~~Proprietary Class 2~~

WCAP 7323

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CONSOLIDATED EDISON CO.
INDIAN POINT UNIT NO. 2 REACTOR VESSEL
RADIATION SURVEILLANCE PROGRAM

By

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May 1969

IPP 106

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ABSTRACT

A pressure vessel steel surveillance program was developed for the Consolidated Edison Company, Indian Point Unit No. 2 nuclear reactor to obtain information on the effects of radiation under reactor operating conditions. A description of the program including the material to be tested, specimen and capsule design, and pre-irradiation test results are presented.

SECTION 1

PURPOSE AND SCOPE

The purpose and scope of this program is to obtain information on the effect of radiation on the reactor vessel materials under actual operating conditions of Consolidated Edison Company, Indian Point Plant Unit No. 2. It is known that radiation can produce shifts to higher temperatures for the ductile-to-brittle "transition" temperature.[1,2] The transition temperature increase with service can be monitored by a surveillance program which consists of periodically checking irradiated reactor vessel surveillance specimens. The nil-ductility transition temperature (NDTT) is defined as the temperature at which a drop weight test specimen is broken in a series of tests in which duplicate no-break performance occurs at a temperature 10°F higher (from ASTM E208; Drop Weight Test to Determine Nil-Ductility-Transition Temperature of Ferritic Steels). The NDTT has been correlated with Charpy V-notch impact tests results; for SA302 Grade B modified steel, the Charpy V-notch "fix" temperature which corresponds to the NDTT is the temperature at 30 ft-lbs.[3] This relationship has been listed in the PB Document 151987 and Section III of the ASME Code for Nuclear Vessels.

The Surveillance program is based on ASTM E185 (Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors). In addition to the transition temperature approach, a fracture mechanics approach utilizing Wedge Opening Loading (WOL) specimens will be used to evaluate the effects of radiation on the fracture toughness of the reactor vessel materials.[4,5,6,7,8,9,10]

Post-irradiation testing of the Charpy impact specimens will provide a guide for determining pressure-temperature limits of the plant considering the presently used conservative margin of NDT temperature concepts.

Charpy impact test data will provide a temperature shift of the NDT temperature with radiation exposure at the plant temperatures since the Charpy specimens are most nearly indicative of the radiation exposure experienced by the vessel, these data can be reviewed to verify or establish new pressure-temperature limits of the vessel during startup and cooldown. This will allow a check of the predicted shift in the NDT temperature. The post-irradiation test results on the WOL specimens will provide allowable stress values considering defect size and temperature and are expected to allow safe relaxation of startup and operating restrictions currently used to prevent brittle fracture of reactor pressure vessels. The present ASME Codes require specific allowable stresses in the design of reactor pressure vessels. These allowable stresses are based on safety factors of three or four, depending on the code. In the case of designing against brittle fracture, the present transition temperature approach does not have a specified safety factor in the conventional sense based on stresses. The transition temperature approach provides a safety factor based on temperature differences. The fracture mechanics approach will provide an allowable stress criterion with engineering safety factors.

Eight materials test capsules will be placed in the Indian Point Plant (IPP) reactor. The capsules will be located between the thermal shield and the vessel wall, opposite the center of the core. The test capsules will be contained in baskets attached to the thermal shield. The capsules will contain samples of SA302B modified (SA533 Grade B Class 1) reactor vessel steel from three 9-5/8 inch thick shell plates from the IPP reactor vessel intermediate shell course adjacent to the core region, and also weld metal and heat affected zone (HAZ) metal. The thermal history or heat treatment given these plates is identical to the thermal history of the IPP reactor vessel material, with the exception of the stress relieving treatment which simulates the stress relieving treatment received by the reactor vessel. In addition, correlation monitors made from fully documented specimens of SA302 Grade B material obtained through Subcommittee II of ASTM Committee E10 on Radioisotopes and Radiation Effects will be inserted in the capsules. This material was made available by the U. S. Steel Corporation. Data on the SA302 Grade B steel used for the correlation monitors have been summarized in a report on surveillance tests.[11]

The eight material test capsules will contain Charpy V-notch impact specimens, tensile specimens and WOL specimens from the three intermediate shell plates of the IPP reactor vessel and associated weld metal, Charpy V-notch impact specimens of HAZ metal, and the U. S. Steel correlation monitor material. Dosimeters to measure the integrated neutron flux and thermal monitors to measure temperature will also be contained in each of the eight material test capsules.

SECTION 2

SAMPLE PREPARATION

2.1 PRESSURE VESSEL MATERIAL

The A533 Grade B IPP reactor vessel material was supplied by Combustion Engineering from the three intermediate shell plates. A weldment which joined plates B2002-1 and B2002-3 was also supplied by Combustion Engineering Inc. Data on the IPP pressure vessel plates are presented in Appendix A.

2.2 CORRELATION MONITOR MATERIAL

The SA302 Grade B material for the correlation monitors was supplied by the U. S. Steel Corporation from 6-inch-thick plate. Data on the correlation monitor material are presented in Appendix B.

2.3 MACHINING

Plate material was obtained from an end of each shell plate after thermal heat treatment and prior to welding the three plates together to form the intermediate shell course. All test specimens were machined from the 1/4 thickness location of the plate after stress relieving. The test specimens represent material taken at least one plate thickness (9-5/8 in.) from the quenched edges of the plates. Specimens were machined from weld metal and heat affected zone metal from plate B2002-3 of a stress-relieved weldment joining plates B2002-1 and B2002-3.

2.3.1 Charpy V-notch Impact Specimens (Figure 1)

The base line of the notch of the Charpy V-notch impact specimens was machined perpendicular to the major surfaces of the plate. The longitudinal axis of the specimen was parallel to the rolling direction of the plate.

2.3.2 Tensile Specimens (Figure 2 - Item 2)

All tensile specimens were machined with the rolling direction of the plate parallel to the longitudinal axis of the specimen.

2.3.3 Wedge Opening Loading Specimen (Figure 3 - Item 1)

All WOL test specimens were machined with the simulated crack of the specimen perpendicular to the rolling direction and the major surfaces of the plant.

2.4 DOSIMETERS

Five Type I capsules (shown in Figure 4) will contain dosimeters of copper, nickel and aluminum-cobalt wire (0.15% Co, cadmium shielded and unshielded). The test specimens will serve as iron dosimeters. Three Type II capsules (shown in Figure 5) will contain dosimeters of copper, pure nickel wire, aluminum-cobalt wire (cadmium shielded and unshielded), Np-237 and U-238. The test specimens will also serve as iron dosimeters. The dosimeters will be used to measure the integrated flux at specific neutron energy levels.

2.5 THERMAL MONITORS

The capsules will contain two low melting point eutectic alloys to define more accurately the temperature attained by the test specimens during irradiation. The thermal monitors will be sealed in Pyrex tubes and then inserted in spacers located as shown in Figures 4 and 5. The two eutectic alloys and their melting points are:

2.5 Ag, 97.5 Pb	Melting Point 579°F
1.75 Ag, 0.75 Sn, 97.5 Pb	Melting Point 590°F

2.6 CAPSULE LOADING

The five Type I and three Type II capsules will be loaded with test specimens as shown in Figures 4 and 5, respectively, and will be located in the reactor between the thermal shield and the vessel wall.

Each Type I capsule will contain thirty-two Charpy V-notch specimens; eight Charpy specimens machined from each of the three IPP vessel plates. The remaining eight Charpy specimens will be machined from correlation monitor material. In addition, each Type I capsule will contain three tensile specimens (one specimen from each of the three IPP plates) and six WOL specimens (two specimens from each of the three plates). Dosimeters of copper, nickel, Al-Co and Cd-shielded Al-Co wire will be secured in holes drilled in specers at the top, middle and bottom of each Type I capsule, as shown in Figure 4.

Each Type II capsule will contain thirty-two Charpy V-notch specimens; eight specimens will be machined from one of the IPP plates, eight specimens of weld metal, eight specimens of HAZ metal and the remaining eight specimens will be correlation monitors. In addition, each Type II capsule will contain four tensile specimens and four WOL specimens; two tensile specimens and two WOL specimens from each one of the IPP plates and the weld metal. Each type II capsule will contain a dosimeter block (Figure 6) at the center of the capsule. Two cadmium oxide shielded capsules, one containing each of the two isotopes U-238 and Np-237 will be contained in the dosimeter block along with wires of Co-Al (cadmium shielded and unshielded) and nickel. The double containment afforded by the dosimeter assembly prevent loss and contamination by the Np-237 and U-238 and their activation products. Each dosimeter block will contain approximately 20 milligrams of Np-237 and 13 milligrams of U-238 contained in a 3/8-inch OD sealed brass tube. Each tube will be placed in a 1/2-inch diameter hole in the dosimeter block (one Np-237 and one U-238 tube per block), and the space around the tube will be filled with cadmium oxide. After placement of this material, each hole will be blocked with two 1/16-inch aluminum spacer discs and an outer 1/8-inch steel cover disc which will be welded in place. Dosimeters of copper, nickel, aluminum-cobalt and cadmium-shielded aluminum-cobalt will also be secured in holes drilled in spacers located at the top and bottom of each Type II capsule as shown in in Figure 5.

The specimen numbering system and location in the Type I and Type II capsules is shown in Tables 1 and 2 respectively.

2.7 SPECIMEN CAPSULE

To prevent corrosion of the surface of the specimen during radiation, the specimens will be seal-welded into a square austenitic stainless steel capsule. The capsules will be hydrostatically tested in demineralized water to collapse the can on the specimens to provide optimum thermal conductivity between the specimens and the reactor coolant. The capsules will be helium leak tested as a final inspection procedure. Fabrication details and testing procedures are listed in Figures 4 and 5.

SECTION 3

PRE-IRRADIATION TESTING

3.1 IMPACT TESTS

Charpy V-notch impact tests were performed on the IPP plates at various temperatures from -40 to +210°F to obtain a full Charpy V-notch transition curve (Tables 3 and Figures 7, 8 and 9). Charpy V-notch impact tests were performed on weld metal and HAZ metal at various temperatures from -190 to +210°F. The results are reported in Tables 4 and 5 and Figures 10 and 11, respectively. The Charpy V-notch impact data for the correlation monitor material are shown in Table 6 and Figure 12.

3.2 TENSILE TESTS

Tensile tests were performed on each IPP plate and the weld metal at room temperature, 200°, 400° and 600°F. The results are shown in Table 7 and Figures 13 through 16.

3.3 WEDGE OPENING LOADING

WOL tests were performed on each of the IPP plates and the weld metal at various temperatures using the 1X WOL shown in Figure 3 and the "T" Type WOL shown in Figure 17. The fracture toughness stress intensity factor (K_{IC}) versus temperature was determined for each plate and is shown in Table 8 through 11. The fracture toughness test procedure is described in Appendix C.

SECTION 4

POST-IRRADIATION TESTING

Specimen capsules will be removed from the reactor only during normal refueling periods. The recommended schedule for removal of capsules is as follows:

Capsule Type	Capsule Identification	Exposure Time
I	T	(Replacement of 1st Region)
II	S	(Replacement of 2nd Region)
I	Z	(Replacement of 4th Region)
II	V	10 years
I	U	Extra capsules for complementary testing or additional exposure
I	W	
I	X	
II	Y	

Each specimen capsule upon removal after radiation exposure will be transferred to a post-irradiation test facility for disassembly of the capsule and testing of all specimens.

4.1 CHARPY V-NOTCH IMPACT TESTS

The testing of the eight Charpy impact specimens from each of the IPP vessel plates, the weld and HAZ metal, and the correlation monitor material in the capsules can be done singulary, making possible the performance of Charpy impact tests at five different temperatures, with three extra specimens to provide an optimum curve for each plate. The initial Charpy specimen from the first capsule removed should be tested at room temperature. The impact energy value for this test temperature should be compared with pre-irradiation test data. The testing temperatures for the remaining specimen should then be appropriately raised or lowered. The test temperatures of specimens from capsules exposed to longer irradiation periods should be determined by the test results for the previous capsule.

4.2 TENSILE TESTS

The two tensile specimens per plate or weld from each of the capsules should be tested at room temperature and the approximate operating temperature of the reactor (550°F).

4.3 WEDGE OPENING LOADING TESTS

The WOL specimens from each individual capsule should be tested at a temperature based on the transition temperature shift obtained from the associated Charpy impact specimens. A mean temperature of -200 °F plus the transition temperature shift should be the initial test temperature.

4.4 POST-IRRADIATION TEST EQUIPMENT

1. Milling machine or special cut-off wheel for opening capsules and dosimeter blocks.
2. Hot-cell tensile testing machine with:
   a. pin-type adapter for pulling tensile tests
   b. clevis and extensometer for pulling WOL specimens.
3. Hot-cell Charpy impact testing machine.
4. NaI scintillation detector and pulse height analyzer for gamma counting of the specific activities of the dosimeters.

SECTION 5

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11. Landerman, E., "Surveillance Tests on Structural Materials in Nuclear Reactors," STP 341, ASTM, Synposium on Radiation Effects on Metals and Neutron Dosimetry, 1963.

APPENDIX A

INDIAN POINT UNIT NO. 2 PRESSURE VESSEL PLATES

Combustion Engineering, Inc., furnished sections from three hot-formed 9 5/8-inch-thick plates (B2002-1, B2002-2 and B2002-3) of SA 302 Grade B modified steel, and a weldment joining two formed plates (B2002-1 and B2002-3) used in the fabrication of the Indian Point Unit No. 2 reactor pressure vessel intermediate shell course. These plates were produced by the Lukens Steel Company.

a. Chemical Analyses (Percent)

Plate No.	Lukens Heat No.	C	Mn	P	S	Si	Ni	Mo
B2002-1	B4688-2	0.20	1.28	0.010	0.019	0.25	0.58	0.46
B2002-2	B4701-2	0.22	1.30	0.014	0.020	0.22	0.46	0.50
B2002-3	B4922-1	0.22	1.29	0.011	0.018	0.25	0.57	0.46

b. Heat Treatment

The sections of formed shell plate material were heat treated by Combustion Engineering as follows:

1550°- 1650°F, 4 hours, Water Quenched
1225° ± 25°F, 4 hours, Air Cooled
1150° ± 25°F, 40 hours, Furnace Cooled to 600°F

The weldment was stress-relieved by Westinghouse as follows:

1150° ± 25°F, 19 3/4 hours; Furnace Cooled to 600°F

APPENDIX B

U. S. STEEL CORPORATION CORRELATION MONITOR MATERIAL

The correlation monitor material SA302 Grade B was furnished by the U. S. Steel Corporation through Subcommittee II of ASTM Committee E10 on Radioisotopes and Radiation Effects. The specimens were machined from a 96-inch-wide by 72-inch-long by 6-inch-thick plate which was melted using a fine-grain practice and a transverse-to-longitudinal rolling ratio of one to one.

a. Chemical Analysis (Percent)

C	Mn	P	S	Mo	Si
0.24	1.34	0.011	0.023	0.51	0.23

b. Heat Treatment

The U. S. Steel material was heat-treated at the U. S. Steel Homestead District Works as follows:

The six-inch-thick plate was charged into a furnace operating at 1100°F, heated at a maximum rate of 63°F per hour to 1650°F, held at temperature for four hours, and water quenched to 300°F. The plate was then recharged into a furnace operating at 700 to 750°F and heated at a maximum rate of 63°F per hour to 1200°F for 6 hours.

APPENDIX C

FRACTURE TOUGHNESS TESTING

Fracture toughness test procedure involves the tension testing of notched specimens which have been precracked in fatigue. Load versus displacement change across the notch is recorded on an autographic recorder. The load corresponding to a prescribed increment of crack extension is established by the occurence of a displacement step in the load-displacement record, or in the absence of such a step, by a specified deviation from the linear portion of the record. The K_{IC} value is calculated from this load by an equation (see Tables 12 and 13) which has been established on the basis of elastic stress analysis of fracture mechanics specimens. The accuracy of the determination of K_{IC} values by this practice depends upon the establishement of a "sharp crack" condition at the tip of the fatigue crack. To establish a suitable crack tip condition, the stress intensity level at which the fatigue pre-cracking was conducted, was limited to a relatively low level. A clevis and pin grip arrangement (Figure 18) is used to load the specimen. Externally mounted conical seats for positive location and positioning of a displacement gage are required.

The displacement gage consists of two strain-gaged cantilever beams assembled as shown in Figure 19. Pivot blocks containing the conical seats are bolted to the specimen using the 4-40 threaded holes on the face of the specimen. Based on the dimensions of the pivot blocks and the dimensions of the displacement gage, the gage can measure displacements to 0.30 in. The output of the gages is approximately 0.019mv/v per 0.001 in. displacement. The precision of the gage corresponds to a maximum deviation of ± 0.001 in. of the individual displacement readings from a least-square-best-fit straight line through the data.

TABLE 1

SPECIMEN IDENTIFICATION AND LOCATION IN THE INDIAN POINT UNIT NO. 2 IRRADIATION TEST CAPSULES TYPE I

Specimen Type		Capsule T	Capsule U	Capsule W	Capsule X	Capsule Z
Charpy		3-8, R-8 1-8, 2-8	3-16, R-16 1-16, 2-16	3-24, R-24 1-24, 2-24	3-32, R-32 1-32, 2-32	3-40, R-40 1-40, 2-40
Tensile and Charpy	Top	R-7, 2-7, 3-1 3-7, 1-7, 3-1	R-15, 2-15, 3-2 3-15, 1-15, 3-2	R-23, 2-23, 3-3 3-23, 2-23, 3-3	R-31, 2-31, 3-4 3-31, 1-31, 3-4	R-39, 2-39, 3-5 3-39, 1-39, 3-5
WOL	↑	3-2	3-4	3-6	3-8	3-10
WOL		3-1	3-3	3-5	3-7	3-9
Charpy		3-6, R-6 1-6, 2-6	3-14, R-14 1-14, 2-14	3-22, R-22 1-22, 2-22	3-30, R-30 1-30, 2-30	3-38, R-38 1-38, 2-38
WOL		2-2	2-4	2-6	2-8	2-10
WOL		2-1	2-3	2-5	2-7	2-9
Charpy	Capsule	3-5, R-5 1-5, 2-5	3-13, R-13 1-13, 2-13	3-21, R-21 1-21, 2-21	3-29, R-29 1-29, 2-29	3-37, R-37 1-37, 2-37
Charpy		3-4, R-4 1-4, 2-4	3-12, R-12 1-12, 2-12	3-20, R-20 1-20, 2-20	3-28, R-28 1-28, 2-28	3-36, R-36 1-36, 2-36
WOL		1-2	1-4	1-6	1-8	1-10
WOL		1-1	1-3	1-5	1-7	1-9
Charpy	↓	3-3, R-3 1-3, 2-3	3-11, R-11 1-11, 2-11	3-19, R-19 1-19, 2-19	3-27, R-27 1-27, 2-27	3-35, R-35 1-35, 2-35
Tensile	Bottom	1-1, 2-1	1-2, 2-2	1-3, 2-3	1-4, 2-4	1-5, 2-5
Charpy		3-2, R-2 1-2, 2-2	3-10, R-10 1-10, 2-10	3-18, R-18 1-18, 2-18	3-26, R-26 1-26, 2-26	3-34, R-34 1-34, 2-34
Charpy		3-1, R-1 1-1, 2-1	3-9, R-9 1-9, 2-9	3-17, R-17 1-17, 2-17	3-25, R-25 1-25, 2-25	3-33, R-33 1-33, 2-33

Specimen Numbering Code and Orientation

1 - Plate B2002-1
2 - Plate B2002-2
3 - Plate B2002-3
R - Correlation Monitor Plate

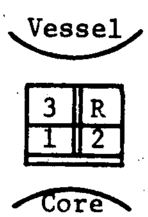


TABLE 2

SPECIMEN IDENTIFICATION AND LOCATION IN THE
INDIAN POINT UNIT NO. 2 IRRADIATION TEST CAPSULES TYPE II

Specimen Type		Capsule S	Capsule V	Capsule Y
Charpy		1-48, R-48 W-8, H-8	2-48, R-56 W-16, H-16	3-48, R-64 W-24, H-24
Charpy	Top	1-47, R-47 W-7, H-7	2-47, R-55 W-15, H-15	3-47, R-63 W-23, H-23
Tensile	↑	1-6, 1-7	2-6, 2-7	3-6, 3-7
WOL		1-12	2-12	3-12
Charpy		1-46, R-46 W-6, H-6	2-46, R-54 W-14, H-14	3-46, R-62 W-22, H-22
WOL		1-11	2-11	3-11
Charpy		1-45, R-45 W-5, H-5	2-45, R-53 W-13, H-13	3-45, R-61 W-21, H-21
Dosimeter	Capsule	23	24	25
Charpy		1-44, R-44 W-4, H-4	2-44, R-52 W-12, H-12	3-44, R-60 W-20, H-20
WOL		W-2	W-4	W-6
Charpy		1-43, R-43 W-3, H-3	2-43, R-51 W-11, H-11	3-43, R-59 W-19, H-19
WOL	↓	W-1	W-3	W-5
Tensile	Bottom	W-1, W-2	W-3, W-4	W-5, W-6
Charpy		1-42, R-42 W-2, H-2	2-42, R-50 W-10, H-10	3-42, R-58 W-18, H-18
Charpy		1-41, R-41 W-1, H-1	2-41, R-49 W-9, H-9	3-41, R-57 W-17, H-17

Specimen Numbering Code and Orientation

1 - Plate B2002-1
2 - Plate B2002-2
3 - Plate B2002-3
W - Weld Metal
H - HAZ Metal
R - Correlation Monitor Plate

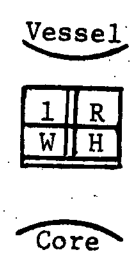


TABLE 3

PRE-IRRADIATION CHARPY V-NOTCH IMPACT DATA FOR THE INDIAN POINT UNIT NO. 2
PRESSURE VESSEL SHELL PLATE MATERIAL

	Plate B2002-1			Plate B2002-2			Plate B2002-3		
Temp, °F	Energy, Ft-lbs	Shear, %	Lateral Expansion, Mils	Energy, Ft-lbs	Shear, %	Lateral Expansion, Mils	Energy, Ft-lbs	Shear, %	Lateral Expansion, Mils
-40	10.0	10	8	6.5	10	4	6.5	10	4
40	9.0	10	6	8.0	10	6	8.0	10	5
40	8.0	10	7	7.5	10	6	6.0	10	7
-20	19.0	15	15	18.0	10	18	25.5	20	20
20	14.5	15	16	9.0	10	7	14.0	15	12
20	8.5	15	8	10.0	10	7	11.0	15	7
0	21.5	25	18	-	-	-	-	-	-
0	33.5	25	28	-	-	-	-	-	-
0	34.0	25	29	-	-	-	-	-	-
10	40.5	30	32	20.0	25	19	41.5	25	33
10	36.0	25	28	42.5	30	34	17.0	25	14
10	35.5	25	27	14.0	25	14	37.5	25	29
30	-	-	-	37.5	30	32	34.0	35	30
30	-	-	-	41.0	35	35	45.5	35	36
30	-	-	-	49.5	30	41	42.5	35	36
60	68.5	45	54	73.5	40	58	54.5	40	45
60	62.0	45	49	49.0	40	39	51.5	40	39
60	50.5	40	40	59.5	40	50	41.0	40	33
110	88.0	65	70	80.5	65	60	71.0	60	60
110	69.5	60	56	76.0	60	60	79.5	70	62
110	77.0	60	61	91.0	65	70	83.5	70	62
160	116.5	98	84	108.0	85	84	116.5	99	83
160	122.0	98	86	120.5	95	85	110.0	95	80
160	112.0	95	85	118.0	95	84	95.5	90	76
210	111.0	100	83	112.0	100	80	109.0	90	80
210	121.5	100	88	120.5	100	83	113.5	100	78
210	119.0	100	83	115.0	100	82	113.0	100	82

TABLE 4

PRE-IRRADIATION CHARPY V-NOTCH IMPACT DATA FOR THE INDIAN POINT UNIT NO. 2 PRESSURE VESSEL WELD METAL

Temp, Test °F	Energy, Ft-lbs	Shear, %	Lateral Expansion, Mils
-150	12.5	10	10
-150	10.5	15	11
-100	35.0	25	29
-100	9.0	20	9
-100	18.0	30	19
- 80	13.0	20	12
- 80	32.5	20	27
- 80	26.0	20	23
- 40	34.0	30	30
- 40	35.5	35	31
- 40	48.0	35	40
10	78.5	60	64
10	74.0	60	60
10	81.0	70	68
60	102.5	80	78
60	102.0	85	82
60	100.0	85	80
110	112.5	99	88
110	108.5	90	87
110	108.5	98	88
160	115.5	100	90
160	113.0	100	92
160	120.0	100	93
210	121.0	100	92
210	123.5	100	91
210	117.5	100	92

TABLE 5

PRE-IRRADIATION CHARPY V-NOTCH IMPACT DATA FOR THE INDIAN POINT UNIT NO. 2 PRESSURE VESSEL WELD HEAT AFFECTED ZONE METAL

Temp, °F	Energy, Ft-lbs	Shear, %	Lateral Expansion, Mils
-190	36.5	15	29
-190	13.0	5	9
-190	30.5	20	18
-140	17.0	30	16
-140	26.0	25	21
-140	35.5	30	23
-120	55.5	40	46
-120	30.0	30	25
-120	46.0	35	35
- 90	40.0	35	32
- 90	44.0	35	33
- 90	49.5	35	39
- 40	53.0	50	44
- 40	71.5	50	44
- 40	79.0	60	61
10	90.5	80	72
10	80.0	75	67
10	90.0	75	63
60	103.0	100	83
60	89.0	95	66
60	87.5	100	78
160	112.5	100	80
160	90.0	100	75
160	109.0	100	85

TABLE 6

PRE-IRRADIATION CHARPY V-NOTCH IMPACT DATA FOR
SA 302 GRADE B CORRELATION MONITOR MATERIAL (SUPPLIED BY U. S. STEEL)

Test Temp, °F	Energy, Ft-lbs	Shear, %	Lateral Expansion, Mils
- 80	4	2	6
- 80	4	2	6
- 60	8	3	6
- 60	6	3	6
- 40	12	10	14
- 40	10	5	10
- 40	6	5	7
- 20	14	15	14
- 20	13	15	14
0	22	30	22
0	18	25	18
20	29	35	28
20	23	35	23
40	36	45	33
40	26	45	26
60	36	50	40
60	33	45	35
80	67	100	60
80	50	70	48
100	68	98	60
100	62	85	58

TABLE 7

PRE-IRRADIATION TENSILE PROPERTIES FOR THE INDIAN POINT UNIT NO. 2 PRESSURE VESSEL PLATE MATERIAL AND WELD METAL

Plate No.	Test Temp., °F	0.2% Yield Strength, psi	Tensile Strength, psi	Total Elongation %	Reduction In Area, %
B2002-1	Room	68,500	89,000	25.1	67.8
B2002-1	Room	65,850	87,800	25.3	67.4
B2002-1	200	61,550	79,900	24.1	68.6
B2002-1	200	67,950	89,400	23.8	67.6
B2002-1	400	57,900	79,900	23.1	64.7
B2002-1	400	59,800	82,200	22.2	67.8
B2002-1	600	56,750	80,550	21.9	64.3
B2002-1	600	57,750	85,700	22.9	64.2
B2002-2	Room	62,350	83,800	27.1	70.0
B2002-2	Room	66,750	90,500	28.2	69.6
B2002-2	200	63,650	84,450	24.8	70.5
B2002-2	200	63,200	83,800	25.5	67.3
B2002-2	400	53,800	77,900	23.1	68.5
B2002-2	400	52,650	73,150	22.4	67.6
B2002-2	600	53,500	78,800	22.7	64.4
B2002-2	600	54,700	81,450	24.7	64.4
B2002-3	Room	65,650	87,300	27.6	67.3
B2002-3	Room	65,000	87,350	24.8	66.7
B2002-3	200	67,800	88,900	23.4	68.6
B2002-3	200	67,700	89,150	22.1	64.9
B2002-3	400	57,950	79,550	22.3	68.7
B2002-3	400	55,350	77,100	23.2	64.9
B2002-3	600	57,750	83,850	24.9	68.2
B2002-3	600	58,350	86,500	24.9	64.7
Weld	Room	64,500	80,700	28.5	73.9
Weld	Room	65,000	81,000	26.9	71.5
Weld	200	63,450	76,100	28.4	72.9
Weld	200	61,050	75,200	25.2	73.0
Weld	400	57,550	75,000	22.9	68.1
Weld	400	58,300	75,800	22.6	69.6
Weld	600	56,650	79,800	24.4	62.0
Weld	600	56,650	79,200	24.0	66.9

TABLE 8

PRE-IRRADIATION RESULTS OF WOL FRACTURE TOUGHNESS SPECIMENS
FOR THE INDIAN POINT UNIT NO. 2, REACTOR VESSEL SHELL PLATE B2002-1

Size	Temp., °F	σ_{ys}, ksi	B, in.	a, in.	a/w	Method	K_Q, ksi$\sqrt{in}$	$(\frac{K_Q}{\sigma_{ys}})^2$	$\frac{B}{(\frac{K_Q}{\sigma_{ys}})^2}$	$\frac{a}{(\frac{K_Q}{\sigma_{ys}})^2}$	K_{Ic}, ksi$\sqrt{in}$	Plastic Zone-Size, r_{Iy}
1x	-320	130.0	1.000	0.541	0.481	FRA(L)	34.5	0.0705	14.20	7.68	34.5	0.004
1x	-320	130.0	1.000	0.507	0.451	FRA(L)	35.3	0.0736	13.60	6.88	35.3	0.004
1x	-250	100.0	1.000	0.524	0.466	FRA(BS)	43.5	0.1890	5.29	2.77	43.5	0.010
1x	-250	100.0	1.000	0.609	0.541	FRA(BS)	57.8	0.3340	2.99	1.62		0.018
1T	-225	95.0	1.000	0.895	0.351	FRA(L)	40.4	0.1810	5.52	4.95	40.4	0.010
1x	-200	92.0	1.000	0.538	0.479	FRA(L)	45.9	0.2490	4.02	2.16		0.013
1x	-200	92.0	1.000	0.538	0.479	FRA(L)	43.8	0.2280	4.38	2.36		0.012
1T	-200	92.0	1.000	0.940	0.369	FRA(L)	47.1	0.2650	3.77	3.54	47.1	0.014
1T	-200	92.0	1.000	0.920	0.361	FRA(L)	40.7	0.1980	5.05	4.65	40.7	0.010
2T	-150	87.5	2.000	1.830	0.358	FRA(L)	66.0	0.5700	3.51	3.21	66.0	0.030
2T	-125	85.5	2.000	1.840	0.360	FRA(L)	65.5	0.5870	3.41	3.13	65.5	0.031

TABLE 9

PRE-IRRADIATION RESULTS OF WOL FRACTURE TOUGHNESS SPECIMENS FOR THE INDIAN POINT UNIT NO. 2, REACTOR PRESSURE VESSEL PLATE B2002-2

Size	Temp., °F	σys, ksi	B, in.	a, in.	a/w	Method	K_Q, ksi$\sqrt{in}$	$(\frac{K_Q}{\sigma ys})^2$	$\frac{B}{(\frac{K_Q}{\sigma ys})^2}$	$\frac{a}{(\frac{K_Q}{\sigma ys})^2}$	K_{Ic}, ksi$\sqrt{in}$	Plastic Zone-Size, r_{Iy}
1x	-320	133.0	1.000	0.536	0.476	FRA(L)	27.4	0.0424	23.60	12.6	27.4	0.002
1x	-320	133.0	1.000	0.556	0.494	FRA(L)	29.5	0.0492	20.30	11.3	29.5	0.003
1x	-250	100.0	1.000	0.523	0.465	FRA(BS)	50.2	0.2520	3.97	2.08		0.013
1x	-250	100.0	1.000	0.568	0.505	FRA(BS)	59.1	0.3500	2.86	1.63		0.019
1x	-200	90.0	1.000	0.609	0.541	FRA(BS)	62.1	0.4760	2.10	1.28		0.025
1x	-200	90.0	1.000	0.488	0.434	FRA(BS)	44.3	0.2430	4.12	2.01		0.013
1T	-200	90.0	1.000	0.912	0.358	FRA(L)	52.0	0.3300	3.03	2.76	52.0	0.018
1T	-200	90.0	1.000	1.050	0.412	FRA(L)	55.3	0.3720	2.69	2.82	55.3	0.020
1T	-175	87.0	1.000	0.890	0.350	FRA(L)	57.1	0.4320	2.32	2.06		0.023
2T	-125	81.0	2.000	1.780	0.348	FRA(L)	60.6	0.560	3.57	3.18	60.6	0.030
2T	-100	79.0	2.000	1.820	0.356	FRA(L)	60.3	0.582	3.44	3.13	60.3	0.031

TABLE 10

PRE-IRRADIATION RESULTS OF WOL FRACTURE TOUGHNESS SPECIMENS
FOR THE INDIAN POINT UNIT NO. 2, REACTOR PRESSURE VESSEL SHELL PLATE B2002-3

Size	Temp., °F	σys, ksi	B, in.	a, in.	a/w	Method	K_Q, ksi$\sqrt{in}$	$(\frac{K_Q}{\sigma ys})^2$	$\frac{B}{(\frac{K_Q}{\sigma ys})^2}$	$\frac{a}{(\frac{K_Q}{\sigma ys})^2}$	K_{1c}, ksi$\sqrt{in}$	Plastic Zone-Size, r_{1y}
1x	-320	122.0	1.000	0.500	0.444	PI(S)	25.3	0.043	23.30	11.60	25.3	0.002
1x	-320	122.0	1.000	0.496	0.441	FRA(L)	41.4	0.115	8.69	4.32	41.4	0.006
1x	-250	95.0	1.000	0.508	0.452	FRA(BS)	57.9	0.372	2.69	1.37		0.020
1x	-250	95.0	1.000	0.547	0.485	FRA(BS)	35.4	0.139	7.18	3.93	35.4	0.007
1x	-200	88.0	1.000	0.484	0.430	SECANT	54.8	0.388	2.58	1.25		0.021
1x	-200	88.0	1.000	0.554	0.492	FRA(BS)	47.9	0.297	3.37	1.87		0.016
1T	-200	88.0	1.000	0.960	0.376	FRA(L)	57.5	0.427	2.34	2.25		0.023
1T	-200	88.0	1.000	0.905	0.355	FRA(L)	42.8	0.237	4.12	3.82	42.8	0.013
1T	-175	86.5	1.000	0.915	0.358	FRA(L)	45.9	0.281	3.56	3.26	45.9	0.015
2T	-125	84.5	2.000	1.810	0.354	FRA(L)	60.1	0.507	3.94	3.57	60.1	0.027
2T	-100	83.5	2.000	1.840	0.360	FRA(BS)	79.9	0.915	2.19	2.01		0.048

TABLE 11

PRE-IRRADIATION RESULTS OF WOL FRACTURE TOUGHNESS SPECIMENS
FOR THE INDIAN POINT UNIT NO. 2, REACTOR PRESSURE VESSEL WELD METAL

Size	Temp., °F	σ_{ys}, ksi	B, in.	a, in.	a/w	Method	K_Q, ksi$\sqrt{in}$	$(\frac{K_Q}{\sigma_{ys}})^2$	$\frac{B}{(\frac{K_Q}{\sigma_{ys}})^2}$	$\frac{a}{(\frac{K_Q}{\sigma_{ys}})^2}$	K_{1c}, ksi$\sqrt{in}$	Plastic Zone-Size, r_{1y}
1x	-320	126.1	1.000	0.547	0.486	FRA(L)	27.9	0.049	20.45	11.18	27.9	0.003
1x	-250	81.4	1.000	0.562	0.500	FRA(L)	40.1	0.242	4.13	2.32		0.128
1x	-250	81.4	1.000	0.562	0.500	FRA(L)	41.4	0.259	3.86	2.17		0.014
1x	-250	81.4	1.000	0.547	0.486	FRA(L)	62.4	0.588	1.70	0.93		0.031

TABLE 12

TABLES FOR CALCULATING FRACTURE TOUGHNESS OF "X" TYPE WOL SPECIMENS

$(\frac{a}{W})$	Y	$(\frac{a}{W})$	Y
.350	7.841	.450	9.623
.355	7.921	.455	9.727
.360	8.002	.460	9.832
.365	8.084	.465	9.939
.370	8.166	.470	10.049
.375	8.250	.475	10.161
.380	8.334	.480	10.276
.385	8.419	.485	10.393
.390	8.504	.490	10.514
.395	8.591	.495	10.638
.400	8.679	.500	10.765
.405	8.767	.505	10.895
.410	8.857	.510	11.030
.415	8.948	.515	11.168
.420	9.040	.520	11.310
.425	9.134	.525	11.457
.430	9.228	.530	11.609
.435	9.325	.535	11.765
.440	9.422	.540	11.927
.445	9.522	.545	12.094
		.550	12.267

Correct Formula for use with above values

$$K_Q = \frac{Y\ P_Q}{B\ W^{1/2}}$$

in which:

P = Load in pounds
B = Thickness of specimen in inches
W = Width of specimen in inches
a = Depth of specimen notch plus fatigue crack in inches
Y = Numerical constant from above table

TABLE 13

TABLES FOR CALCULATING FRACTURE TOUGHNESS
OF "T" TYPE WOL SPECIMENS

$(\frac{a}{W})$	Y	$(\frac{a}{W})$	Y
.350	7.330	.450	9.149
.355	7.410	.455	9.255
.360	7.490	.460	9.362
.365	7.573	.465	9.472
.370	7.656	.470	9.584
.375	7.740	.475	9.699
.380	7.825	.480	9.816
.385	7.912	.485	9.936
.390	7.999	.490	10.058
.395	8.088	.495	10.184
.400	8.178	.500	10.313
.405	8.269	.505	10.446
.410	8.361	.510	10.582
.415	8.455	.515	10.722
.420	8.549	.520	10.866
.425	8.646	.525	11.015
.430	8.743	.530	11.168
.435	8.842	.535	11.326
.440	8.943	.540	11.490
.445	9.045	.545	11.659
		.550	11.834

Correct formula for use with above values

$$K_Q = \frac{Y\ P_Q}{B\ W^{1/2}}$$

in which:

P = Load in pounds
B = Thickness of specimen in inches
W = Width of specimen in inches
a = Depth of specimen notch plus fatigue crack in inches
Y = Numerical constant from above table

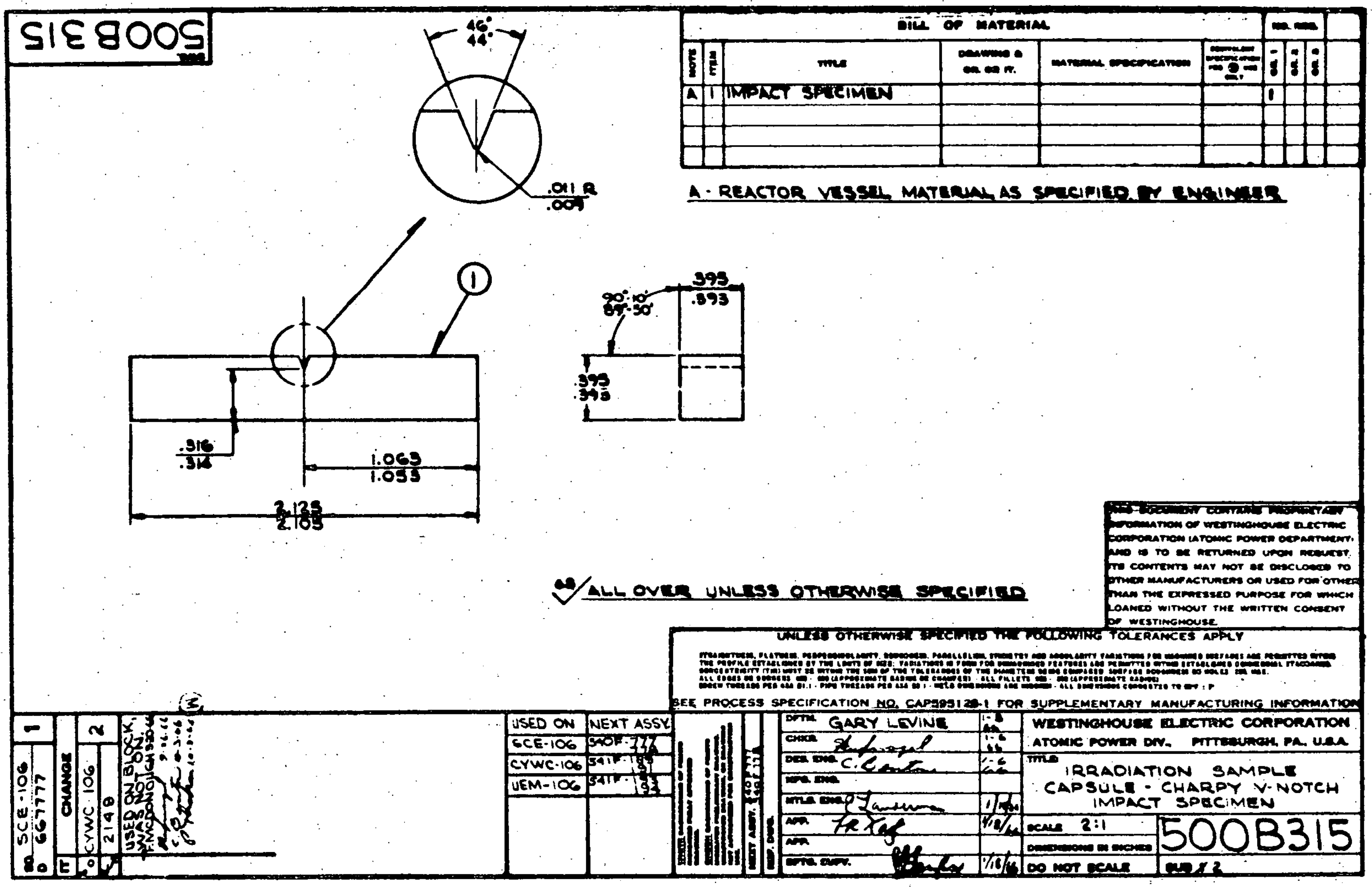

500B315
46°
44°
.011 R
.009
BILL OF MATERIAL
IMPACT SPECIMEN
A - REACTOR VESSEL MATERIAL AS SPECIFIED BY ENGINEER
90°10'
89°50'
.395
.393
.316
.314
1.063
1.053
2.125
2.105
ALL OVER UNLESS OTHERWISE SPECIFIED
UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
SEE PROCESS SPECIFICATION NO. CAP595128-1 FOR SUPPLEMENTARY MANUFACTURING INFORMATION
USED ON
NEXT ASSY.
SCE-106
CYWC-106
UEM-106
CHANGE
GARY LEVINE
WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DIV. PITTSBURGH, PA. U.S.A.
IRRADIATION SAMPLE
CAPSULE - CHARPY V-NOTCH
IMPACT SPECIMEN
SCALE 2:1
DIMENSIONS IN INCHES
DO NOT SCALE
500B315

Figure 1

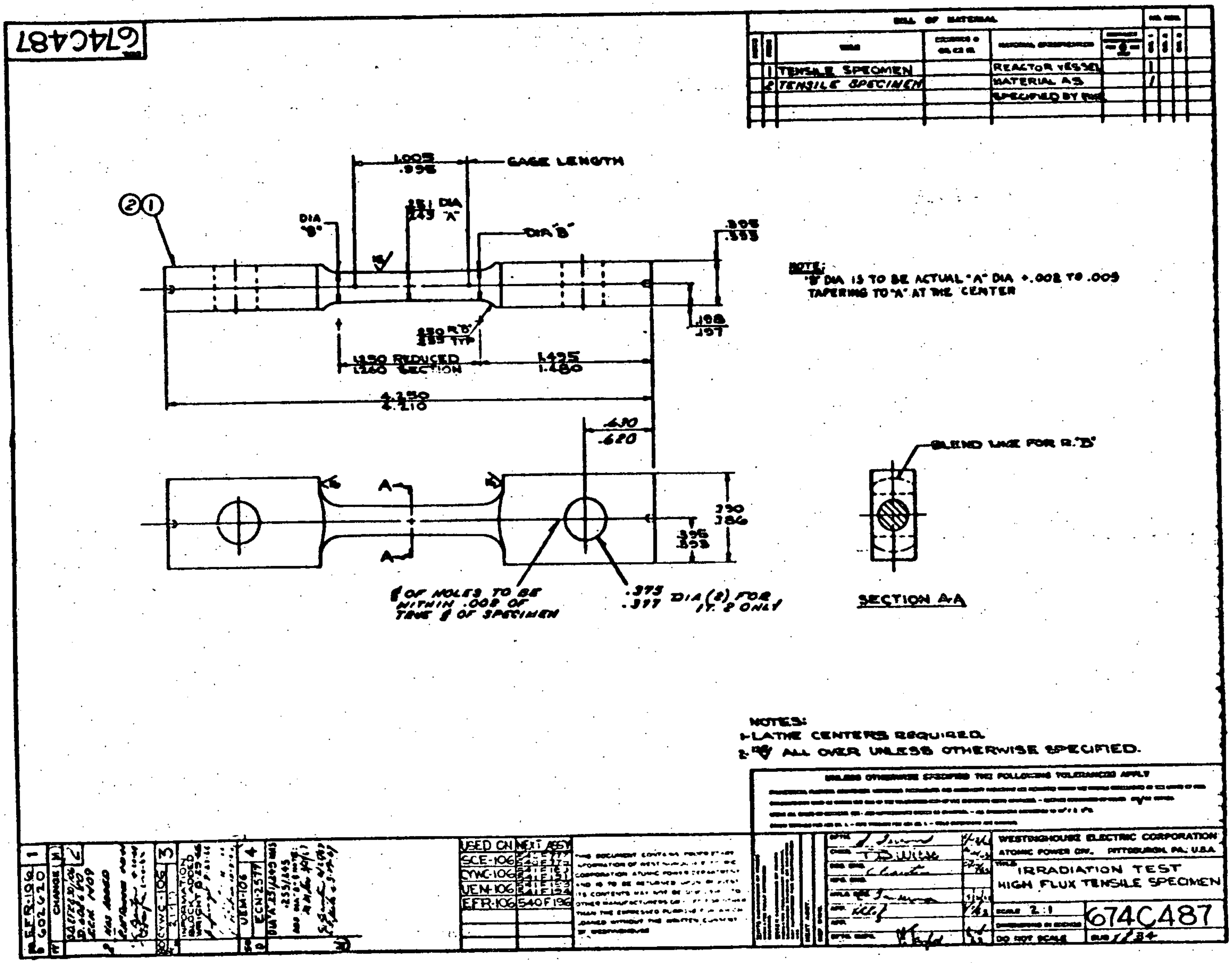

674C487
TENSILE SPECIMEN
TENSILE SPECIMEN
REACTOR VESSEL
MATERIAL AS
GAGE LENGTH
NOTE:
"B" DIA IS TO BE ACTUAL "A" DIA +.002 TO .005
TAPERING TO "A" AT THE CENTER
BLEND LINE FOR R."B"
SECTION A-A
NOTES:
1-LATHE CENTERS REQUIRED.
2- ALL OVER UNLESS OTHERWISE SPECIFIED.
USED ON
NEXT ASSY
SCE-106
CYWC-106
UEN-106
EFR-106
540F196
WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DIV. PITTSBURGH, PA. U.S.A.
IRRADIATION TEST
HIGH FLUX TENSILE SPECIMEN
SCALE 2:1
DO NOT SCALE
674C487

Figure 2

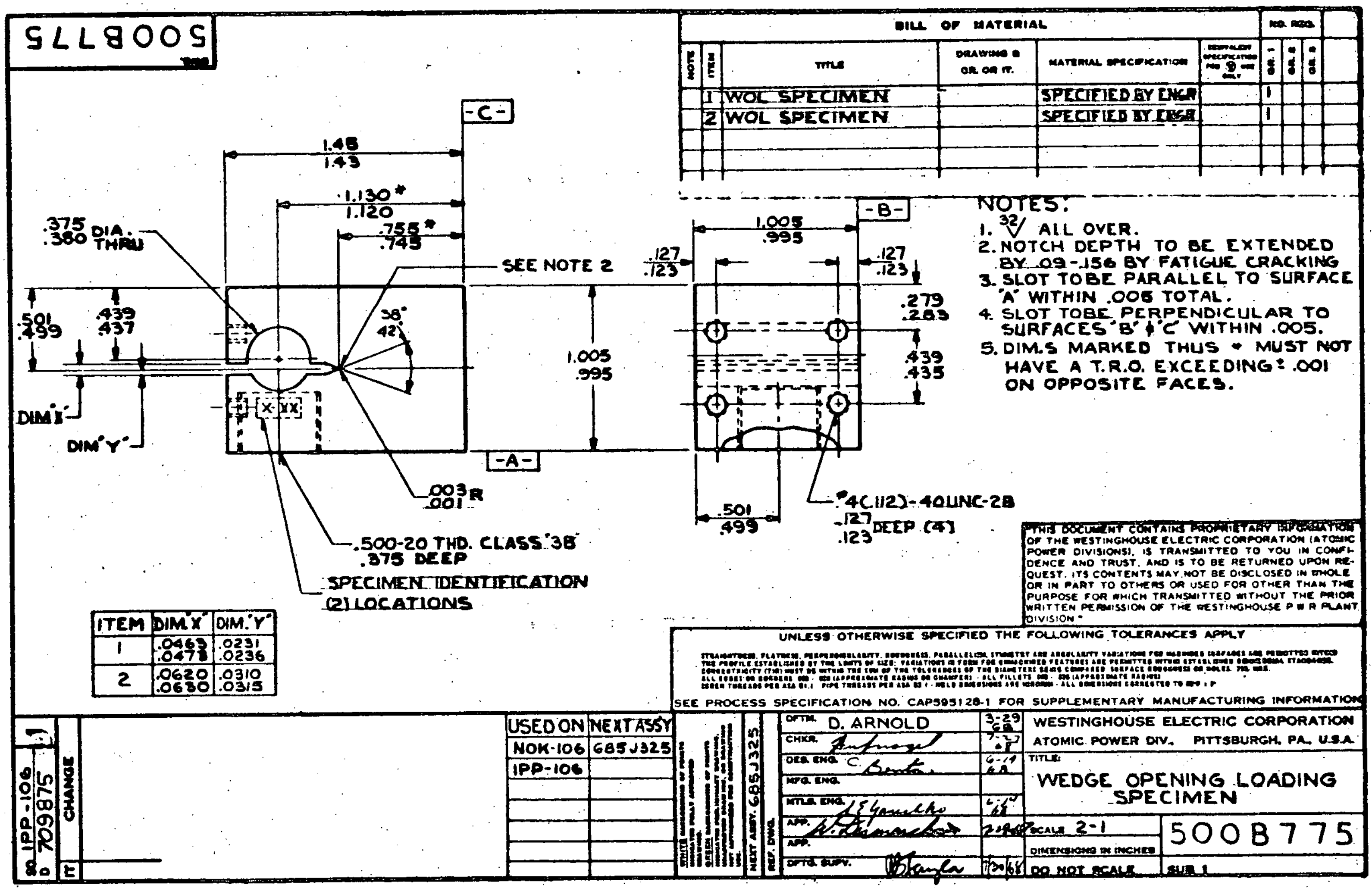

500B775
BILL OF MATERIAL
NOTE
ITEM
TITLE
DRAWING & GR. OR IT.
MATERIAL SPECIFICATION
NO. REQ.
1 WOL SPECIMEN SPECIFIED BY ENGR 1
2 WOL SPECIMEN SPECIFIED BY ENGR 1
-C-
1.48
1.43
1.130*
1.120
.755*
.745
.375
.380 DIA. THRU
SEE NOTE 2
.501
.499
.439
.437
38°
42°
1.005
.995
DIM'X'
DIM'Y'
X-XX
-A-
.003
.001 R
.500-20 THD. CLASS 3B
.375 DEEP
SPECIMEN IDENTIFICATION
(2) LOCATIONS
-B-
1.005
.995
.127
.123
.279
.283
.439
.435
.501
.499
#4(.112)-40UNC-2B
.127
.123 DEEP (4)
NOTES:
1. 32/ ALL OVER.
2. NOTCH DEPTH TO BE EXTENDED BY .09-.156 BY FATIGUE CRACKING
3. SLOT TO BE PARALLEL TO SURFACE 'A' WITHIN .006 TOTAL.
4. SLOT TO BE PERPENDICULAR TO SURFACES 'B' & 'C' WITHIN .005.
5. DIM.S MARKED THUS * MUST NOT HAVE A T.R.O. EXCEEDING ±.001 ON OPPOSITE FACES.
ITEM | DIM.'X' | DIM.'Y'
1 | .0463 .0473 | .0231 .0236
2 | .0620 .0630 | .0310 .0315
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION OF THE WESTINGHOUSE ELECTRIC CORPORATION (ATOMIC POWER DIVISIONS), IS TRANSMITTED TO YOU IN CONFIDENCE AND TRUST, AND IS TO BE RETURNED UPON REQUEST. ITS CONTENTS MAY NOT BE DISCLOSED IN WHOLE OR IN PART TO OTHERS OR USED FOR OTHER THAN THE PURPOSE FOR WHICH TRANSMITTED WITHOUT THE PRIOR WRITTEN PERMISSION OF THE WESTINGHOUSE P W R PLANT DIVISION
UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
SEE PROCESS SPECIFICATION NO. CAP595128-1 FOR SUPPLEMENTARY MANUFACTURING INFORMATION
USED ON | NEXT ASSY
NOK-106 | 685J325
IPP-106
IPP-106
709875
CHANGE
NEXT ASSY. 685J325
DFTM. D. ARNOLD 3-29-68
CHKR.
DES. ENG. C.
MFG. ENG.
MTLS. ENG.
APP.
DFTG. SUPV.
WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DIV. PITTSBURGH, PA. U.S.A.
TITLE:
WEDGE OPENING LOADING SPECIMEN
SCALE 2-1
DIMENSIONS IN INCHES
DO NOT SCALE
SUB 1
500B775

Figure 3

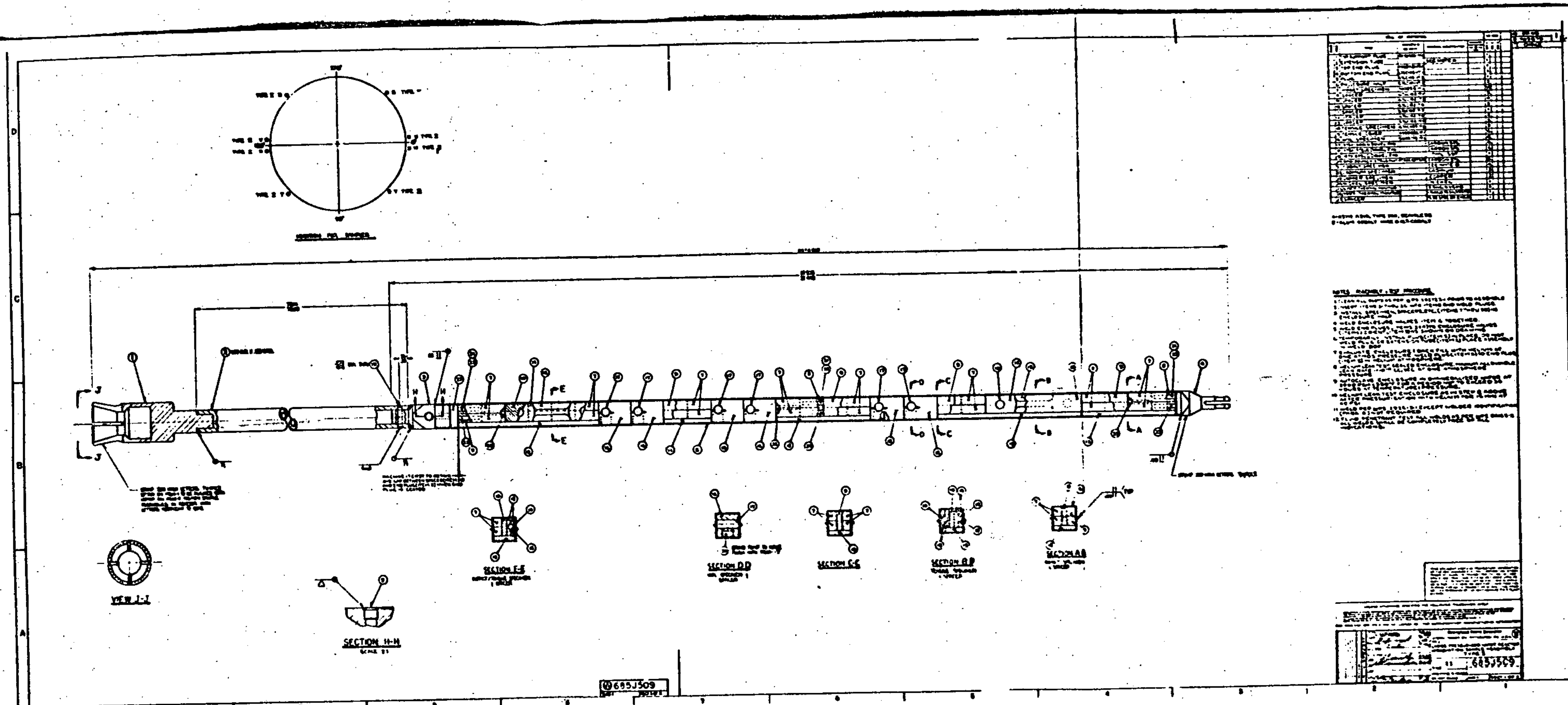


Figure 4.

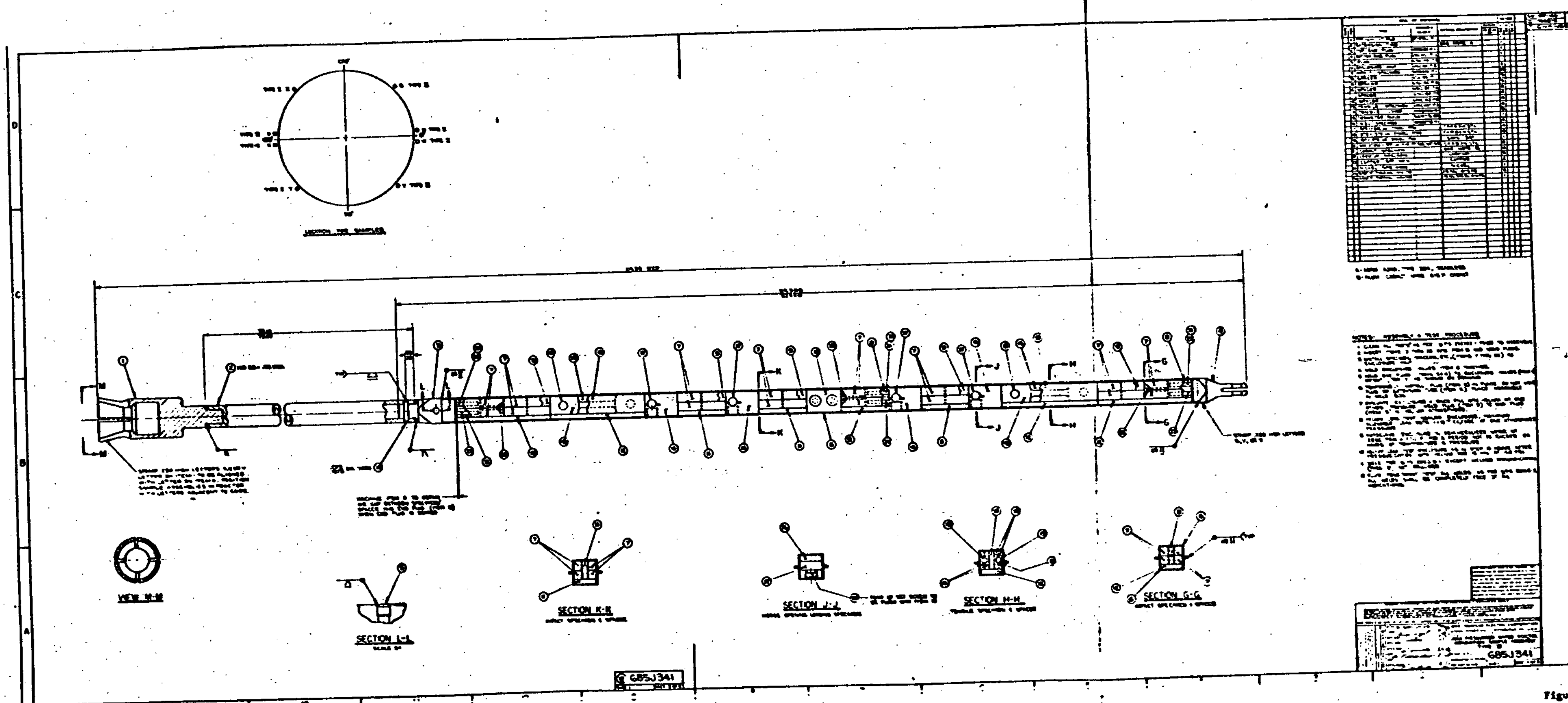
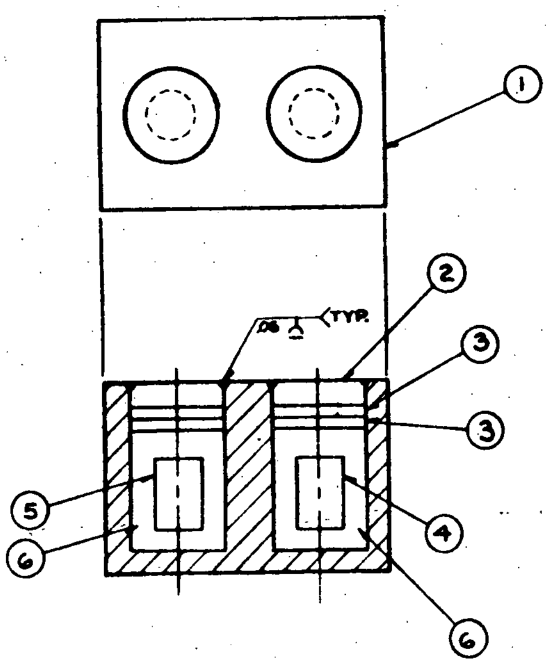

VIEW M-M
SECTION L-L
SECTION K-K
SECTION J-J
SECTION H-H
SECTION G-G
G85J341
G85J341

Figure 5.

5008776



		BILL OF MATERIAL				NO. REQ.		
NOTE	ITEM	TITLE	DRAWING & GR. OR IT.	MATERIAL SPECIFICATION		GR. 1	GR. 2	GR. 3
	1	BLOCK	5008777 IT.-1			1		
	2	COVER	5008777 IT.-2			2		
	3	SPACER	5008777 IT.-3			4		
	4	NEPTUNIUM ^{237} SEALED CAPSULE						
		(.250 O.D. × .375 LG)		BRASS		1		
	5	URANIUM ^{238} SEALED CAPSULE						
		(.250 OD × .375 LG.)		BRASS		1		
	6	CADMIUM OXIDE				AS REQ		

UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY

SEE PROCESS SPECIFICATION NO. CAP595128-1 FOR SUPPLEMENTARY MANUFACTURING INFORMATION

USED ON	NEXT ASSY	DFTM. D. ARNOLD	5-25-68
		CHKR.	7-31-68
		DES. ENG.	6-19-68
		MFG. ENG.	
		MTLS. ENG.	6-14-68
		APP.	
		APP.	
		DFTG. SUPV.	7/30/68

WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DIV., PITTSBURGH, PA., U.S.A.

TITLE: DOSIMETER BLOCK ASSEMBLY

SCALE 2-1 | DIMENSIONS IN INCHES | DO NOT SCALE | SH. 1

5008776

IPP-106
D 705875
CHANGE

Figure 6

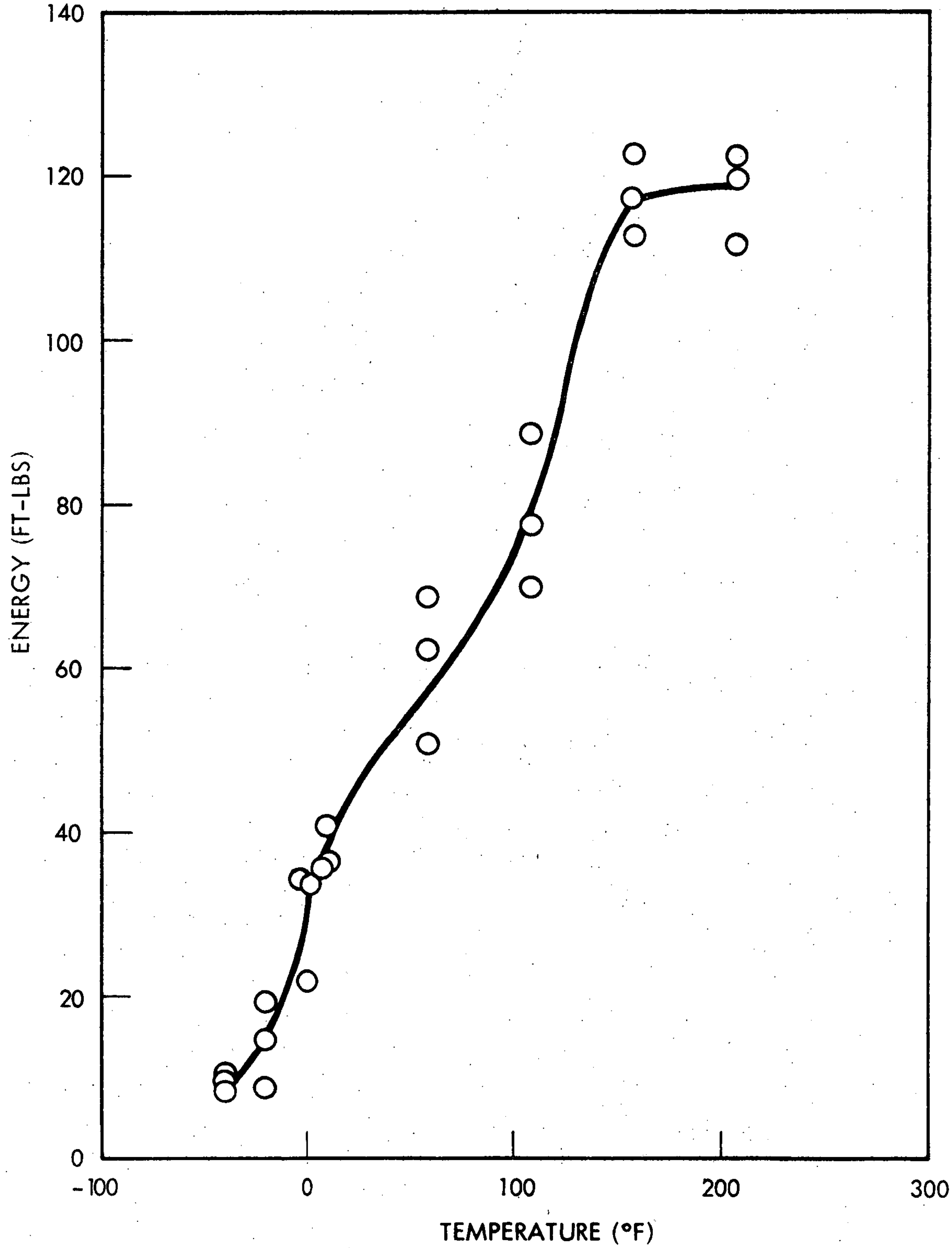


Figure 7. Pre-Irradiation Charpy V-Notch Impact Energy for the Indian Point Unit #2 Reactor Pressure Vessel Shell Plate B2002-1

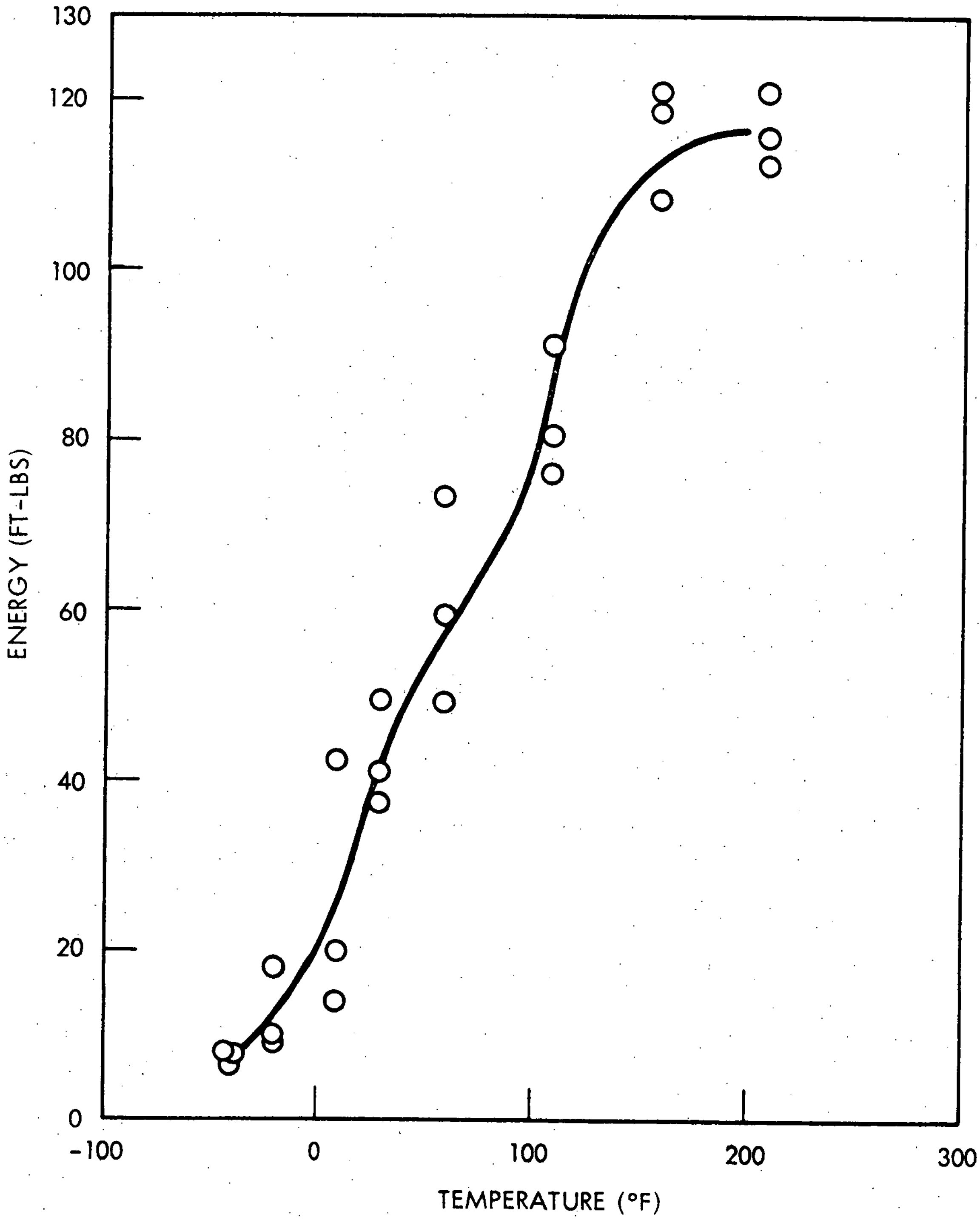


Figure 8. Pre-Irradiation Charpy V-Notch Impact Energy for the Indian Point Unit #2 Reactor Pressure Vessel Shell Plate B2002-2

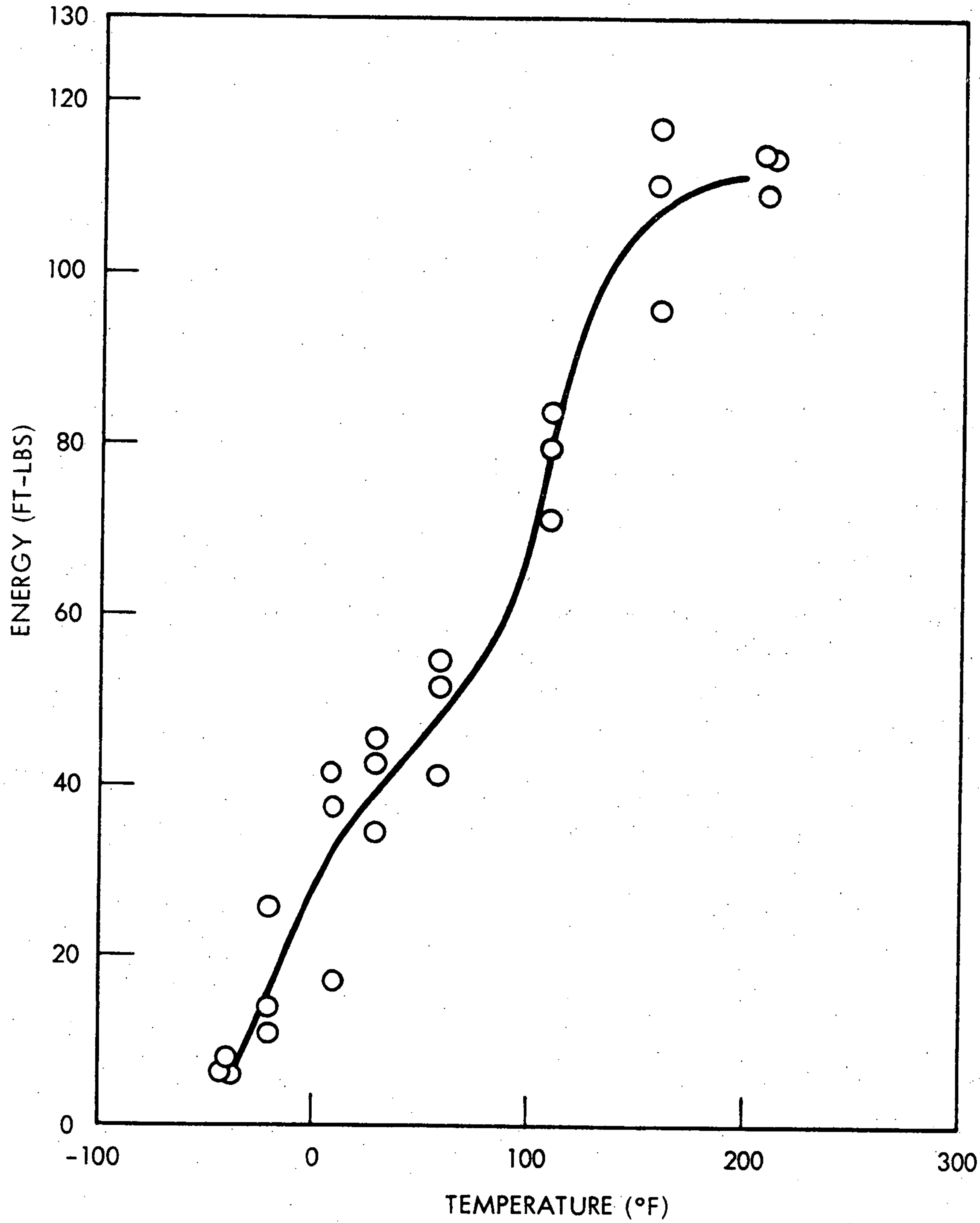


Figure 9. Pre-Irradiation Charpy V-Notch Impact Energy for the Indian Point Unit #2 Reactor Pressure Vessel Shell Plate B2002-3

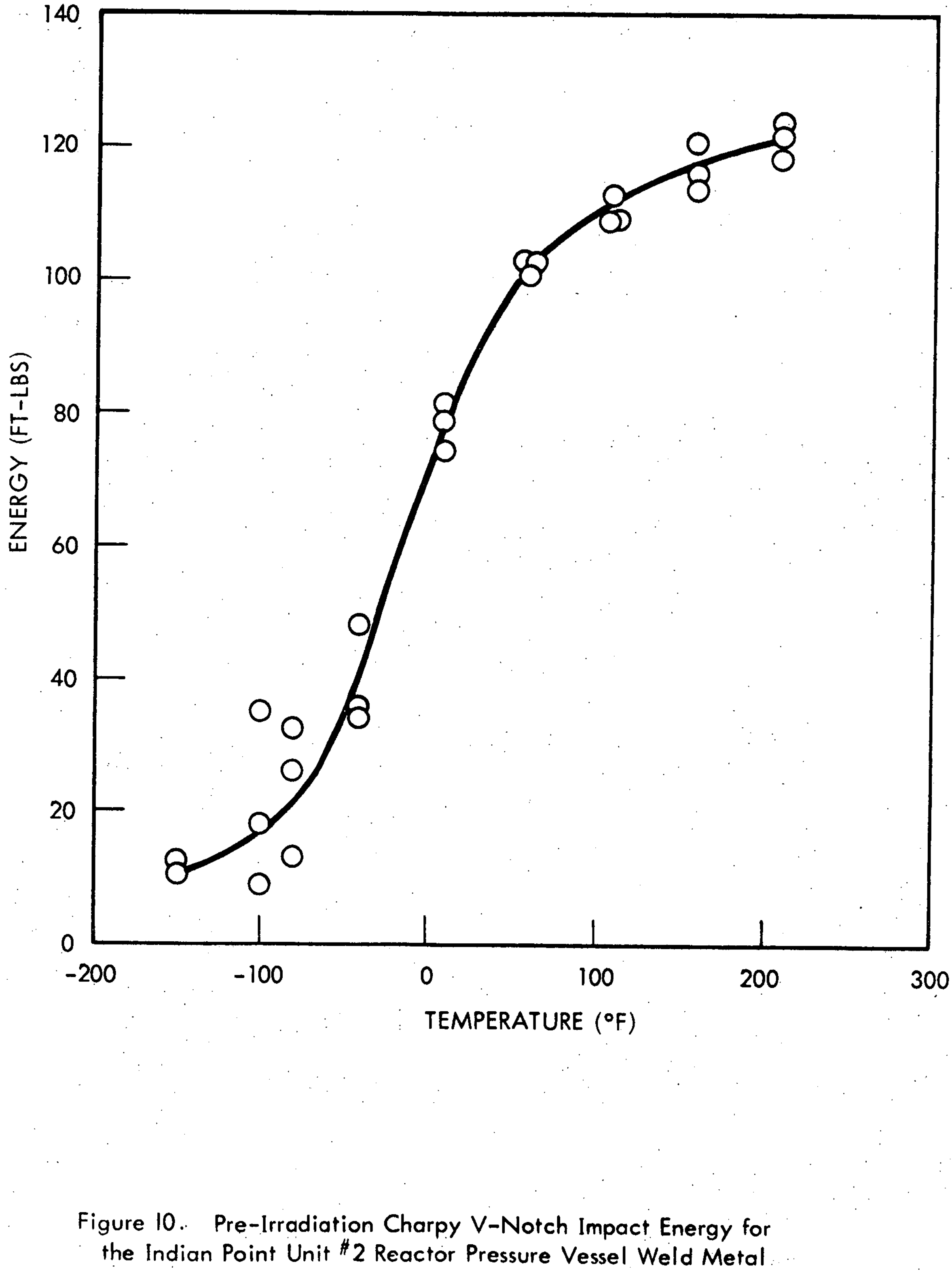


Figure 10. Pre-Irradiation Charpy V-Notch Impact Energy for the Indian Point Unit #2 Reactor Pressure Vessel Weld Metal

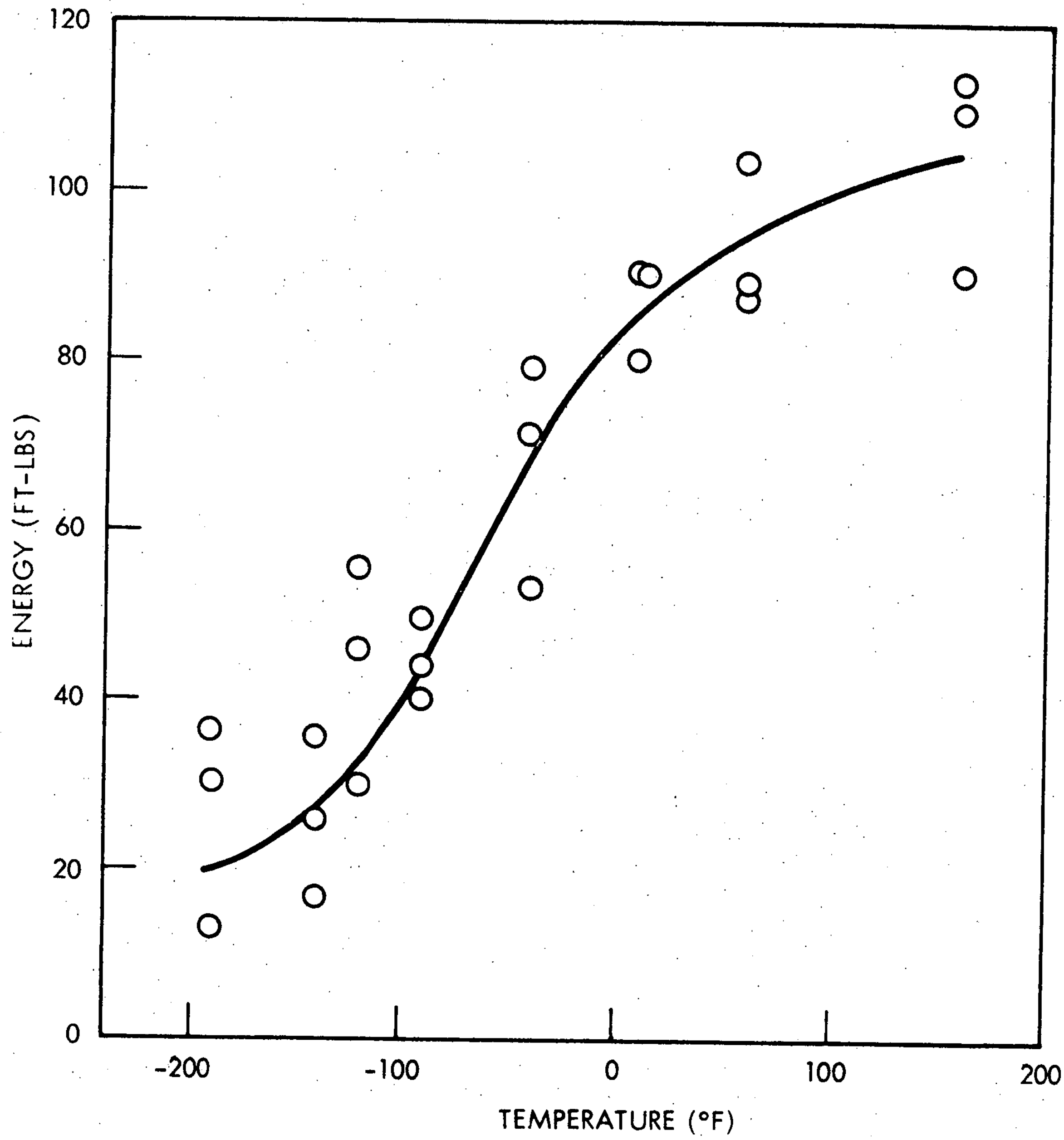


Figure II. Pre-Irradiation Charpy V-Notch Impact Energy for the Indian Point Unit #2 Reactor Pressure Vessel Weld Heat Affected Zone Metal

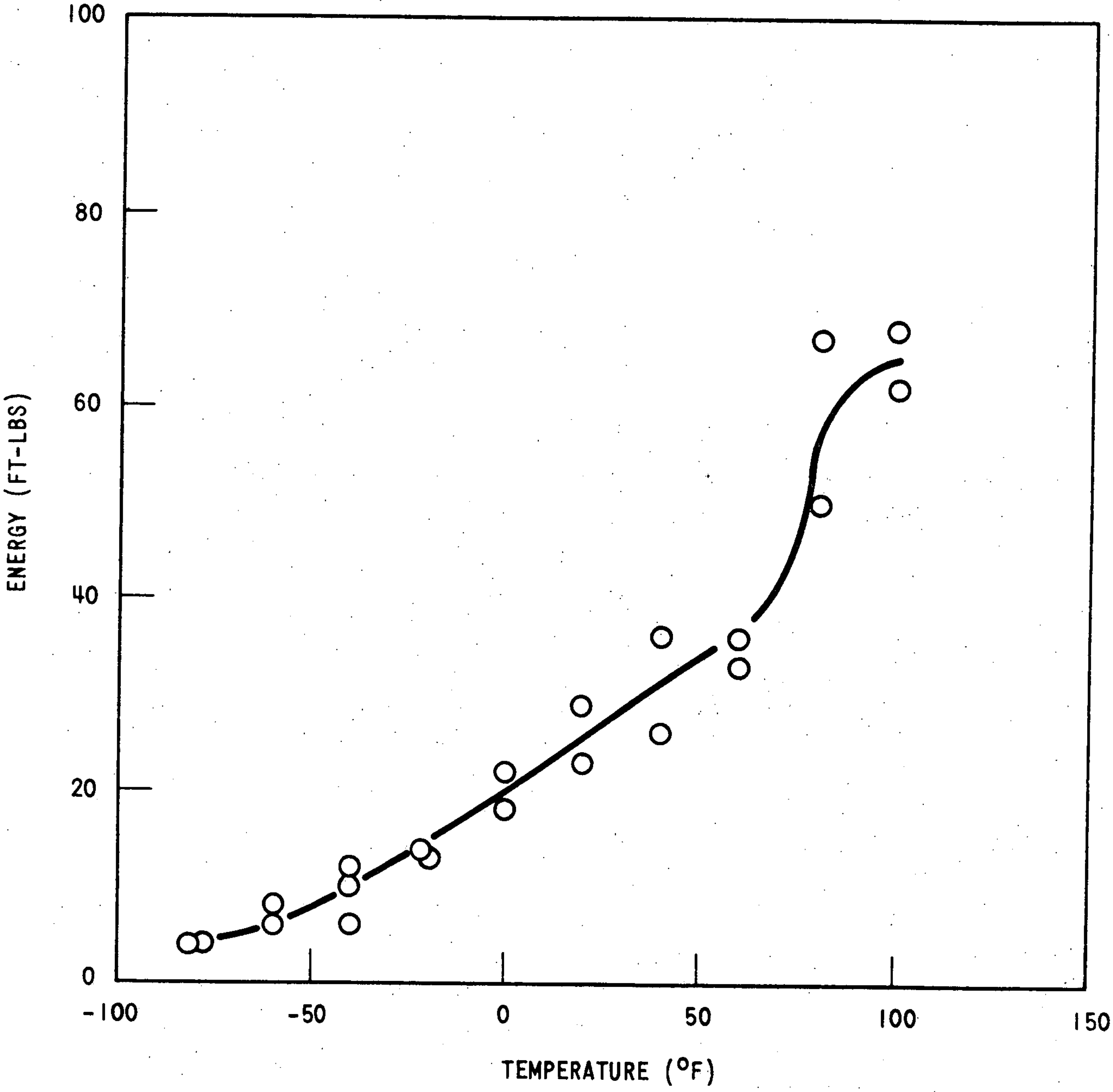


Figure 12. Pre-Irradiation Charpy V-Notch Impact Data for SA 302 Grade B Correlation Monitor Material (Supplied by U.S. Steel)

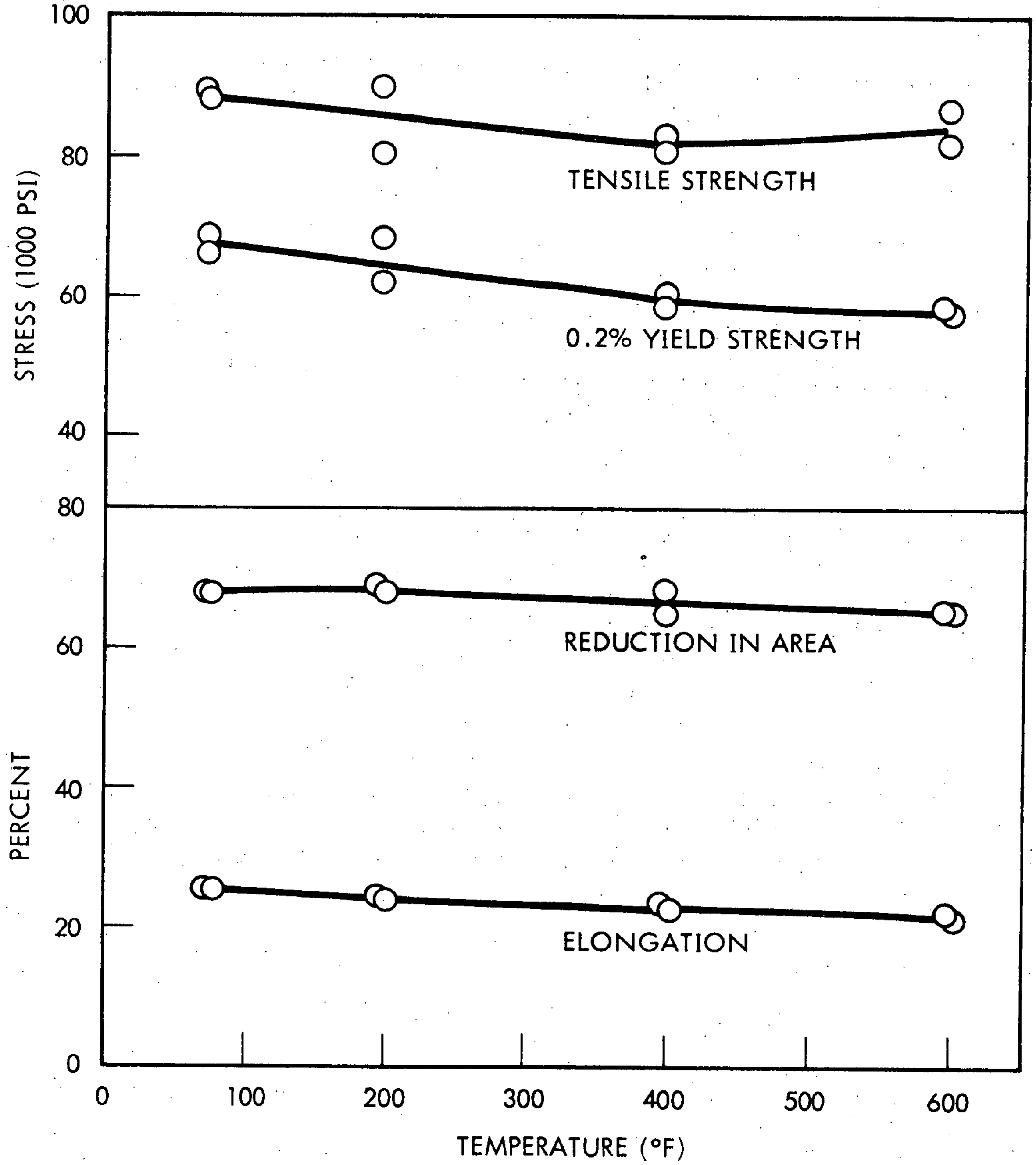


Figure 13. Pre-Irradiation Tensile Properties for the Indian Point Unit #2 Reactor Pressure Vessel Shell Plate B2002-1

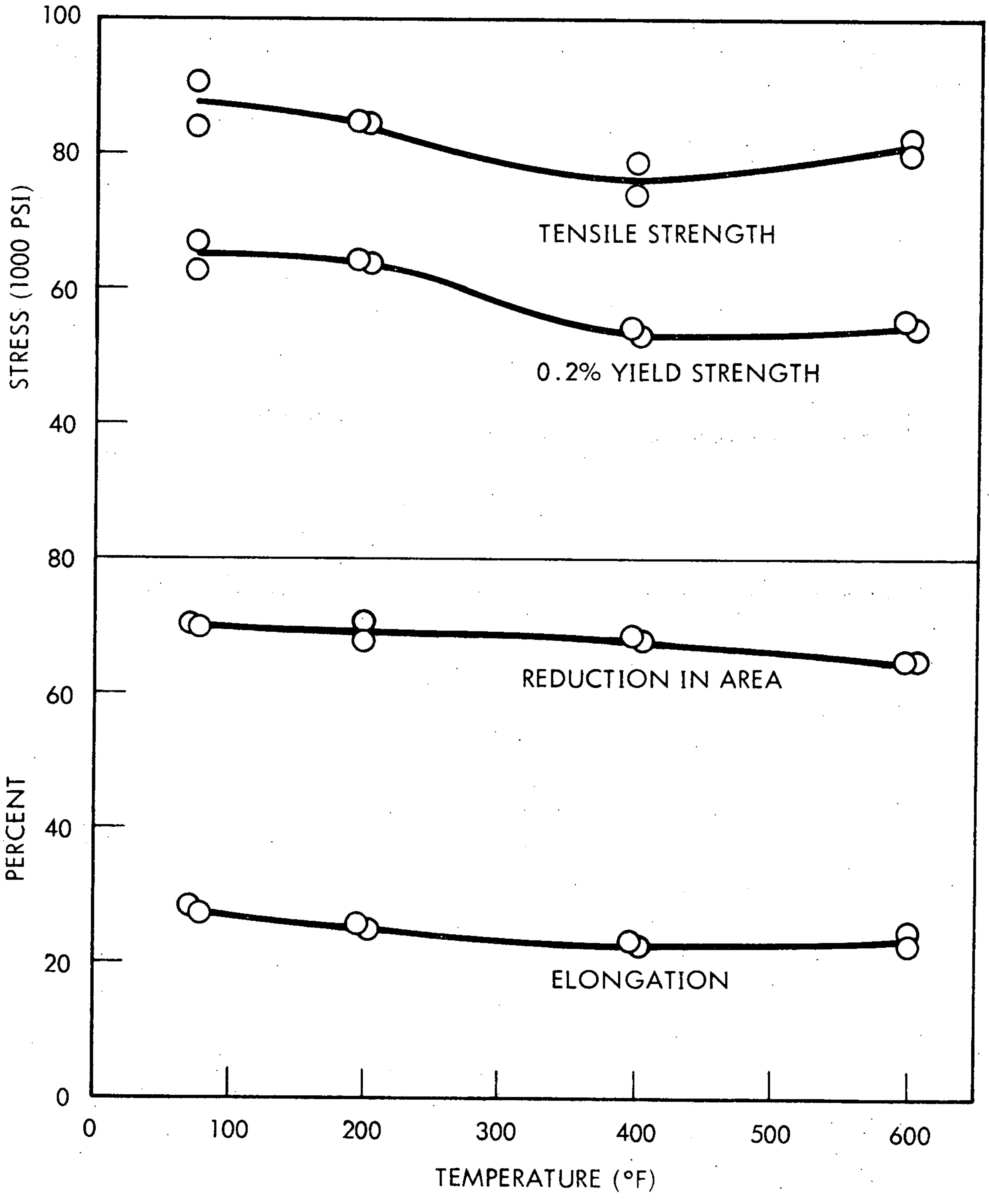


Figure 14. Pre-Irradiation Tensile Properties for the Indian Point Unit #2 Reactor Pressure Vessel Shell Plate B2002-2

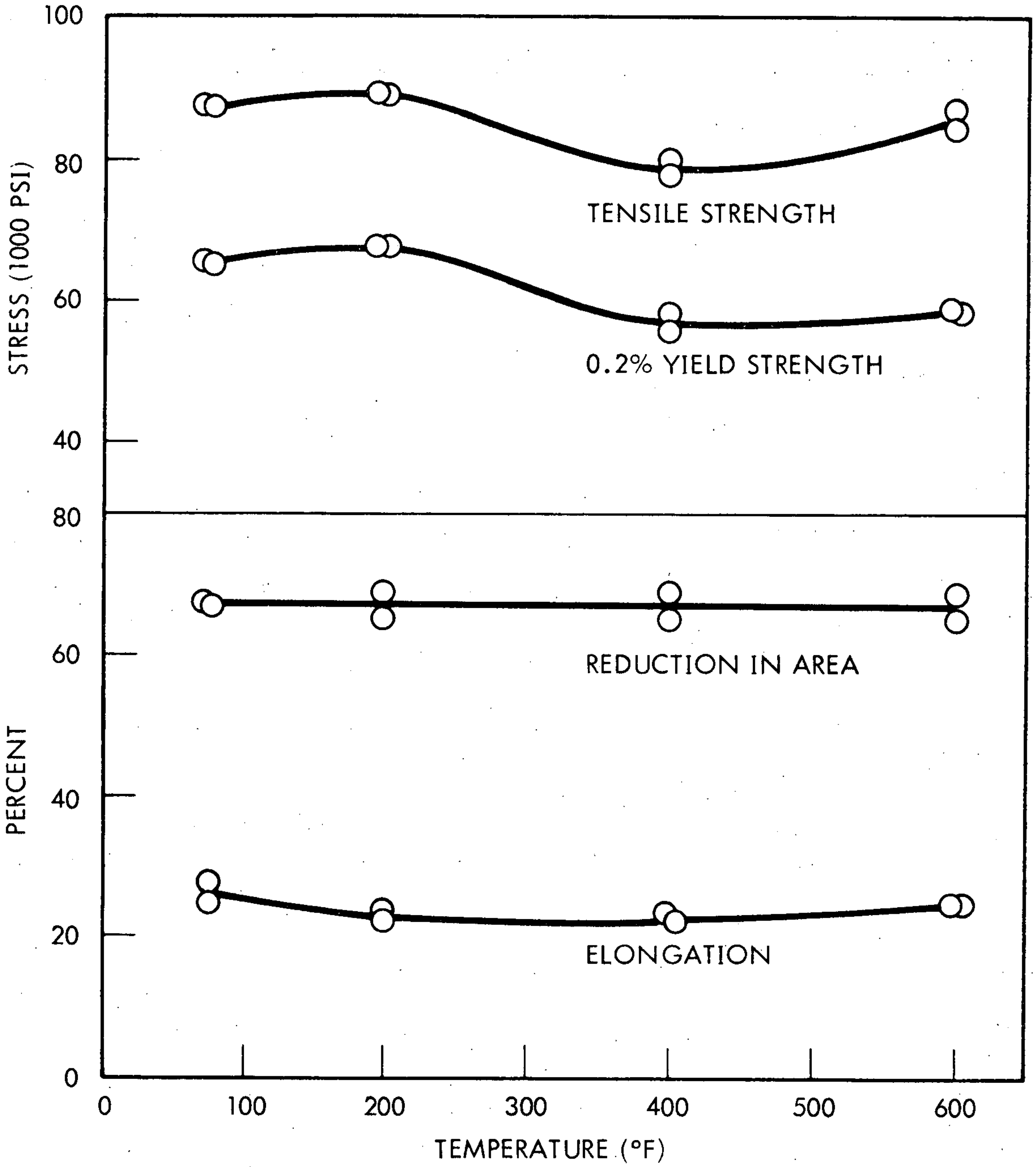


Figure 15. Pre-Irradiation Tensile Properties for the Indian Point Unit #2 Reactor Pressure Vessel Shell Plate B2002-3

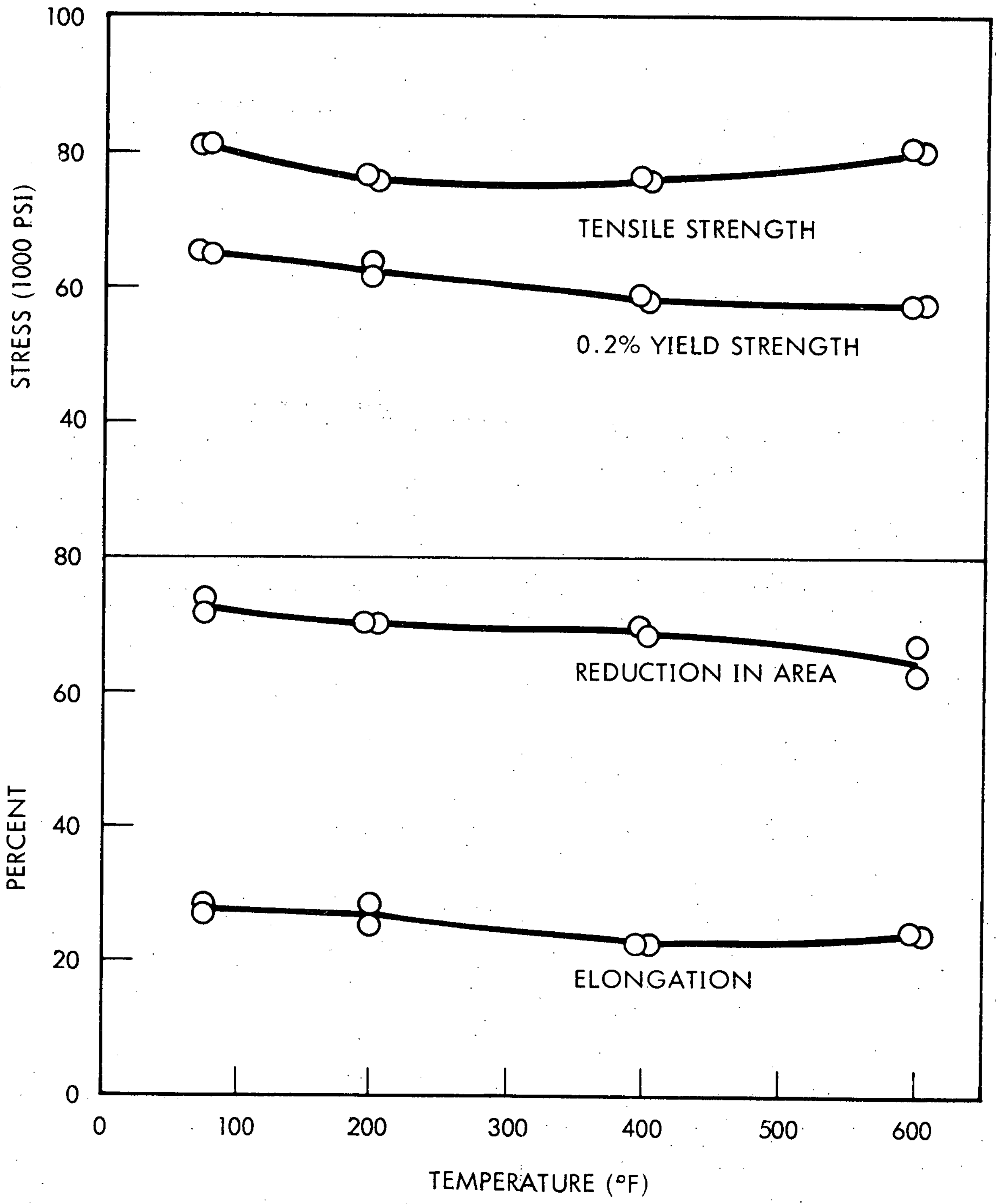


Figure 16. Pre-Irradiation Tensile Properties for the Indian Point Unit #2 Reactor Pressure Vessel Weld Metal

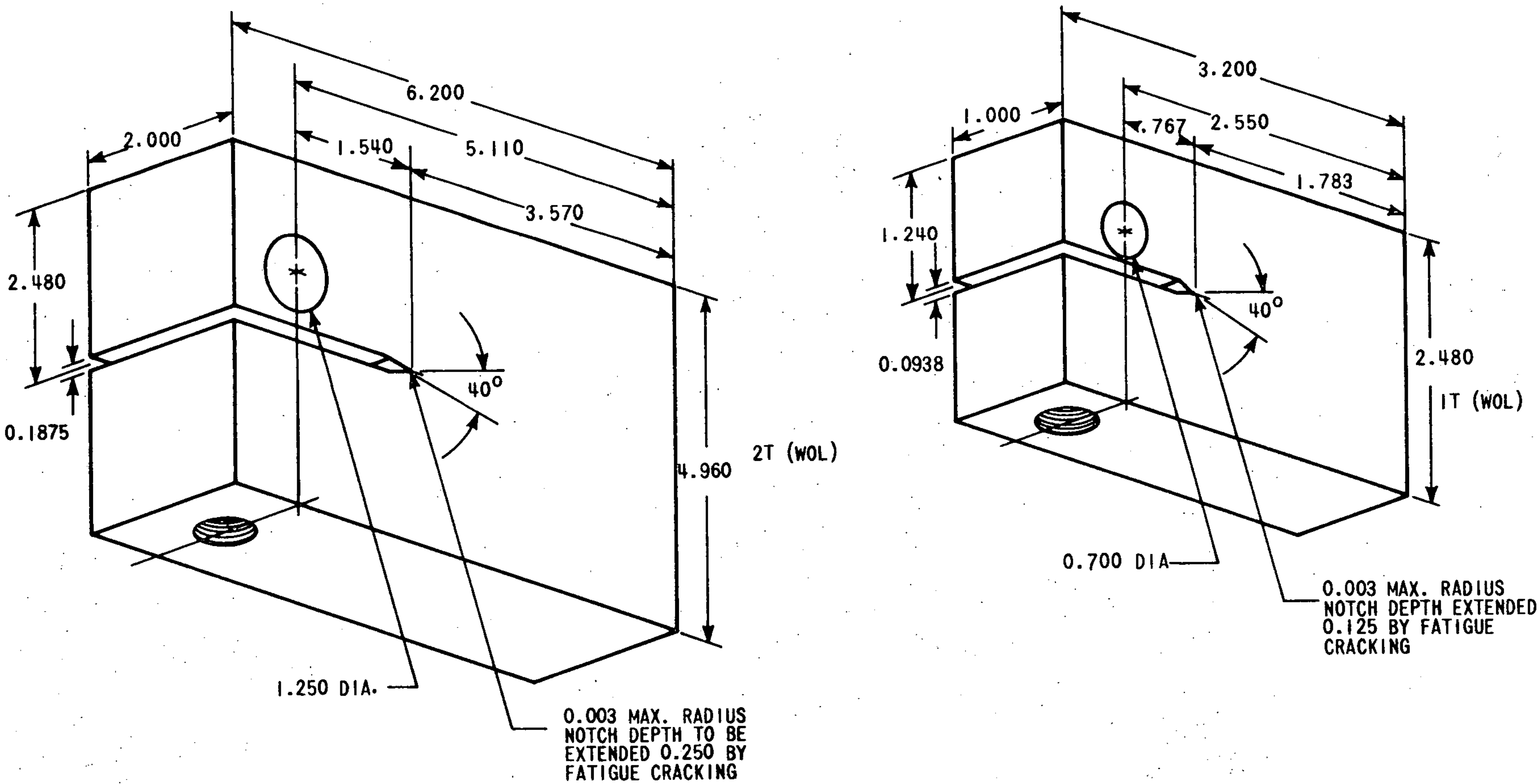
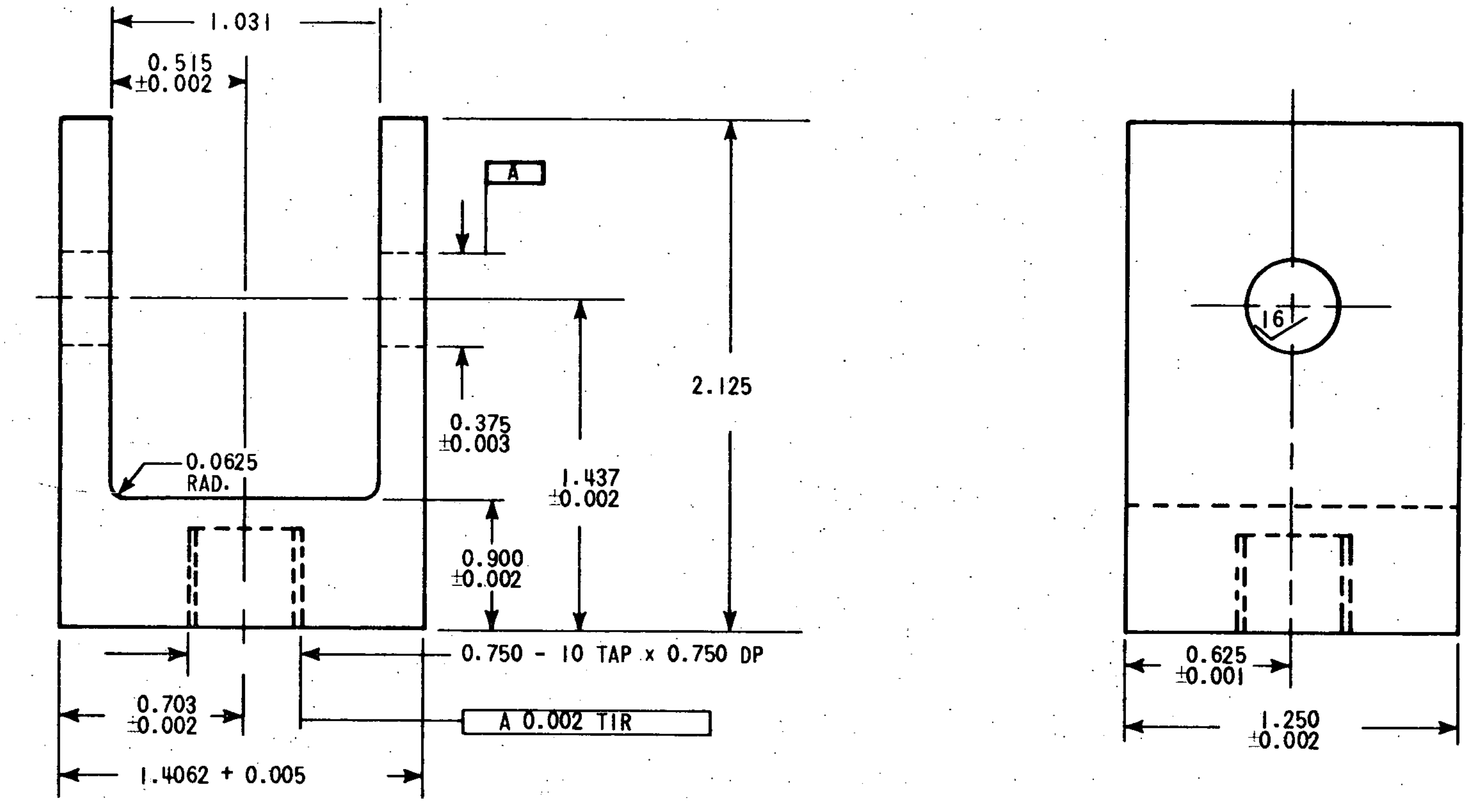
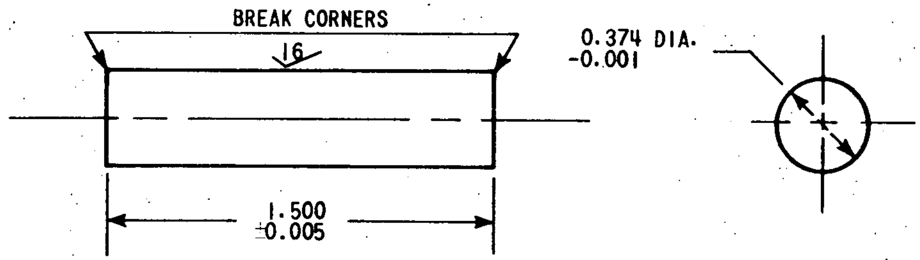


Figure 17. Wedge Opening Loading (WOL) Specimens ("T" Type)

1297-3



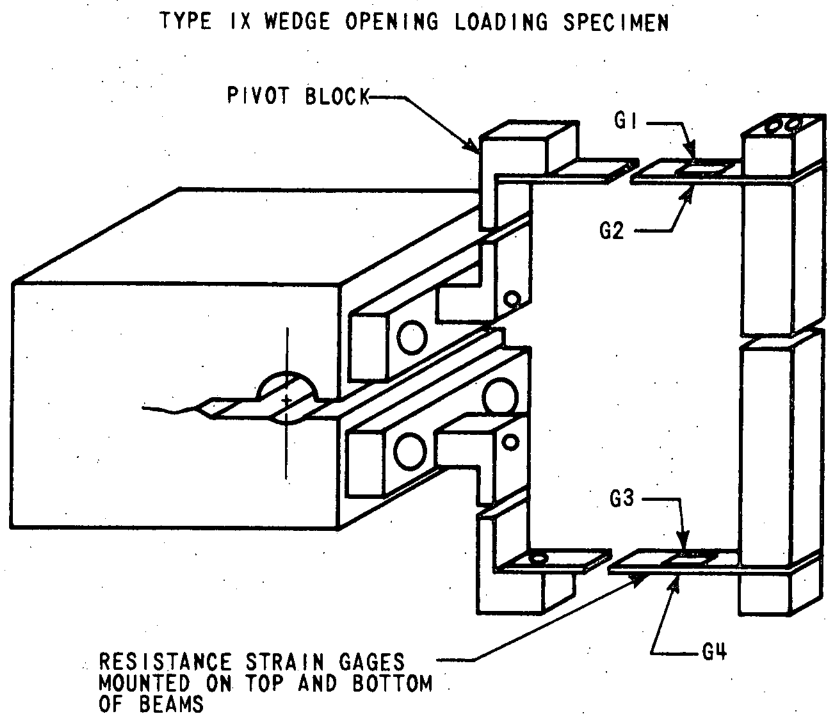


TOLERANCES (IN.)		
UNLESS OTHERWISE SPECIFIED		
2 PL. DEC.	3 PL. DEC.	ANGLES
± 0.02	± 0.005	± 0.5°

FINISH TO BE 32/ UNLESS OTHERWISE SPECIFIED
MATERIAL - 300 GRADE MARAGING STEEL

Figure 18. Dimensions and Tolerances for Grips for X Type WOL Specimens

1297-4



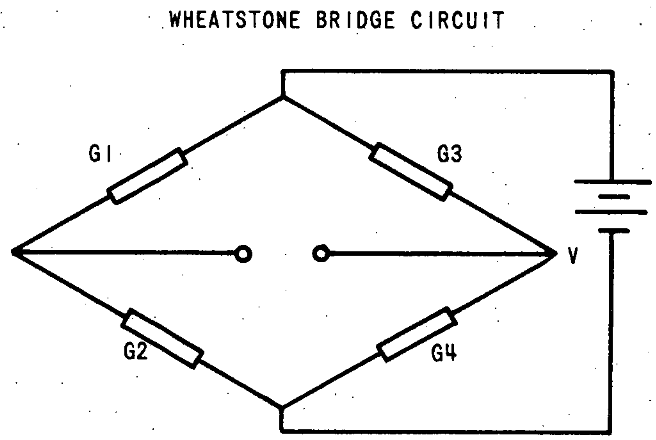


Figure 19. Pivot Block Displacement Gage Mounting Arrangement