1485 (REV. 10/82) FSV80-2221 A

GA Technologies Inc.

ISSUE SUMMARY

TITLE TEST REPORT: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

☐ R&D ☒ DV&S ☐ DESIGN

APPROVAL LEVEL 2

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
N	18	RTE	7400	907057	A

QUALITY ASSURANCE LEVEL	SAFETY CLASSIFICATION	SEISMIC CATEGORY	ELECTRICAL CLASSIFICATION
I	SC-1	CAT-I	N/A

ISSUE	DATE	PREPARED BY	APPROVAL: ENGINEERING	APPROVAL: QA	APPROVAL: FUNDING PROJECT	APPROVAL: APPLICABLE PROJECT	ISSUE DESCRIPTION/ CWBS NO.
A	SEP 23 1983	R.J. Price R.J.Price 9/9/83	G.B. Engle R.J.Price for G.B.E. 9/9/83	D.S. Brush DJ Brush 9/7/83			Initial Release 7415020206.

RELEASED

CONTINUE ON GA FORM 1485-1

NEXT INDENTURED DOCUMENTS
906770

NON-CONTROLLED COPY
VERIFY ISSUE STATUS
WITH DOCUMENT CONTROL
PRIOR TO USE

REV																											
SH																											
REV																											
SH	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
REV																											
SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

Notations in this column indicate where changes have been made

TABLE OF CONTENTS

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

LIST OF TABLES

LIST OF FIGURES

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

Notations in this column indicate where changes have been made

1. INTRODUCTION

As a part of the destructive examination of the cracked Fort St. Vrain Fuel Element 1-2415 [1], tensile tests were performed on coupon specimens machined from the graphite block after the fuel had been removed in the hot cell. Tests were also performed on companion specimens of unirradiated H-327 graphite as a check on the machining and test techniques. The test results are given in this report.

2. MATERIAL

2.1 Unirradiated Companion Material

Unirradiated companion specimens were machined from Great Lakes Carbon Corp. grade H-327 graphite, billet number 6484-136, manufactured lot number 56, piece number 5612. Specimens were taken about 1 inch from the edge of a 6 inch deep slab cut perpendicular to the billet axis at the midlength location. Specimens with even identification numbers were oriented axially, and specimens with odd identification numbers were oriented transverse to the billet axis.

2.2 Irradiated Material

Fort St. Vrain fuel element 1-2415, made from H-327 graphite, was found to have a hairline crack running axially down the center of one of its hexagonal faces when it was removed from the reactor in April 1982. The accumulated fast fluence was approximately 1.55×10^{21} n/cm^2 (E > 0.18 MeV, HTGR) and the time- and volume-averaged temperature was 650°C [1]. After removal of the fuel in the GA Hot Cell, the element was section as shown in Figure 1. The 6 inch deep section whose faces were located 8 in. and 14 in. above the bottom of the element was used for the tensile specimens. The hexagonal faces of the section were identified as shown in Figure 1; the cracked face was designated B.

A slab of graphite approximately 0.44-in. thick was cut adjacent to each of the six faces and cores were taken as shown in Figure 2. The small diameter cores measured 0.270 in. diameter x 4 in. long, and the large diameter core measured 0.40-in. diameter x 0.44-in. long. Several of the small diameter transverse cores broke during coring, as indicated on Figure 2, and additional cores were taken so that four full length transverse cores and four full length axial cores were available from each face. The cores were machined into test specimens as shown in Table 1, using a lathe enclosed in a glove box. The specimens were identified by the core number followed by A, B, or C, with the A cores being

taken from the sawn surface of the slab. The specimens for thermal property measurements were held for later tests, and the tensile specimens were tested as described below.

3. TEST METHOD

The specimens were cemented between aluminum end pieces using alignment fixtures and mounted in an Instron testing machine. Chain linkage were used to apply the load. Two 0.5-in. gauge length extensometers were clipped onto opposite sides of the specimen. A glove box enclosure exhausted through an absolute filter was used. The stress on the specimen was increased to 1000 psi, reduced to 100 psi, and then increased until the specimen fractured. The extensometer and load cell signals were processed by a MINI 11 laboratory computer which calculated the ultimate tensile strength, Young's modulus over the 100 psi to 1000 psi reloading part of the curve, and the fracture strain. Further details of the test method appear in Ref. 2.

4. RESULTS

4.1 Unirradiated Specimens

The test results for the unirradiated companion specimens are shown in Table 2 (a and b). The mean tensile strength of 19.5 MPa (axial) and 10.3 MPa (transverse) are about 17% higher than the nominal strengths for H-327 graphite (midlength edge location) given the Graphite Design Data Manual [3]. The mean Young's moduli (13.2 MPa axial and 5.1 MPa transverse) are 9% and 13%, respectively, higher than the nominal handbook values. These small differences are within the normal log-to-log scatter for H-327 graphite.

4.2 Irradiated Specimens

The test results for the irradiated specimens taken from Fuel Element 1-2415 are shown in Table 3 (a-f). The data are summarized in Table 4. The handbook values are the mean of the unirradiated midlength-edge and end-edge properties given in Ref. 3, multiplied by factors of 1.93 for Young's modulus, 1.55 for the axial tensile strength, and 1.30 for the radial tensile strength. These factors allow for the stiffening and strengthening effects of a neutron fluence of 1.55×10^{21} n/cm^2 at 650°C [3]. The tensile strength data are plotted for each face of the block in Figure 3, and the Young's modulus data are plotted in Figure 4. There is no systematic face-to-face trend in property values. Data from the cracked face B fall in about the center of the band in all cases. Furthermore, the measured values are in good agreement with the values given in the Graphite Design Data Manual.

Notations in this column indicate where changes have been made

5. SUMMARY AND CONCLUSIONS

As part of the destructive examination of Fort St. Vrain fuel element 1-2415, tensile tests in both axial and transverse directions were performed on coupon specimens machined from the block. There was no systematic variation in either tensile strength and Young's modulus between material from the six hexagonal faces. The measured property values were in good agreement with the Graphite Design Data Manual. Thus, there is no evidence that the material near the cracked face B was abnormally weak, or that fuel element 1-2415 had properties different from the general population of H-327 graphite billets.

6. REFERENCES

[1] F. McCord, "Test Procedure for the Destructive Examination of Fort St. Vrain Fuel Element 1-2415," Document No. 906770, Issue A (Feb. 25, 1983).

[2] "Test Method: Tensile Properties of Graphite." Document No. 904252, Issue A (Sept. 12, 1979).

[3] Graphite Design Data Manual, Document No. 906374, Issue 1 (May 19, 1983).

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

Table 1. Test Specimens Machined from Fuel Element 1-2415

Type of Test	Specimen Diameter (in.)	Specimen Length (in.)	Orientation	Number of Specimens per Face
Tensile	0.25	1.25	Axial	6
Tensile	0.25	1.25	Transverse	6
Thermal Expansivity	0.25	1.00	Axial	3
Thermal Expansivity	0.25	1.00	Transverse	3
Thermal Diffusivity	0.40	0.10	Radial	3

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Notations in this column indicate where changes have been made

Table 2(a)

TENSILE PROPERTIES OF UNIRRADIATED H-327 GRAPHITE

OREINTATION--AXIAL LOCATION--MLE

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
6484-136-	4A	20.0189	14 1412	.209049
6484-136-	4B	21.8558	14.4721	.22485
6484-136-	6A	20.1744	14.541	.204025
6484-136-	6B	19.8328	13.2793	.226434
6484-136-	8A	20.0868	11.8728	.262964
6484-136-	8B	18.2153	13.6516	.183056
6484-136-	8C	21.115	13.1483	.240143
6484-136	10B	19.5545	13.8636	.231916
6484-136	12A	18.8799	12.068	.212472
6484-136	12B	19.1816	12.2803	.245149
6484-136	14A	16.0547	12.9771	.165259
6484-136	14B	18.4784	11.8074	.242569
	MEAN -	19.454	13.1752	.220657
	STD. DEV.-	1.48831	.992045	.0276151

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

Notations in this column indicate where changes have been made

Table 2(b)

TENSILE PROPERTIES OF UNIRRADIATED H-327 GRAPHITE

OREINTATION--RADIAL LOCATION--MLE

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
6484-136	1A	10.1486	5.0056	.262183
6484-136-	1B	8.78889	5.26553	.201887
6484-136-	3A	10.2851	4.76083	.23226
6484-136-	3B	9.11611	5.63991	.226764
6484-136-	5A	10.2466	4.74704	.282838
6484-136-	5B	11.0578	5.32069	.275014
6484-136-	7A	10.8582	5.60889	.273386
6484-136-	7B	9.21512	4.44023	.272313
6484-136-	7C	9.44617	4.81254	.245948
6484-136	9A	9.79121	4.9273	.233485
6484-136	9B	12.4144	5.16982	.361324
6484-136	11A	10.6829	5.4128	.282394
6484-136	11B	11.1707	4.8659	.309738
6484-136	13A	11.4563	5.66474	.310042
6484-136	13B	10.0838	4.74008	.307536
	MEAN -	10.3175	5.09213	.271808
	STD. DEV.-	.982589	.380594	.040663

Notations in this column indicate where changes have been made

Table 3(a)

TENSILE PROPERTIES OF IRRADIATED H-327 GRAPHITE

OREINTATION--AXIAL LOCATION--A

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	2A	24.4069	21.7676	.12724
1-2415	2B	26.8594	22.2542	.152931
1-2415	4A	23.7426	19.2478	.147947
1-2415	4B	24.1272	17.535	.126846
1-2415	6A	24.3219	17.7113	.134686
1-2415	6B	23.6499	16.7272	.146269
	MEAN -	24.518	19.2072	.13932
	STD. DEV.-	1.18664	2.3249	.0112332

OREINTATION--AXIAL LOCATION--B

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	2A	24.6017	15.9591	.133313
1-2415	2B	22.9112	16.1096	.142872
1-2415	4A	21.9886	18.9884	.133482
1-2415	4B	23.3126	21.2437	.133069
1-2415	6A	26.4886	20.1634	.159527
1-2415	6B	25.7015	23.0018	.13967
	MEAN -	24.1674	19.2444	.140322
	STD. DEV.-	1.7312	2.81587	.0102397

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

Notations in this column indicate where changes have been made

Table 3(b)

TENSILE PROPERTIES OF IRRADIATED H-327 GRAPHITE

OREINTATION--AXIAL LOCATION--C

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	8A	22.2162	19.5733	.124686
1-2415	2B	22.8262	17.0391	.154669
1-2415	4A	23.2825	21.1071	.12268
1-2415	4B	21.3045	19.0565	.122834
1-2415	6A	22.2937	19.3451	.129177
1-2415	6B	23.2304	20.639	.13548
	MEAN -	22.5256	19.46	.131588
	STD. DEV.-	.748371	1.42498	.0123071

OREINTATION--AXIAL LOCATION--D

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	2A	22.2086	17.9031	.135371
1-2415	2B	20.9293	20.6709	.117263
1-2415	4A	20.8551	21.3614	.107408
1-2415	4B	22.6955	20.5435	.118113
1-2415	6A	24.1655	22.7706	.128064
1-2415	8A	22.1456	19.2234	.231266
	MEAN -	22.1666	20.4122	.139581
	STD. DEV.-	1.22708	1.68857	.0459358

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Table 3(c)

TENSILE PROPERTIES OF IRRADIATED H-327 GRAPHITE

OREINTATION--AXIAL LOCATION--E

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	2A	26.4924	22.6485	.137974
1-2415	2B	25.7052	21.2453	.141422
1-2415	4A	23.1157	20.8749	.118351
1-2415	4B	27.4565	21.657	.147115
1-2415	6A	24.8276	24.631	.111315
1-2415	8A	22.9728	20.489	.131214
	MEAN -	25.095	21.9244	.131232
	STD. DEV.-	1.81079	1.51942	.0138865

OREINTATION--AXIAL LOCATION--F

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	2A	22.9659	22.9062	.126203
1-2415	2B	21.4681	20.7642	.118723
1-2415	4A	26.6497	16.8403	.161692
1-2415	4B	18.9052	21.6348	.108402
1-2415	6A	21.1616	23.3944	.11322
1-2415	6B	23.8749	20.9881	.129292
	MEAN -	22.5042	21.088	.126255
	STD. DEV.-	2.64971	2.32731	.0190284
	OVERALL MEAN -	23.4962	20.2227	.134717
	OVERALL STD. DEV.-	1.9290	2.1857	.021548

Notations in this column indicate where changes have been made

Table 3(d)

TENSILE PROPERTIES OF IRRADIATED H-327 GRAPHITE

OREINTATION--TRANSVERSE LOCATION--A

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	1A	9.2857	7.93721	.112458
1-2415	1B	11.0073	7.66576	.169076
1-2415	7A	12.7421	7.59403	.196043
1-2415	7A	11.4003	7.92561	.165746
1-2415	9A	10.5606	8.30074	.147659
1-2415	9B	12.2288	7.21106	.189278
	MEAN -	11.2041	7.7724	.163377
	STD. DEV.-	1.23181	.37095	.0303836

OREINTATION--TRANSVERSE LOCATION--B

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	1A	8.88635	8.51609	.115529
1-2415	1B	12.1151	7.69831	.182041
1-2415	3A	11.8946	8.51065	.160248
1-2415	3B	13.0714	7.58388	.198502
1-2415	7A	14.1619	8.10343	.203983
1-2415	7B	12.4116	8.99743	.166588
	MEAN -	12.0902	8.23497	.171982
	STD. DEV.-	1.76983	.541396	.0332484

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Table 3(e)

TENSILE PROPERTIES OF IRRADIATED H-327 GRAPHITE

OREINTATION--TRANSVERSE LOCATION--C

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	1A	14.0114	9.53675	.160396
1-2415	1B	14.0002	8.77258	.177843
1-2415	3A	15.1607	8.78818	.210088
1-2415	3B	13.2439	8.48645	.182357
1-2415	5A	14.7816	8.64084	.199035
1-2415	5B	9.08823	8.94309	.17995
	MEAN -	13.381	8.86131	.184945
	STD. DEV.-	2.20712	.364761	.0174095

OREINTATION--TRANSVERSE LOCATION--D

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	1A	12.0504	8.56207	.158447
1-2415	3B	8.2404	7.92974	.0969362
1-2415	5A	11.3146	8.46677	.142726
1-2415	5B	12.9649	8.30199	.192079
1-2415	7A	12.425	7.71043	.188924
1-2415	7B	11.694	8.06893	.158921
	MEAN -	11.4482	8.17332	.156339
	STD. DEV.-	1.67246	.328116	.0348259

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

Notations in this column indicate where changes have been made

Table 3(f)

TENSILE PROPERTIES OF IRRADIATED H-327 GRAPHITE

OREINTATION--TRANSVERSE LOCATION--E

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	1A	13.9167	8.92454	.185836
1-2415	1B	12.1287	8.53567	.178462
1-2415	3A	7.20397	7.09947	.100369
1-2415	3B	12.577	8.32427	.131553
1-2415	5A	11.2562	7.48047	.172757
1-2415	5B	10.1736	7.91046	.134257
	MEAN -	11.2094	8.04581	.150539
	STD. DEV.-	2.33081	.681642	.0336504

OREINTATION--TRANSVERSE LOCATION--F

BILLET NO.	SPECIMEN NO.	TENSILE STRENGTH(MPa)	YOUNG'S MODULUS (GPa)	FRACTURE STRAIN (%)
1-2415	5A	15.2905	9.31854	.198197
1-2415	5B	12.7525	8.2764	.180043
1-2415	7A	10.3877	8.83729	.12623
1-2415	3A	13.5747	8.55807	.178736
1-2415	3B	15.7659	8.8322	.214284
1-2415	3C	11.7079	7.80718	.166459
	MEAN -	13.2465	8.60495	.177325
	STD. DEV.-	2.06964	.521802	.0301322
	OVERALL MEAN -	12.0966	8.2821	.167418
	OVERALL STD. DEV.-	2.0000	0.5775	.030715

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Notations in this column indicate where changes have been made

Table 4. Tensile Properties of Coupon Specimens from Fort St. Vrain Fuel Element 1-2415 (H-327) Graphite

Orientation	Face	Tensile Strength, MPa (± std. dev.)	Young's Modulus, GPa (± std. dev.)
Axial	A	24.5 ± 1.2	19.2 ± 2.3
	B	24.2 ± 1.7	19.2 ± 2.8
	C	22.5 ± 0.7	19.5 ± 1.4
	D	22.2 ± 1.2	20.4 ± 1.7
	E	25.1 ± 1.8	21.9 ± 1.5
	F	22.5 ± 2.6	21.2 ± 2.3
	All faces	23.5 ± 1.9	20.2 ± 2.2
Handbook value		25.2 ± 2.6	23.0 ± 7.9
Transverse	A	11.2 ± 1.2	7.8 ± 0.4
	B	12.1 ± 1.8	8.2 ± 0.5
	C	13.4 ± 2.2	8.9 ± 0.4
	D	11.4 ± 1.7	8.1 ± 0.3
	E	11.2 ± 2.3	8.0 ± 0.7
	F	13.2 ± 2.1	8.6 ± 0.5
	All faces	12.1 ± 2.0	8.3 ± 0.6
Handbook value		12.1 ± 1.3	8.8 ± 2.6

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

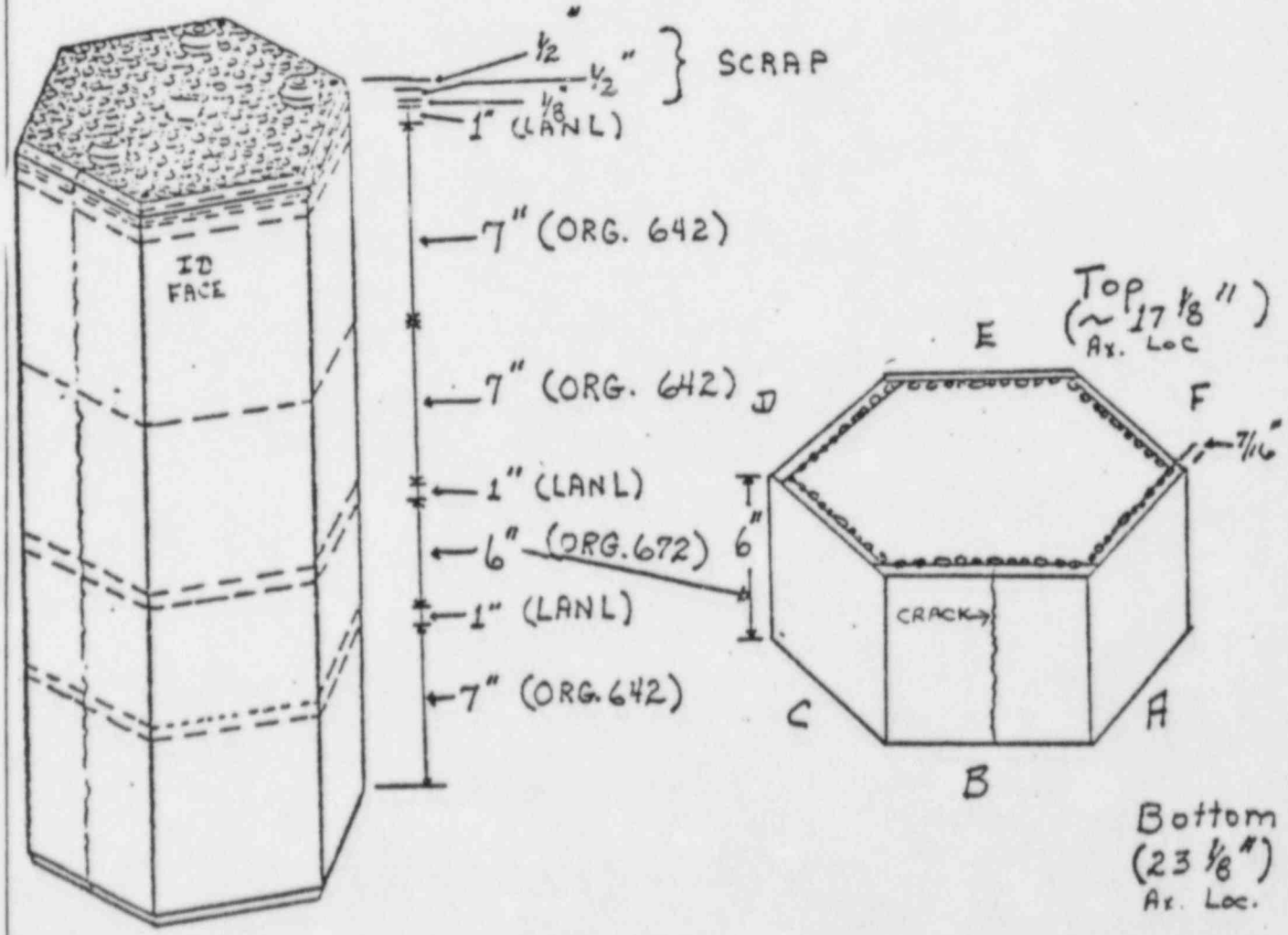
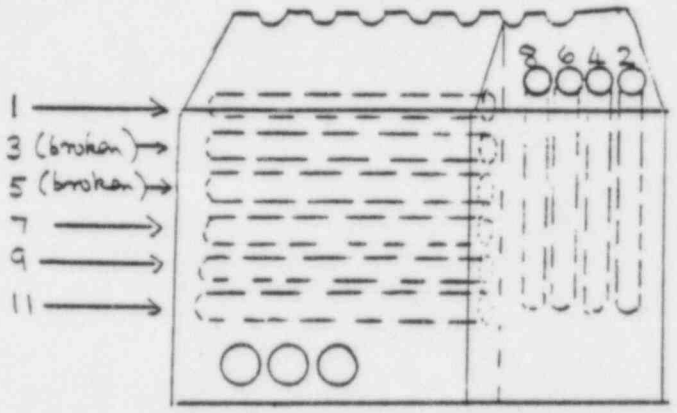


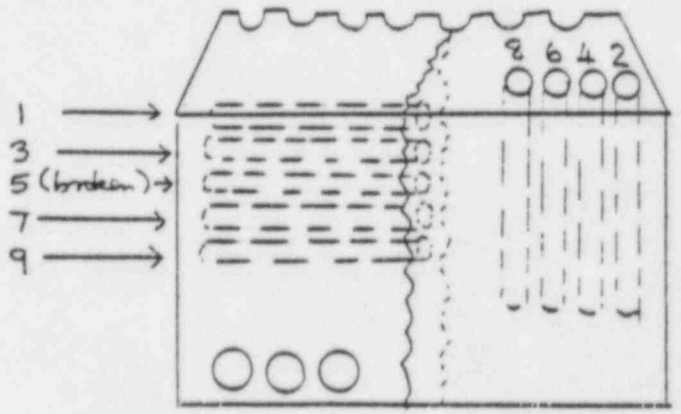
Figure 1. Sectioning of FSV S/N: 1-2415

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

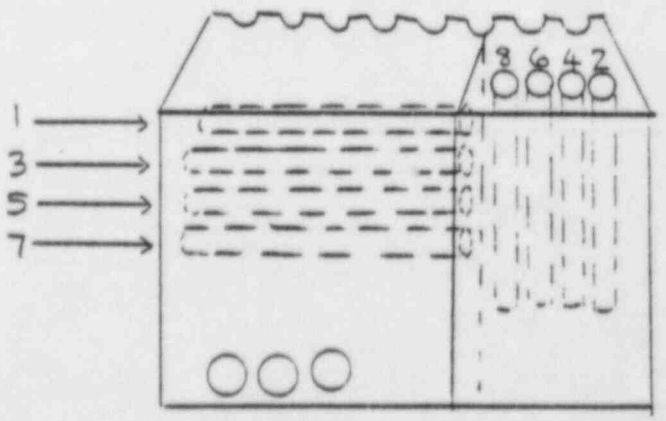
Document No. 907057 | Issue A



FACE A



FACE B (CRACKED)



FACE C

Figure 2(a). Coring Plan - Faces A, B, and C

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

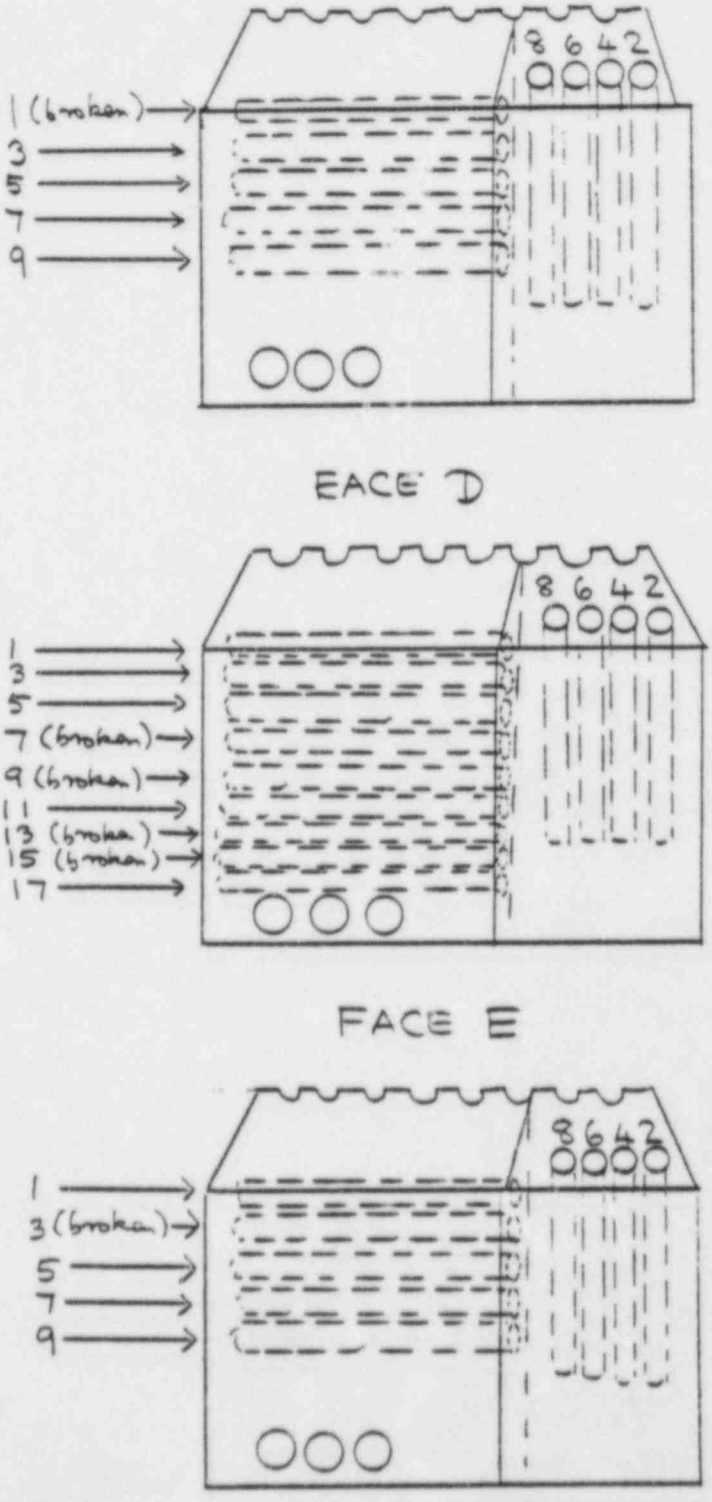


Figure 2(b). Coring Plan - Faces E, E, and F

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

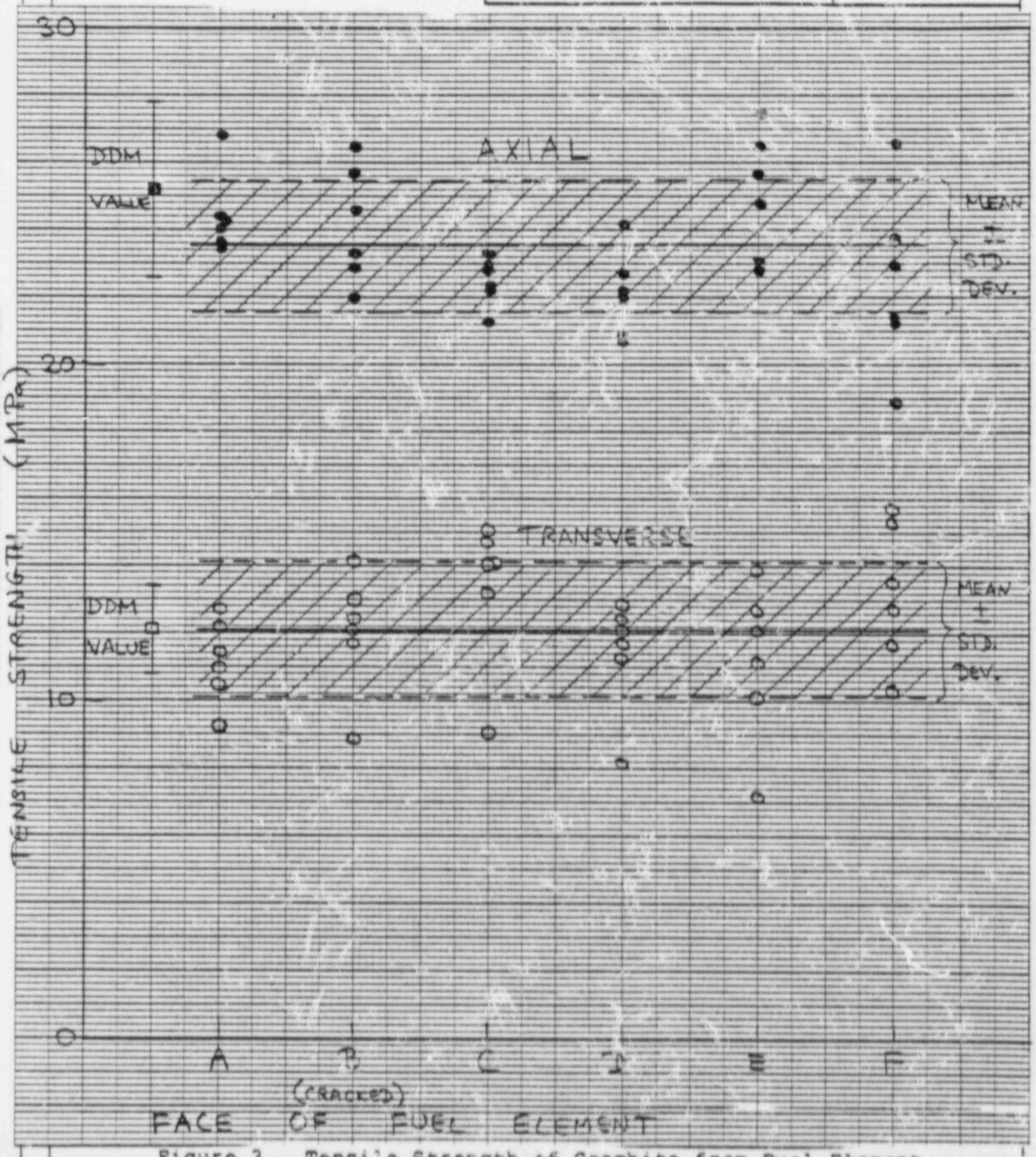


Figure 3. Tensile Strength of Graphite from Fuel Element 1-2415 for Each Face of the Block

Notations in this column indicate where changes have been made

TITLE: TENSILE PROPERTIES OF FORT ST. VRAIN FUEL ELEMENT 1-2415

Document No. 907057 | Issue A

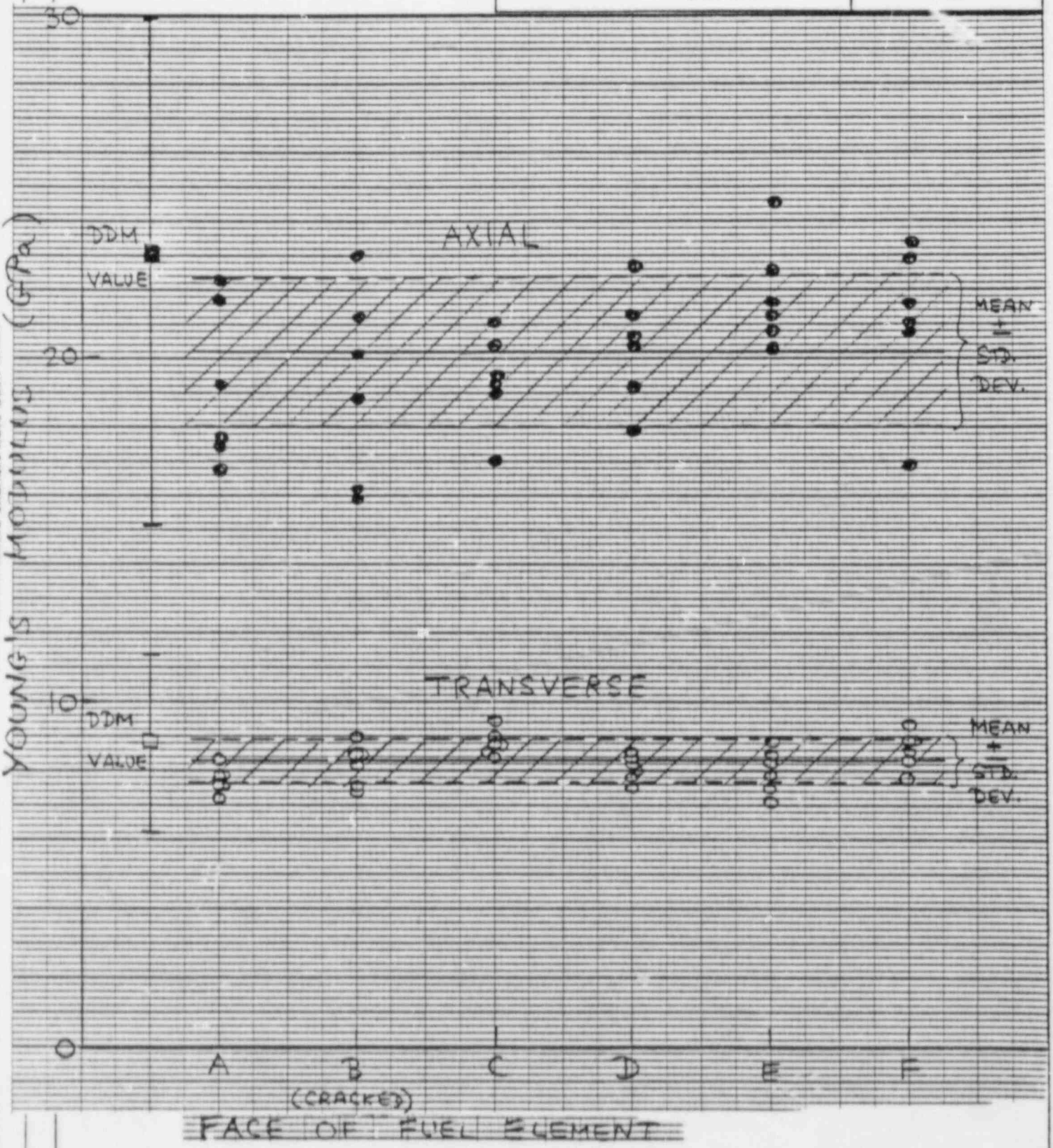


Figure 4. Young's Modulus of Graphite from Fuel Element 1-2415 for Each Face of the Block