed the calculated (SURVEY/STRESS) strains to be underpredicted in almost every case. The differences between the calculated and measured axial strains were less than 0.16% for fast fluences less than or equal to 2.0×10^{25} n/m^2. For fast fluence greater than 2.0×10^{25} n/m^2 the maximum difference was 0.45%. The differences between calculated and measured radial strains were 0.12% and 0.34% for less than and greater than 2.0×10^{25} n/m^2, respectively. The polynomial expression for the H-327 graphite irradiation induced strain calculations models the strains better at lower fluences. The measured bow was consistently higher than the SURVEY/STRESS calculated values.

Gamma dose rates were calculated with the gamma shielding code PATH and compared with measured dose rates. The maximum measured dose rate at a distance of 36.0 inches (91 cm) for the examined elements was 2815 R/h. The calculated to measured ratio for gamma dose rate ranged from 0.78 to 2.11 with an average ratio of 1.04. If the worst case of 2.11 is omitted, the range is from 0.78 to 1.33 with an average of 0.99. These results are considered to be quite good for gamma dose rate calculations.

6.3 FTE-2 Performance

The visual examination of FTE-2 provided observable and concrete evidence of the H-451 graphite structural integrity and performance. There were small scratches, but no significant structural damage. A few darkened areas were observed on the top surface, but these discolorations were not considered significant. No cracks were observed on any of the surfaces. There was no evidence of graphite oxidation.

The measured strains were slightly lower than the calculated strains. The differences between the calculated and measured axial and radial strains were -0.018% and -0.112%, respectively.

7. ACKNOWLEDGMENTS

The author wishes to acknowledge the following individuals who contributed to this project:

Preparation and Pre-irradiation Characterization of Surveillance Elements:

W. W. Hudritsch, W. J. Scheffel, and O. M. Stansfield

Metrology Robot Development and Maintenance:

Hardware:

C. F. Wallroth, T. L. Smith, N. I. Marsh, J. P. Smith, P. Macy

Software:

J. Saurwein, R. Acotte (Simpact Associates)

Examination of Core Components at FSV:

F. C. Montgomery (Coordinator), W. Hoskins, W. Lefler, J. Saurwein, P. Macy, C. Miller, R. Precourt, J. W. Ketterer, K. Partain, T. Smith and M. Dolphin.

Also, the following employees of PSC: L. Bishard, T. Schuyler, and crews (fuel handling); F. Novachek, M. Daum and J. Eggebroten (technical services); and W. Woodard and staff (health physics).

Nuclear, Thermal, and Strain Calculations:

W. Lefler, K. Partain, J. Ketterer.

Gamma Dose Rate Calculations:

K. Baylor and S. Su

Calibration of Instruments for Gamma and Neutron Dose Rate Measurements:

J. R. Shoptaugh, Jr.

Interpretation of Photographs:

R. J. Price

Quality Assurance:

V. Nicolayeff

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12. MEYER, R. J., ''Fort St. Vrain In-Core Inspection, Region 35 and Region 13 Core Support Block'', General Atomic Report GA-A15465, June 1979.

13. MILLER, C. M., ''Preirradiation Characterization of Fuel Test Elements FTE-1 through FTE-8'', Document No. 904451, Issue A, May 1, 1980.

14. SAURWEIN, J. J., ''Status Report: Non-Destructive Examination of FSV Fuel Test Element FTE-1'', Document No. 906511, June 25, 1982.

APPENDIX A

METROLOGY ROBOT CALIBRATION

Eight full-length inspections of calibration element 8-0182* were performed prior to shipping the metrology robot to FSV for the surveillance of core segment 3. The accuracies of the robot measurements were determined and found to satisfy the accuracy requirements specified in Ref. 8 (Table A-1). The results were reviewed and approved by GA Quality Assurance (QA). Quality Assurance approval of these results constituted QA acceptance of the metrology robot for shipment to FSV (Table A-1).

Five more inspections of calibration element 8-0182* were performed at FSV prior to the inspection of the first irradiated element. The results of the first four of these inspections (Table A-2) demonstrated that the quality of the robot measurements had not deteriorated after shipping and established the measurement biases to be used in processing the robot measurement data into fuel or reflector block dimensions. Run 5 included the biases and was used to verify calibration runs 1 through 4 (Table A-3). The robot calibration procedure (Ref. 8) specifies that a final inspection of calibration element 8-0182 be performed after the last irradiated element of a surveillance campaign has been examined, this was done and the results are in Table A-4.

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*Element 8-0182 is a fully-machined graphite fuel element on which quality control measurements, corresponding to those performed on irradiated core components by the metrology robot, have been performed using calibrated measurement equipment traceable to the National Bureau of Standards. GA Quality Assurance has certified element 8-0182 as a special calibration standard for the metrology robot.

GA 1396

TABLE A-1

DOCUMENT NO. 907785 | ISSUE NO./LTR. N/C

NO. 1180

☐ TOOL ☒ GAGE INSPECTION RECORD

☐ TOOL IN LIEU OF GAGE

1. INTERVAL As Used

PAGE 1 OF 2

TOOL GAGE NO	REV.	3. UNIT	4. FILE NO.	5. DATE	6. T.O. NO.	7. WORK ORDER NO.	8. PREV. TGIR
903910	B	1	SIG-28	5-14-84	—	7736902110	—

9. TOOL GAGE NAME Metrology Robot

10. SUPPLIER GA

11. INSPECT AT ☐ SV-INSP ☒ OTHER (SPECIFY) L-519

12. TOOL INSP. PLAN G.P. Conners

E APPR'VD G.P. Conners 5-14-84

14. ☐ NEW OR MODIFIED ☐ REWORK/ REPAIR ☒ RECYCLE INSP. ☐ OTHER (SPECIFY)

15. TOOL PROOF REQ'D ☐ YES ☒ NO

16. SOAK 24 HRS

17. NO.	18. ITEM	19 QTY	20. REQUIREMENT	21. RECYCLE	22. ACTUAL RESULTS	23. DISCREP	24. DISPOSITION
01	1	1	Recalibrate The Metrology Robot Per Test Procedure #905979-A (F.C. SEGMENT 3)	⊗	SEE PAGE 2		

⊗ RECYCLE INSPECTION SHALL BE PERFORMED PRIOR TO NEXT USE (SEGMENT 4)

25. INSPECTOR F. MONTGOMERY/N. NICOLAIEFF 5/18/84 DATE

STAMP GA 15

26. INSP. SUPERVISOR N. Nickoloff DATE 5/18/84

30. PROJ. DESIGN REP. — DATE

DISPOSITION ACCEPT

28. PROJ. [illegible] ENGR DATE

29. QUAL. ENGR DATE

31. CUSTOMER REP. DATE

REJECTED

RESPONSIBILITY

☐ RETURN TO SUPPLIER

32. REWORK REPAIR

☐ ACCEPTABLE

NEW TGIR NO.

34. INSPECTOR DATE

GAGE INSPECTION RECORD # 1180
PAGE 2 of 2

Notations in this column indicate where changes have been made

TABLE A-1
(CONTINUE)

Table 7

Summary of Robot Measurement Accuracy - Calibration Element 8-0182

Type of Measurement	Test	SONY - L. Pot		SONY - LVDT		R. Rot - L. Pot		R. Pot - LVDT		Mean
		Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	B ias	
Distance Across Flats	1	0.003	-0.001	0.002	-0.001	0.002	-0.005	0.002	-0.007	
	2	0.002	-0.003	0.003	-0.003	0.002	-0.004	0.003	-0.006	
	Mean	0.003	-0.002	0.003	-0.002	0.002	-0.005	0.003	-0.007	—
Side Face Measurements	1	0.001	0.002	0.001	0.002	0.001	0.002	0.001	0.002	
	2	0.001	0.002	0.001	0.002	0.001	0.002	0.001	0.002	
	Mean	0.001	0.002	0.001	0.002	0.001	0.002	0.001	0.002	—
Element Length *	1	0.003	-0.003	0.002	0	0.005	0.001	0.006	0.001	
	2	0.002	-0.002	0.002	-0.003	0.005	0.001	0.002	0.001	
	Mean	0.003	-0.003	0.002	-0.002	0.005	0.001	0.004	0.001	—
Distance between Coolant Holes	1	0.003	-0.001	0.004	-0.001	0.004	-0.004	0.004	-0.007	
	2	0.004	-0.004	0.004	-0.002	0.004	-0.006	0.003	-0.007	
	Mean	0.004	-0.003	0.004	-0.002	0.004	-0.005	0.004	-0.007	—
Coolant Hole Diameters	1	0.001	0.002	0.001	0.003	0.002	0.006	0.001	0.008	
	2	0.001	0.005	0.001	0.003	0.001	0.007	0.001	0.008	
	Mean	0.001	0.004	0.001	0.003	0.002	0.007	0.001	0.008	—
Distance between Fiducial Hole	1	0.002	-0.001	0.002	-0.001	0.003	-0.002	0.002	-0.001	
	2	0.002	-0.001	0.002	-0.001	0.002	-0.001	0.002	-0.001	-
	Mean	0.002	-0.001	0.002	-0.001	0.003	-0.001	0.002	-0.001	—

* All element length measurement biases given in Table 3 have been increased by 0.005 in. to correct for use of an incorrect z reference coordinate in the data analysis program. The program was subsequently changed to include the correct reference coordinate.

QC Stamp and Signature GA 5 QE 5/18/84

Notations in this column indicate where changes have been made

TABLE A-2

Run 1

Across Flat Dimensions - Calibration Element 8-0182

(inches)

INSTRUMENTATION

Probe Table Position SONY's

Probe Displacement Linear Pots

Faces/ Corner	Measurement	Test Combination -			Mean	Std. Dev.
		1 - 2	3 - 4	5 - 6		
A - D	Q. C.	14.175	14.176	14.175	14.175	.0006
	Robot	14.174	~~14.167~~	14.175	14.174	.0044
2	Robot - Q. C.	-.001	[redacted]	0	-.001	.0049
A - D	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.175	14.174	14.174	14.174	.0006
5	Robot - Q. C.	-.001	-.002	-.002	-.002	.0006
B - E	Q. C.	14.175	14.174	14.174	14.174	.0006
	Robot	14.173	14.173	14.173	14.173	0
3	Robot - Q. C.	-.002	-.001	-.001	-.001	.0006
B - E	Q. C.	14.174	14.174	14.174	14.174	0
	Robot	14.175	14.174	14.175	14.175	.0006
6	Robot - Q. C.	+.001	0	+.001	+.001	.0006
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	~~14.166~~	14.173	14.171	14.170	.0036
1	Robot - Q. C.	OK ~~-.010~~	-.003	-.005	-.006	.0036
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.174	14.174	14.177	14.175	.0017
4	Robot - Q. C.	-.002	-.002	+.001	-.001	.0017
Robot - Q. C.	Mean	-.0025	-.003	-.001	-.002	.0010
	Std. Dev.	.0038	.0032	.0023	.0024	.0031

Notations in this column indicate where [illegible]nges have been made

A

TABLE A-2 (CONT)

R-A 1

SIDE FACE BOW(a) - CALIBRATION ELEMENT 8-0182
(inches)

INSTRUMENTATION

Probe Table Position [illegible]

Probe Displacement [illegible]

Axial Level(b)	Face A(c)	Face B(c)	Face C(c)	Face D(c)	Face E(c)	Face F(c)	Mean	St.Dev.
2	+.001	+.001	+.001	+.001	+.001	+.001	+.001	0
3	+.002	+.003	+.002	+.002	+.002	+.002	+.002	.0004
4	+.002	+.004	+.003	+.003	+.003	+.003	+.003	.0006
5	+.003	+.004	+.003	+.003	+.003	+.003	+.003	.0004
6	+.003	+.003	+.003	+.003	+.002	+.003	+.003	.0004
7	+.003	+.003	+.002	+.003	+.003	+.003	+.003	.0005
8	+.001	+.002	+.002	+.002	+.002	+.002	+.002	.0004
9	+.001	+.001	+.001	+.002	+.001	+.002	+.001	.0005
10	0	+.001	0	+.001	0	+.001	+.0005	.0005
Mean	+.002	+.002	+.002	+.002	+.002	+.002	+.002	0
St.Dev.	.0011	.0012	.0011	.0008	.0011	.0008	.0010	.0010

(a) Average for 5 points.

(b) Both measured and actual bow are 0 at levels 1 and 11, by definition.

(c) The measured bow represents a measurement error since the actual bow (determined from QC measurements) is zero (<0.0005 in.) at all axial levels for all faces.

Notations in this column indicate whe[illegible]nges have been made

TABLE A-2 (CONT)

Run 1

Element Length - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position [illegible]

Probe Displacement [illegible]

Measurement	Location	Q. C.	Robot	Robot - Q. C.
1	C-324	31.223		-.020
2	321-322	31.223		-.017
3	S-319	31.223		[illegible]
4	316-317	31.223		[illegible]
5	C-314	31.223		[illegible]
6	275-289	31.223		-.024
7	293-294	31.222		-.019
8	296-297	31.222		-.020
9	289-301	31.223		-.021
10	S-259	31.222		[illegible]
11	257-272	31.222		-.021
12	237-254	31.223		-.019
13	251-252	31.222		-.021
14	233-249	31.222		-.019
15	246-262	31.222		-.026
16	S-244	31.222		-.025
17	190-209	31.223		-.030
18	192-211	31.222		-.026
19	195-214	31.222		-.023
20	203-221	31.222		-.026
21	206-224	31.222		[illegible]
22	208-226	31.222		-.025
23	C-171	31.223		-.019
24	165-166	31.222		-.027
25	SH-163	31.222		-.021
26	SH-200	31.222		-.023
27	SH-198	31.222		-.027
28	SH-127	31.222		-.023
29	SH-125	31.222		-.022
30	SH-162	31.222		-.021
31	159-160	31.222		-.027
32	C-154	31.223		-.017
33	99-117	31.223		-.026
34	101-119	31.222		[illegible]
35	104-122	31.222		-.021
36	111-130	31.222		-.021
37	114-133	31.222		-.024
38	116-135	31.223		-.026
39	S-81	31.222		-.016
40	63-79	31.222		-.023
41	76-92	31.222		-.024
42	73-74	31.222		-.024
43	71-88	31.222		-.025
44	53-68	31.222		-.019
45	S-66	31.223		-.017
46	24-37	31.223		[illegible]
47	28-29	31.222		[illegible]
48	31-32	31.222		-.024
49	36-50	31.222		-.024
50	C-11	31.222		-.024
51	3-9	31.222		-.022
52	S-6	31.222		-.022
53	3-4	31.222		-.026
54	C-1	31.222		-.016
Mean Std. Dev.	X	31.222 .0004	X	-.024 .0027

.002 (-)

Notations in this column indicate where changes have been made

A

TABLE A-2 (CONT.)

Distances Between Coolant Holes - Calibration Element 8-0182

Run 1

INSTRUMENTATION

Probe Table Position Scales

Probe Displacement Linear Pots

Hole to Hole	Q. C.	Robot	Robot - Q. C.
312 to 270	1.595	1.593	-.002
270 to 219	1.594	1.591	-.003
219 to 106	3.814	3.818	+.004
106 to 55	1.594	1.591	-.003
55 to 13	1.593	1.588	-.005
312 to 13	12.693	12.694	+.001
319 to 295	0.656	0.652	-.004
295 to 267	0.657	0.652	-.005
267 to 235	0.656	0.653	-.003
235 to 90	4.500	4.499	-.001
90 to 58	0.656	0.652	-.004
58 to 30	0.655	0.651	-.004
30 to 6	0.655	0.651	-.004
319 to 6	12.189	12.182	-.007
303 to 264	1.595	1.591	-.004
264 to 216	1.594	1.589	-.005
216 to 109	3.814	3.812	-.002
109 to 61	1.593	1.589	-.004
61 to 22	1.593	1.587	-.006
303 to 22	12.693	12.682	[illegible]
170 to 167	1.594	1.589	-.005
167 to 164	1.595	1.593	-.002
164 to 161	3.815	3.819	+.004
161 to 158	1.594	1.592	-.002
158 to 155	1.594	1.593	-.001
170 to 155	12.695	12.700	+.005
13 to 22	6.034	6.025	-.009
22 to 170	6.033	6.031	-.002
170 to 312	6.033	6.035	+.002
312 to 303	6.034	6.037	+.003
303 to 155	6.034	6.034	—
155 to 13	6.033	6.023	-.010
Mean Std. Dev.	X	X	-.0026 .0036

TABLE A-2
(CONTINUED)

Coolant Hole Diameters - Calibration Element 8-0182 Run 1

INSTRUMENTATION

Probe Table Position SCN93

Probe Displacement Linear Pot's

Hole	Q. C.	Robot	Robot - Q. C.
6	.627	.631	+.004
13	.627	.632	+.005
22	.627	.632	+.005
30	.627	.630	+.003
55	.626	.629	+.003
58	.627	.629	+.002
61	.627	.630	+.003
66	.626	.630	+.004
81	.626	.630	+.004
90	.626	.629	+.003
103	.626	.629	+.003
106	.626	.629	+.003
109	.626	.629	+.003
112	.626	.630	+.004
126	.498	.503	+.005
144	.498	.502	+.004
145	.498	.503	+.005
155	.626	.628	+.002
158	.626	.628	+.002
161	.625	.628	+.003
164	.626	.629	+.003
167	.626	.630	+.004
170	.626	.631	+.005
180	.498	.499	+.001
181	.498	.500	+.002
199	.498	.502	+.004
213	.625	.629	+.004
216	.626	.628	+.002
219	.626	.627	+.001
222	.626	.628	+.002
235	.626	.628	+.002
244	.626	.630	+.004
259	.626	.628	+.002
264	.626	.628	+.002
267	.626	.628	+.002
270	.625	.629	+.004
295	.626	.629	+.003
303	.626	.629	+.003
312	.626	.629	+.003
319	.626	.629	+.003
Mean Std. Dev.	X	X	+.0032 .001

Notations in this column indicate where changes have been made

TABLE A-2 (CONT.)

Run 1

Distances between Fiducial Holes - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position S/N's

Probe Displacement Linear Pot's

Corner No.	Measurement	L Dim	M Dim	N Dim	R Dim
1	Q. C.	9.003	9.002	9.000	27.005
	Robot	8.997	8.997	8.997	26.991
	Robot - Q. C.	-.006	-.005	-.003	-.014
2	Q. C.	9.003	9.001	9.000	27.004
	Robot	8.999	8.996	9.000	26.995
	Robot - Q. C.	-.004	-.005	0	-.009
3	Q. C.	9.003	9.001	9.001	27.005
	Robot	9.002	8.998	8.999	26.999
	Robot - Q. C.	-.001	-.003	-.002	-.006
4	Q. C.	9.004	9.001	9.001	27.007
	Robot	8.998	8.999	9.001	26.998
	Robot - Q. C.	-.006	-.002	0	-.008
5	Q. C.	9.004	9.002	9.001	27.006
	Robot	8.997	8.997	9.002	26.996
	Robot - Q. C.	-.007	-.005	+.001	-.010
6	Q. C.	9.002	9.002	9.001	27.005
	Robot	8.998	9.000	9.003	27.001
	Robot - Q. C.	-.004	-.002	+.002	-.004
Robot - Q. C.	Mean Std. Dev.	-.005 .0022	-.004 .0015	-.0003 .0019	-.0085 .0034

Grand Mean -.0029
Std. Dev .0026
(N-18)
9.000 only

Notations in this column indicate where changes have been made

A

TABLE A-2 (CONT.)-

Run 2

Distances Between Coolant Holes - Calibration Element 8-0182

INSTRUMENTATION

Probe Table Position [illegible]

Probe Displacement Linear Pots

Hole to Hole	Q. C.	Robot	Robot - Q. C.
312 to 270	1.595	1.596	+.001
270 to 219	1.594	1.593	-.001
219 to 106	3.814	3.819	+.005
106 to 55	1.594	1.592	-.002
55 to 13	1.593	1.589	-.004
312 to 13	12.693	12.695	+.002
319 to 295	0.656	0.655	-.001
295 to 267	0.657	0.653	-.004
267 to 235	0.656	0.656	0
235 to 90	4.500	4.502	+.002
90 to 58	0.656	0.655	-.001
58 to 30	0.655	0.653	-.002
30 to 6	0.655	0.652	-.003
319 to 6	12.189	12.184	-.005
303 to 264	1.595	1.592	-.003
264 to 216	1.594	1.591	-.003
216 to 109	3.814	3.816	+.002
109 to 61	1.593	1.591	-.002
61 to 22	1.593	1.589	-.004
303 to 22	12.693	12.686	-.007
170 to 167	1.594	1.591	-.003
167 to 164	1.595	1.595	0
164 to 161	3.815	3.822	+.007
161 to 158	1.594	1.593	-.001
158 to 155	1.594	1.593	-.001
170 to 155	12.695	12.703	+.008
13 to 22	6.034	6.032	-.002
22 to 170	6.033	6.034	+.001
170 to 312	6.033	6.030	-.003
312 to 303	6.034	6.036	+.002
303 to 155	6.034	6.035	+.001
155 to 13	6.033	6.034	+.001
Mean Std. Dev.	X	X	-.0006 .0033

Notations in this column indicate where changes have been made

TABLE A-2 (CONT.)

Run 2

Coolant Hole Diameters - Calibration Element 8-0182

INSTRUMENTATION

Probe Table Position [illegible]

Probe Displacement Linear Pots

Hole	Q. C.	Robot	Robot - Q. C.
6	.627	.630	+.003
13	.627	.631	+.004
22	.627	.628	+.001
30	.627	.628	+.001
55	.626	.628	+.002
58	.627	.627	0
61	.627	.628	+.001
66	.626	.627	+.001
81	.626	.627	+.001
90	.626	.625	-.001
103	.626	.626	0
106	.626	.626	0
109	.626	.626	0
112	.626	.627	+.001
126	.498	500	+.002
144	.498	500	+.002
145	.498	500	+.002
155	.626	.627	+.001
158	.626	.628	+.002
161	.625	.626	+.001
164	.626	.627	+.001
167	.626	.628	+.002
170	.626	.630	+.004
180	.498	.499	+.001
181	.498	.499	+.001
199	.498	.500	+.002
213	.625	.626	+.001
216	.626	.626	0
219	.626	.626	0
222	.626	.628	+.002
235	.626	.626	0
244	.626	.629	+.003
259	.626	.629	+.003
264	.626	.627	+.001
267	.626	.627	+.001
270	.625	.626	+.001
295	.626	.626	0
303	.626	.627	+.001
312	.626	.628	+.002
319	.626	.626	0
Mean Std. Dev.	X	X	+.0013 .0011

Notations in this column indicate changes have been made

TABLE A-2(CONT)

Run 2

Distances between Fiducial Holes - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position South

Probe Displacement Linear Axis

Corner No.	Measurement	L Dim	M Dim	N Dim	R Dim
1	Q. C.	9.003	9.002	9.000	27.005
	Robot	8.996	9.000	9.001	26.997
	Robot - Q. C.	-.007	-.002	+.001	-.008
2	Q. C.	9.003	9.001	9.000	27.004
	Robot	8.996	8.997	9.002	26.995
	Robot - Q. C.	-.007	-.004	+.002	-.009
3	Q. C.	9.003	9.001	9.001	27.005
	Robot	8.998	9.000	9.000	26.998
	Robot - Q. C.	-.005	-.001	-.001	-.007
4	Q. C.	9.004	9.001	9.001	27.007
	Robot	8.992	8.995	9.007	26.994
	Robot - Q. C.	-.012	-.006	+.006	-.013
5	Q. C.	9.004	9.002	9.001	27.006
	Robot	9.002	8.999	8.998	26.999
	Robot - Q. C.	-.002	-.003	-.003	-.007
6	Q. C.	9.002	9.002	9.001	27.005
	Robot	8.996	8.999	8.998	26.993
	Robot - Q. C.	-.006	-.003	-.003	-.012
Robot - Q. C.	Mean Std. Dev.	-.0065 .0033	-.003 .0017	+.0003 .0034	-.009 .0026

Grand Mean -.0031
Std Dev .0040
(N-18)
9.000 only

Notations in this column indicate where changes have been made

TABLE A-2 (CONT.)

Run 3

Across Flat Dimensions - Calibration Element 8-0182

(inches)

INSTRUMENTATION

Probe Table Position SCNTS

Probe Displacement [illegible] Pots

Faces/ Corner	Measurement	Test Combination -			Mean	Std. Dev.
		1 - 2	3 - 4	5 - 6		
A - D	Q. C.	14.175	14.176	14.175	14.175	.0006
	Robot	14.174	~~[illegible]~~	14.174	14.174	⊖
2	Robot - Q. C.	-.001	—	-.001	-.001	⊖
A - D	Q. C.	14.176	14.176	14.176	14.176	⊖
	Robot	14.175	14.175	14.173	14.174	.0012
5	Robot - Q. C.	-.001	-.001	-.003	-.002	.0012
B - E	Q. C.	14.175	14.174	14.174	14.174	.0006
	Robot	14.172	14.171	14.173	14.172	.0010
3	Robot - Q. C.	-.003	-.003	-.001	-.002	.0012
B - E	Q. C.	14.174	14.174	14.174	14.174	⊖
	Robot	14.172	14.171	14.172	14.172	.0006
6	Robot - Q. C.	-.002	-.003	-.002	-.002	.0006
C - F	Q. C.	14.176	14.176	14.176	14.176	⊖
	Robot	~~14.169~~	14.172	14.172	14.171	.0017
1	Robot - Q. C.	ok ~~-.007~~	-.004	-.004	-.005	.0017
C - F	Q. C.	14.176	14.176	14.176	14.176	⊖
	Robot	14.170	14.173	14.173	14.172	.0017
4	Robot - Q. C.	-.006	-.003	-.003	-.004	.0017
Robot - Q. C.	Mean	-.003	-.003	-.002	-.003	.0006
	Std. Dev.	.0026	.0011	.0012	.0015	.0017

TABLE A-2 (CONT.)

A

Run 3

SIDE FACE BOW[a] - CALIBRATION ELEMENT 8-0182
(inches)

INSTRUMENTATION

Probe Table Position SONY

Probe Displacement Linear-Pots

Axial Level[b]	Face A[c]	Face B[c]	Face C[c]	Face D[c]	Face E[c]	Face F[c]	Mean	St.Dev.
2	0	+.001	0	+.001	+.001	0	+.0005	.0005
3	+.002	+.002	+.001	+.002	+.002	+.002	+.002	.0004
4	+.003	+.002	+.002	+.002	+.002	+.002	+.002	.0004
5	+.003	+.003	+.002	+.003	+.002	+.002	+.0025	.0005
6	+.002	+.003	+.002	+.003	+.003	+.003	+.003	.0005
7	+.002	+.002	+.001	+.002	+.002	+.002	+.002	.0006
8	+.001	+.001	+.001	+.002	+.002	+.002	+.0015	.0005
9	+.001	+.001	0	+.002	+.001	+.002	+.001	.0006
10	0	0	+.001	0	0	+.001	0	.0005
Mean	+.002	+.002	+.001	+.002	+.002	+.002	+.002	.0004
St.Dev.	.0011	.0010	.0008	.0010	.0009	.0008	.0010	.0009

(a) Average for 5 points.

(b) Both measured and actual bow are 0 at levels 1 and 11, by definition.

(c) The measured bow represents a measurement error since the actual bow (determined from QC measurements) is zero (<0.0005 in.) at all axial levels for all faces.

Notations in this column indicate where changes have been made

Notations in this column indicate where changes have been made

TABLE A-2 (CONT.)

Run 3

Element Length - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position SONY

Probe Displacement Linear Pot

Measurement	Location	Q. C.	Robot	Robot - Q. C.
1	C-324	31.223		-.011
2	321-332.	31.223		-.009
3	S-319	31.223		-.014
4	316-317	31.223		-.013
5	C-314	31.223		-.016
6	275-289	31.223		-.015
7	293-294	31.222		-.010
8	296-297	31.222		-.008
9	288-301	31.223		-.009
10	S-259	31.222		-.011
11	257-272	31.222		-.007
12	237-254	31.223		-.013
13	251-252	31.222		-.010
14	233-249	31.222		-.016
15	246-252	31.222		-.015
16	S-244	31.222		-.017
17	190-209	31.223		-.023
18	192-211	31.222		-.017
19	195-214	31.222		-.020
20	203-221	31.222		-.013
21	206-224	31.222		-.014
22	208-226	31.222		-.012
23	C-171	31.223		-.011
24	165-166	31.222		-.014
25	HH-163	31.222		-.020
26	HH-200	31.222		-.020
27	HH-198	31.222		-.026
28	HH-127	31.222		-.014
29	HH-125	31.222		-.015
30	HH-162	31.222		-.017
31	159-160	31.222		-.018
32	C-154	31.223		-.023
33	99-117	31.223		-.022
34	101-119	31.222		-.015
35	104-122	31.222		-.016
36	112-130	31.222		-.016
37	114-133	31.222		-.017
38	116-135	31.223		-.026
39	S-81	31.222		-.019
40	63-79	31.222		-.021
41	76-92	31.222		-.019
42	73-74	31.222		-.023
43	71-88	31.222		-.022
44	53-68	31.222		-.022
45	S-66	31.223		-.021
46	24-37	31.222		-.022
47	28-29	31.222		-.018
48	31-32	31.222		-.018
49	36-50	31.222		-.015
50	C-11	31.222		-.016
51	3-9	31.222		-.013
52	5-6	31.222		-.014
53	3-4	31.222		-.018
54	C-1	31.222		-.016
Mean Std. Dev.	X	31.222 .0004	X	-.017 .003

.003 (1σ)

Notations in this column indicate w[illegible] changes have been made

TABLE A-2 (CONT.)

Rev 4

Across Flat Dimensions - Calibration Element 8-0182

(inches)

INSTRUMENTATION

Probe Table Position [illegible]

Probe Displacement Linear Pots

Faces/ Corner	Measurement	Test Combination -			Mean	Std. Dev.
		1 - 2	3 - 4	5 - 6		
A - D	Q. C.	14.175	14.176	14.175	14.175	.0006
	Robot	14.173	~~14.163~~	14.172	14.172	.0007
2	Robot - Q. C.	-.002	—	-.003	-.003	.0007
A - D	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.172	14.172	14.173	14.172	.0006
5	Robot - Q. C.	-.004	-.004	-.003	-.004	.0006
B - E	Q. C.	14.175	14.174	14.174	14.174	.0006
	Robot	14.173	14.170	14.170	14.171	.0017
3	Robot - Q. C.	-.002	-.004	-.004	-.003	.0012
B - E	Q. C.	14.174	14.174	14.174	14.174	0
	Robot	14.173	14.173	14.174	14.173	.0006
6	Robot - Q. C.	-.001	-.001	0	-.001	.0006
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	~~14.173~~	14.172	14.172	14.172	0
1	Robot - Q. C.	SC ~~-.004~~	-.004	-.004	-.004	0
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.171	14.172	14.173	14.172	.0010
4	Robot - Q. C.	-.005	-.004	-.003	-.004	.0010
Robot - Q. C.	Mean	-.003	-.003	-.003	-.003	0
	Std. Dev.	.0015	.0013	.0015	.0012	.0014

Notations in this column indicate where changes have been made

TABLE A-2 (CONT.)

Run 4

Element Length - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position [illegible]

Probe Displacement [illegible]

Measurement	Location	Q. C.	Robot	Robot - Q. C.
1	C-324	31.223		-.013
2	321-322	31.223		-.012
3	S-319	31.223		-.013
4	316-317	31.223		-.012
5	C-314	31.223		-.013
6	275-289	31.223		-.021
7	293-294	31.222		-.015
8	296-297	31.222		-.013
9	298-301	31.223		-.014
10	S-259	31.222		-.013
11	257-272	31.222		-.017
12	237-254	31.223		-.013
13	251-252	31.222		-.012
14	233-249	31.222		-.014
15	246-262	31.222		-.021
16	S-244	31.222		-.034
17	190-209	31.223		-.023
18	192-211	31.222		-.022
19	195-214	31.222		-.021
20	203-221	31.222		-.022
21	206-224	31.222		-.017
22	208-226	31.222		-.017
23	C-171	31.223		-.016
24	165-166	31.222		-.023
25	HH-163	31.222		-.023
26	HH-200	31.222		-.025
27	HH-198	31.222		-.021
28	HH-127	31.222		-.017
29	HH-125	31.222		-.021
30	HH-162	31.222		-.017
31	159-160	31.222		-.017
32	C-154	31.223		-.023
33	99-117	31.223		-.024
34	101-119	31.222		-.021
35	104-122	31.222		-.021
36	112-130	31.222		-.018
37	114-133	31.222		-.017
38	116-135	31.223		-.022
39	S-61	31.222		-.022
40	63-79	31.222		-.019
41	76-92	31.222		-.016
42	73-74	31.222		-.025
43	71-88	31.222		-.027
44	53-68	31.222		-.026
45	S-66	31.223		-.020
46	24-37	31.223		-.020
47	28-29	31.222		-.017
48	31-32	31.222		-.018
49	36-50	31.222		-.016
50	C-11	31.222		-.019
51	8-9	31.222		-.021
52	5-6	31.222		-.020
53	3-4	31.222		-.020
54	C-1	31.222		-.022
Mean Std. Dev.	X	31.222 .0004	X	-.020 .0033

.004 (1-?)

TABLE A-3

Calibration Run 5 at FSV 6/12/84
Verif of Calib. Runs 1-4

Across Flat Dimensions - Calibration Element 8-0182

(inches)

INSTRUMENTATION

Probe Table Position SONY's

Probe Displacement Linear POT's

Faces/ Corner	Measurement	Test Combination - 1 - 2	3 - 4	5 - 6	Mean	Std. Dev.
A - D	Q. C.	14.175	14.176	14.175	14.175	.0006
	Robot	14.180	14.175	14.180	14.178	.0029
2	Robot - Q. C.	.005	-.001	.005	.003	.0035
A - D	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.185	14.177	14.178	14.180	.0044
5	Robot - Q. C.	.009	.001	.002	.004	.0044
B - E	Q. C.	14.175	14.174	14.174	14.174	.0006
	Robot	14.187	14.178	14.179	14.181	.0049
3	Robot - Q. C.	.012	.004	.005	.007	.0044
B - E	Q. C.	14.174	14.174	14.174	14.174	0
	Robot	14.175	14.181	14.179	14.178	.0031
6	Robot - Q. C.	.001	.007	.005	.004	.0031
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.174	14.178	14.174	14.175	.0023
1	Robot - Q. C.	-.002	.002	-.002	-.001	.0023
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.177	14.182	14.182	14.180	.0029
4	Robot - Q. C.	.001	.006	.006	.004	.0029
Robot - Q. C.	Mean	.0043	.0032	.0035	.0035	—
	Std. Dev.	.0054	.0031	.0030	.0038	—

Notations in this column indicate where changes have been made

A

TABLE A-3 (Cont.)

Calib Run 5 at FSV 6/12/84
Verification of Calib Runs 1-4

SIDE FACE BOW[a] - CALIBRATION ELEMENT 8-0182
(inches)

INSTRUMENTATION

Probe Table Position SONY's

Probe Displacement Linear POT's

Axial Level[b]	Face A[c]	Face B[c]	Face C[c]	Face D[c]	Face E[c]	Face F[c]	Mean	St.Dev.
2	0	0	0	0.001	0.001	0.001	0.0005	0.0005
3	0	0	0	0.001	0.001	0.001	0.0005	0.0005
4	0	0.001	0	0	0.001	0.001	0.0005	0.0005
5	0	0	0	0.001	0.001	0.001	0.0005	0.0005
6	0	0	0.001	0	0	0	0.0002	0.0004
7	0.001	0.001	0.001	0	0	0	0.0005	0.0005
8	0	0.001	0.001	0	0	0	0.0003	0.0005
9	0.001	0	0.002	0.001	0	0.001	0.0008	0.0008
10	0.001	0	0.001	0.001	0.001	0	0.0007	0.0005
Mean	0.0003	0.0003	0.0007	0.0006	0.0006	0.0006	0.0005	0.0002
St.Dev.	0.0005	0.0005	0.0007	0.0005	0.0005	0.0005	0.0005	0.0001

[a] Average for 5 points.

[b] Both measured and actual bow are 0 at levels 1 and 11, by definition.

[c] The measured bow represents a measurement error since the actual bow (determined from QC measurements) is zero (<0.0005 in.) at all axial levels for all faces.

Notations in this column indicate wh[illegible]anges have been made

TABLE A-3 (CONT.) -

Calib Run 5 at FSV 6/12/84
verif. of Calib Runs 1-4

Element Length - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position SONY's

Probe Displacement Linear POT's

Measurement	Location	Q. C.	Robot	Robot - Q. C.
1	C-324	31.223		.005
2	321-322	31.223		.005
3	S-319	31.223		.002
4	316-317	31.223		.006
5	C-314	31.223		-.001
6	275-289	31.223		0
7	293-294	31.222		.001
8	296-297	31.222		.007
9	288-301	31.223		.003
10	S-259	31.222		.003
11	257-272	31.222		.004
12	237-254	31.223		.003
13	251-252	31.222		0
14	233-249	31.222		.004
15	246-262	31.222		0
16	S-244	31.222		0
17	190-209	31.223		0
18	192-211	31.222		0
19	195-214	31.222		.006
20	203-221	31.222		.004
21	206-224	31.222		.003
22	208-226	31.222		.005
23	C-171	31.223		.006
24	165-166	31.222		.004
25	HH-163	31.222		0
26	HH-200	31.222		0
27	HH-193	31.222		0
28	HH-127	31.222		.001
29	HH-125	31.222		0
30	HH-162	31.222		0
31	159-160	31.222		.001
32	C-154	31.223		-.003
33	99-117	31.223		-.001
34	101-119	31.222		.001
35	104-122	31.222		.001
36	111-130	31.222		.004
37	114-133	31.222		.005
38	116-135	31.223		.001
39	S-81	31.222		0
40	63-79	31.222		.005
41	76-92	31.222		.005
42	73-74	31.222		.001
43	71-68	31.222		-.001
44	53-68	31.222		0
45	S-56	31.223		.002
46	24-37	31.223		.005
47	23-29	31.222		.002
48	31-32	31.222		.002
49	36-50	31.222		.004
50	C-11	31.222		.008
51	8-9	31.222		-.001
52	5-6	31.222		.001
53	3-4	31.222		.002
54	C-1	31.222		.001
Mean Std. Dev.		31.222 .0004	X	.0022 .0025

Notations in this column indicate w changes have been made

TABLE A-3 (CONT.)

Calib Run 5 @ FSV 6/12/84

TABLE · verif. of Runs 1-4

Distances Between Coolant Holes - Calibration Element 8-0182

INSTRUMENTATION

Probe Table Position SONY's

Probe Displacement Linear POT's

A

Hole to Hole	Q. C.	Robot	Robot - Q. C.
312 to 270	1.595	1.597	.002
270 to 219	1.594	1.596	.002
219 to 106	3.814	3.822	.008
106 to 55	1.594	1.598	.004
55 to 13	1.593	1.593	0
312 to 13	12.693	12.693	0
319 to 295	0.656	.658	.002
295 to 267	0.657	.658	.001
267 to 235	0.656	.656	0
235 to 90	4.500	4.505	.005
90 to 58	0.656	.658	.002
58 to 30	0.655	.654	-.001
30 to 6	0.655	.657	.002
319 to 6	12.189	12.191	.002
303 to 264	1.595	1.594	-.001
264 to 216	1.594	1.595	.001
216 to 109	3.814	3.824	.010
109 to 61	1.593	1.593	0
61 to 22	1.593	1.594	.001
303 to 22	12.693	12.696	.003
170 to 167	1.594	1.593	-.001
167 to 164	1.595	1.594	-.001
164 to 161	3.815	3.813	-.002
161 to 158	1.594	1.599	.005
158 to 155	1.594	1.591	-.003
170 to 155	12.695	12.700	.005
13 to 22	6.034	6.048	.014
22 to 170	6.033	6.033	0
170 to 312	6.033	6.019	-.014
312 to 303	6.034	6.022	-.012
303 to 155	6.034	6.023	-.011
155 to 13	6.033	6.063	.030
Mean Std. Dev.	X	X	.0024 .0074

Notations in this column indicate w changes have been made

TABLE A-3 (CONT.)

Calib Run 5 @ FSV 6/12/84
verif of Runs 1 - 4

Coolant Hole Diameters - Calibration Element 8-0182

INSTRUMENTATION

Probe Table Position Sony's

Probe Displacement Linear POT's

Hole	Q. C.	Robot	Robot - Q. C.
6	.627	.625	- .002
13	.627	.625	- .002
22	.627	.625	- .002
30	.627	.625	- .002
55	.626	.623	- .003
58	.627	.625	- .002
61	.627	.626	- .001
66	.626	.623	- .003
81	.626	.626	0
90	.626	.624	- .002
103	.626	.625	- .001
106	.626	.619	- .007
109	.626	.625	- .001
112	.626	.626	0
126	.498	.499	.001
144	.498	.495	- .003
145	.498	.495	- .003
155	.626	.627	.001
158	.626	.624	- .002
161	.625	.626	.001
164	.626	.630	.004
167	.626	.629	.003
170	.626	.629	.003
180	.498	.500	.002
181	.498	.494	- .004
199	.498	.496	- .002
213	.625	.627	.002
216	.626	.623	- .003
219	.626	.621	- .005
222	.626	.623	- .003
235	.626	.626	0
244	.626	.625	- .001
259	.626	.622	- .004
264	.626	.622	- .004
267	.626	.625	- .001
270	.625	.624	- .001
295	.626	.621	- .005
303	.626	.627	.001
312	.626	.627	.001
319	.626	.623	- .003
Mean Std. Dev.	X	X	- .0013 .0024

Notations in this column indicate wh anges have been made

TABLE A-3 (CONT.)

Distances between Fiducial Holes - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position (CONT')

Probe Displacement Linear POT's

Corner No.	Measurement		L Dim	M Dim	N Dim	R Dim
1	Q. C.		9.003	9.002	9.000	27.005
	Robot		9.000	9.005	9.000	27.006
	Robot - Q. C.		-.003	.003	0	.001
2	Q. C.		9.003	9.001	9.000	27.004
	Robot		9.004	8.999	9.001	27.005
	Robot - Q. C.		.001	-.002	.001	.001
3	Q. C.		9.003	9.001	9.001	27.005
	Robot		9.003	9.003	8.999	27.006
	Robot - Q. C.		0	.002	-.002	.001
4	Q. C.		9.004	9.001	9.001	27.007
	Robot		9.007	8.997	9.006	27.011
	Robot - Q. C.		.003	-.004	.005	.004
5	Q. C.		9.004	9.002	9.001	27.006
	Robot		9.005	9.002	9.002	27.010
	Robot - Q. C.		.001	0	.001	.004
6	Q. C.		9.002	9.002	9.001	27.005
	Robot		8.996	9.007	9.000	27.004
	Robot - Q. C.		-.006	.005	-.001	-.001
Robot - Q. C.		Mean Std. Dev.	-.0007 .0033	.0007 .0033	.0007 .0024	.0017 .0020

Grand mean 0.0006

SD .0010

Notations in this [illegible] changes have been made

TABLE A-3 (CONT)

Summary of Robot Measurement Accuracy - Calibration Element 8-0182

Type of Measurement	Test	SONY - L. Pot		SONY - LVDT		R. Rot - L. Pot		R. Pot - LVDT		Mean
		Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	B ias	
Distance Across Flats	1	.0035	.0038							
	2									
	Mean									
Side Face Measurements	1	.0005	.0005							
	2									
	Mean									
Element Length	1	.0022	.0025							
	2									
	Mean									
Distance between Coolant Holes	1	.0024	.0074							
	2									
	Mean									
Coolant Hole Diameters	1	-.0013	+.0024							
	2									
	Mean									
Distance between Fiducial Hole	1	.0006	.0010							
	2									
	Mean									

ONLY DATA TAKEN

QC Stamp and Signature 1/21/85

Notations in this column indicate where changes have been made

TABLE A-4

Calib Blk @ FSV 6/23/84

Across Flat Dimensions - Calibration Element 8-0182

(inches)

INSTRUMENTATION

Probe Table Position Sony)

Probe Displacement Linear Pot',

Faces/ Corner	Measurement	Test Combination - 1 - 2	3 - 4	5 - 6	Mean	Std. Dev.
A - D	Q. C.	14.175	14.176	14.175	14.175	.0006
	Robot	14.174	14.175	14.175	14.174	.0006
2	Robot - Q. C.	-.001	-.001	-.001	-.001	0
A - D	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.179			14.179	—
5	Robot - Q. C.	.003			.003	—
B - E	Q. C.	14.175	14.174	14.174	14.174	.0006
	Robot	14.176	14.175	14.181	14.177	.0032
3	Robot - Q. C.	.001	.001	.007	.0030	.0035
B - E	Q. C.	14.174	14.174	14.174	14.174	0
	Robot	14.169			14.169	—
6	Robot - Q. C.	-.005			-.005	—
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.171	14.178	14.181	14.177	.0051
1	Robot - Q. C.	-.005	.002	.005	0.0007	.0051
C - F	Q. C.	14.176	14.176	14.176	14.176	0
	Robot	14.170			14.170	—
4	Robot - Q. C.	-.006			-.006	—
Robot - Q. C.	Mean	-.0022	.0007	.0037	+.0007	—
	Std. Dev.	.0037	.0015	.0042	.0031	—

TABLE A-4 (CONT.)

Calib. Block 6/23/84

A

Notations in this column indicate where changes have been made

SIDE FACE BOW(a) - CALIBRATION ELEMENT 8-0182
(inches)

INSTRUMENTATION

Probe Table Position SONY'S

Probe Displacement LINEAR POT'S

Axial Level(b)	Face A(c)	Face B(c)	Face C(c)	Face D(c)	Face E(c)	Face F(c)	Mean	St.Dev.
2	0	0	.001	.002	0	.001	.0007	.0008
3	.001	.001	0	.001	.001	.001	.0008	.0004
4	.001	0	.002	.001	.001	0	.0008	.0008
5	.001	0	.001	0	0	.001	.0005	.0005
6								
7								
8								
9								
10								
Mean	.0008	.0003	.0010	.0010	.0005	.0008	.0007	
St.Dev.	.0005	.0005	.0008	.0008	.0006	.0005	.0006	

(a) Average for 5 points.

(b) Both measured and actual bow are 0 at levels 1 and 11, by definition.

(c) The measured bow represents a measurement error since the actual bow (determined from QC measurements) is zero (<0.0005 in.) at all axial levels for all faces.

Notations in [illegible] column indicate [illegible] changes have been made

TABLE A-4 (CONT.)

Calib. Block 6/23/84

Element Length - Calibration Element 8-0182
(inches)

INSTRUMENTATION

Probe Table Position SONY's
Probe Displacement Linear POT's

Measurement	Location	Q. C.	Robot	Robot - Q. C.
1	C-324	31.223		.001
2	321-322	31.223		0
3	S-319	31.223		0
4	316-317	31.223		.001
5	C-314	31.223		-.004
6	275-289	31.223		-.003
7	293-294	31.222		-.001
8	296-297	31.222		.001
9	288-301	31.223		.002
10	S-259	31.222		.001
11	257-272	31.222		-.002
12	237-254	31.223		-.003
13	251-252	31.222		-.003
14	233-249	31.222		-.005
15	246-262	31.222		-.004
16	S-244	31.222		-.005
17	190-209	31.223		-.011
18	192-211	31.222		-.007
19	195-214	31.222		-.002
20	203-221	31.222		-.004
21	206-224	31.222		-.004
22	208-226	31.222		0
23	C-171	31.223		-.002
24	165-166	31.222		-.006
25	HH-163	31.222		-.006
26	HH-200	31.222		-.006
27	HH-193	31.222		-.009
28	HH-127	31.222		-.001
29	HH-125	31.222		-.001
30	HH-162	31.222		-.002
31	159-160	31.222		-.003
32	C-154	31.223		-.004
33	99-117	31.223		-.006
34	101-119	31.222		-.003
35	104-122	31.222		.001
36	111-130	31.222		-.003
37	114-133	31.222		0
38	116-135	31.223		-.001
39	S-81	31.222		-.004
40	63-79	31.222		-.006
41	76-92	31.222		-.003
42	73-74	31.222		-.007
43	71-88	31.222		-.004
44	53-68	31.222		-.008
45	S-56	31.223		-.006
46	24-37	31.223		-.006
47	23-[illegible]	31.222		-.006
48	31-32	31.222		-.006
49	36-50	31.222		0
50	C-11	31.222		-.001
51	8-9	31.222		-.007
52	S-5	31.222		-.022
53	3-4	31.222		-.003
54	C-1	31.222		-.007
Mean Std. Dev.		—	—	-.004 .004

TABLE A-4(CONT.)

Last Calibration Ck @ FSV 6/23/84

Summary of Robot Measurement Accuracy - Calibration Element 8-0182

Type of Measurement	Test	SONY - L. Pot		SONY - LVDT		R. Rot - L. Pot		R. Pot - LVDT		Mean
		Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	Bias	Accuracy ± # 1σ	B ias	
Distance Across Flats	1 2	+.0007	.0031							
	Mean									
Side Face Measurements	1 2	.0007	.0006							
	Mean									
Element Length	1 2	-.004	.004							
	Mean									
Distance between Coolant Holes	1 2									
	Mean									
Coolant Hole Diameters	1 2									
	Mean									
Distance between Fiducial Hole	1 2									
	Mean									

ONLY RESULTS RECORDED

QC Stamp and Signature GA 5 QE 1/21/85