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EVALUATION OF THE UNIRRADIATED CHARPY UPPER SHELF ENERGY OF MILLSTONE UNIT 2 RPV INTERMEDIATE SHELL COURSE PLATES

A REPORT TO
NORTHEAST UTILITIES SERVICE COMPANY

BY
MATERIALS & CHEMICAL TECHNOLOGY
ABB COMBUSTION ENGINEERING NUCLEAR SERVICES
COMBUSTION ENGINEERING, INC.
WINDSOR, CONNECTICUT

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VERIFICATION STATUS: COMPLETE

The Safety-Related design information contained in this document has been verified to be correct by means of Design Review using Checklist(s) 1, 5, 9 of QAM-101.

Name E.P. Kurdziel Signature E.P. Kurdziel Date 7/7/93
Independent Reviewer

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1.0 INTRODUCTION

Initial testing of the unirradiated plate materials for the Millstone Unit 2 reactor pressure vessel (RPV) beltline was performed on longitudinal oriented specimens. At the time of fabrication of the vessel, this was the required orientation for Charpy impact testing of the vessel materials. Since the time of Millstone Unit 2 vessel manufacture, the Codes, Standards and Regulations applicable to nuclear components have been revised. Current versions of Codes, Standards and Regulations require Charpy impact data from transverse oriented specimens. The transverse orientation is considered to be more conservative since the toughness properties are generally lower in the transverse direction than in the longitudinal direction.

Toughness requirements for the RPV beltline materials include both the reference temperature indexed by the drop-weight nil-ductility temperature, RT_{NDT}, and a minimum upper shelf energy, USE. The USE is required to be a minimum of 75 ft-lbs. at the beginning of life and should not fall below 50 ft-lbs. at end-of-life (EOL) due to irradiation induced decrease in toughness properties. In the absence of actual data on transverse specimens, reasonably conservative methods have been developed to estimate the transverse properties from longitudinal data. The additional conservatism of using estimated initial material properties can sometimes result in predicted EOL properties that do not meet the required minimum value of 50 ft-lbs. for USE. Therefore, there is a distinct benefit to obtain additional unirradiated data on the RPV beltline materials, if the materials in question, either plates or weldments, are available.

This report presents the results of Charpy impact testing on unirradiated archive material for the three plates used in the intermediate shell course of the Millstone Unit 2 reactor vessel. The Charpy impact test specimens were machined from the plates in the transverse orientation. The transverse data are compared to the original test results on longitudinally oriented specimens. The actual USE value obtained by testing for each plate is compared to the estimated value obtained using current industry practice.

2.0 BACKGROUND

The Millstone Unit 2 RPV (Ref. 1) was designed and fabricated to the requirements of the 1968 edition of the ASME Boiler and Pressure Vessel Code (Ref. 2). The requirements of this Code edition (Paragraph N-331.2) for Charpy V-Notch impact testing were in accordance with SA-370 of the same Code edition. The applicable revision of SA-370 (Ref. 3, Paragraph 23.(a)) required that longitudinally oriented specimens be used for the Charpy impact tests. The definition of longitudinal test signifies that the lengthwise axis of the test specimen is parallel to the direction of the greatest extension of the steel during rolling or forging. For plate materials, this corresponds to the axis of the Charpy specimen being parallel to the major rolling direction.

The ASME Boiler and Pressure Vessel Committee recognized fracture toughness as a critical material property for nuclear components and requested the Pressure Vessel Research Council (PVRC) to provide recommendations for revising the requirements for material fracture toughness for Section III of the Code (Ref. 4). The ASME Code was revised in the Summer 1972 Addenda to Section III based on the PVRC Task Group recommendations. One of the recommendations was that test specimens should be oriented in the direction normal to the principal direction in which the material was worked (other than thickness direction), so that the specimens represent the generally lower toughness of that orientation (Ref. 4).

The ASME Code has been requiring transverse orientation for Charpy impact specimens since the Summer 1972 Addenda through the current editions of the Code (Ref. 5). Similarly, other Standards and Regulations have adopted either the use of the ASME Code test requirements or changed their own requirements to be consistent with the changes that were made to the Code. ASTM E 185 (Refs. 6-8) provides a standard set of requirements for surveillance testing of RPV beltline materials. ASTM E 185-70 (Ref. 6) was the revision in effect at the time when the surveillance program requirements were developed for Millstone Unit 2. This revision required Charpy impact specimens to be oriented with the longitudinal axis of the specimen parallel with the circumferential direction of the vessel. This orientation corresponds to the longitudinal orientation, since the circumferential direction in the vessel is parallel to the major rolling direction of the plates used to fabricate the shell courses (Ref. 19). Later revision of ASTM E 185, including the -73, -79 and -82 revisions recognized in 10CFR50 Appendix H (Ref. 10), require Charpy impact specimens with transverse orientation for surveillance programs.

Other regulatory documents also include requirements for Charpy impact data on transverse specimens. 10CFR50 Appendix G requires Charpy impact testing in accordance with the ASME Code. In addition, minimum initial USE of 75 ft-lbs. and minimum EOL USE of 50 ft-lbs. are required by Appendix G. Regulatory Guide 1.99, Rev. 2 (Ref. 11) provides guidelines for predicting radiation embrittlement of reactor vessel materials. Methods are provided for predicting changes in both

RT_{NDT} and USE with and without available surveillance data. All of these methods are based on transverse Charpy data.

For older plants, such as Millstone 2, that were constructed to ASME Code editions prior to the Summer 1972 Addenda of the 1971 edition the fracture toughness data and data analyses must be supplemented in order to demonstrate equivalence with the fracture toughness requirements (Ref. 9). One method that is available is the Branch Technical Position MTEB 5-2 (Ref. 12). MTEB 5-2 provides a means to convert limited fracture toughness data from either drop-weight tests and/or Charpy impact tests on longitudinal specimens to an estimated value for the transverse orientation of the material. For example, transverse USE may be estimated from tests on longitudinal oriented specimens by reducing the values to 65% of the measured value.

MTEB 5-2 may be described as "reasonably" conservative in that the estimated values for transverse properties are close to measured values. However, the use of MTEB 5-2 introduces another measure of conservatism which is then carried through all other calculations which utilize the estimated values. For example, when changes in USE are predicted using Regulatory Guide 1.99 (Ref. 11), if the estimated value of USE is 10% lower than the actual then the predicted USE will always be 10% lower than if the actual properties were used.

Therefore, the use of actual materials data is preferred to eliminate the need to introduce additional conservatism into the procedures for predicting the irradiated properties of the RPV beltline materials. Archive materials are not available for all RPV materials and some plants are forced to use the estimation procedures for establishing unirradiated properties for beltline materials. Archive materials were identified in ABB-CENS inventory for the plates used in the intermediate shell and lower shell courses for the Millstone Unit 2 RPV. The following sections of this report document the materials, testing and results for Charpy impact testing of transverse orientation specimens from the intermediate shell plate archive materials. These data may now be used in the evaluation of the Millstone Unit 2 intermediate shell plates for prediction of irradiation damage, instead of the estimated values from MTEB 5-2 (Ref. 12).

3.0 MATERIALS

The intermediate shell plates of Millstone Unit 2 RPV are identified as Piece Numbers C-505-1, C-505-2 and C-505-3 (Ref. 20). The heat number is C5843 from Lukens steel. Portions of each of the intermediate shell course plates were retained as archive materials, as shown on C-E Drawings E-233-535 and E-233-798 (Refs. 21 & 22). The simulated post-weld heat treatment (PWHT) of these plate sections had been previously certified (Ref. 13). A copy of the certification for the simulated PWHT conditions is included as Appendix A-1 to this report for convenience. The ABB-CENS archive inventory numbers for these three pieces of

plate are F04 (C-505-1), F05 (C-505-2) and F06 (C-505-3).

The plate materials used for testing were retrieved from the archive storage location. The identification markings as shown in Refs. 21 & 22 were verified along with the ABB-CENS archive inventory marking and the direction of major rolling. A section was taken from each piece of archive plate for machining the Charpy impact specimens. A specimen layout was provided to the machine shop with the specimen axis in the transverse direction with respect to the direction of major rolling of the plate. A total of 24 Charpy impact specimens were machined for each plate material. The width of the archive plate sections was sufficient to obtain the set of 24 specimens from a double layer of specimens taken at a 1/4t position in the plate thickness. It was not possible to confirm positively that the 1/4t location from which the specimens were machined corresponds to the 1/4t position of the Millstone Unit 2 reactor vessel. The specimen location could be either the 1/4t or 3/4t location with respect to the plate in the RPV. Either location is acceptable according to both ASME Code (Ref. 5, Paragraph NB-2222) and ASTM E 185 (Ref. 8) requirements for specimen location for determining material properties.

4.0 TESTING

Standard Charpy impact testing was performed in accordance with ABB-CENS Procedure 00000-MCC-113 (Ref. 16) and ASTM E 23 (Ref. 17). The Charpy impact test system was certified using NIST standard reference material (SRM) test specimens. Testing was performed over a temperature range of -80°F to 300°F to establish the full Charpy impact curve from lower shelf, transition region and upper shelf. Temperature baths using freon, ethylene glycol and silicone oil were utilized for low, medium and high temperatures, respectively. Specimens tested at 300°F were pre-heated in an air oven prior to testing. In each case, a calibrated digital thermometer was used to monitor the specimen temperatures for each test.

Upon completion of testing, lateral expansion measurements were taken on each fractured specimen using a calibrated dial indicator lateral expansion gage (EW-184). Percent shear fracture for each specimen was estimated visually and by comparison to the fracture appearance charts contained in ASTM E 23 (Ref. 17).

Test data were compiled in a data base format compatible with the PR-EDB database (Ref. 18). Data for Millstone Unit 2 surveillance materials were sorted out from the PR-EDB data base and compiled with the test data and previous test results for the Millstone Unit 2 RPV beltline materials obtained from the original Certified Material Test Reports (CMTR's) for the lower and intermediate shell course plates. The PR-EDB programs were then used to provide hyperbolic tangent curve fits for each set of test data contained in the data file.

5.0 RESULTS & DISCUSSION

The results of the Charpy impact tests on the transverse specimens are provided in Tables 1, 3 and 5 for plates C-505-1, C-505-2 and C-505-3, respectively. The corresponding longitudinal data from the original testing of each plate is shown in Tables 2, 4 and 6. Tables 7, 8 and 9 provide the Charpy impact data for lower shell plate C-506-1 from the surveillance program baseline results and the original CMTR for the material. Tables 10 and 11 provide the longitudinal Charpy impact test data for the remaining two lower shell plates C-506-2 and C-506-3. There are no transverse data available for either of these two plates.

Hyperbolic tangent curve fits were performed for each plate for all of the available Charpy impact data for the Millstone Unit 2 intermediate and lower shell course plates. The curve fitting was performed using the database generated from the current test data, original CMTR test results and baseline data from the surveillance program. The database was compiled in a format compatible with the PR-EDB database. (Ref. 18) Curve fitting was performed with the PR-EDB program. The parameters for the hyperbolic tangent curve obtained from the curve fitting are shown in Table 12.

The longitudinal and transverse data for plates C-505-1, 2 and 3 are shown in Figures 1, 2 and 3, respectively. The hyperbolic tangent curve fit for each data set is also plotted on the figures. Figure 4 shows the longitudinal data for plate C-506-1 and Figure 5 shows a comparison of both transverse and longitudinal data for this same plate from the surveillance program baseline testing results (Ref. 14). Figures 6 and 7 show the available longitudinal data for plates C-506-2 and C-506-3. Note in Figures 4, 6 and 7 that test samples were taken and reported on the CMTR's at both the 1/4t and 1/2t locations in these plates. Only the test data taken on 1/4t specimens was used for the hyperbolic tangent curve fits shown in these figures.

Photographs of the fracture surfaces of the Charpy specimens are shown in Figures 8, 9 and 10 for plates C-505-1, C-505-2 and C-505-3, respectively.

ASTM E 185-82 defines the upper shelf energy level as being the average energy value for all Charpy specimens whose test temperature is above the upper end of the transition region. For specimens tested in sets of three at each test temperature, the set having the highest average may be regarded as defining the upper shelf energy (Ref. 8). Table 13 shows a determination of upper shelf energy based on the ASTM E 185-82 definition for the three intermediate shell plates from the current test data. The USE values based on the transverse specimen test data are significantly higher than what was previously reported for USE of these plates (Ref. 1). The previous values were determined from the longitudinal Charpy data using MTEB 5-2 (Ref. 12). Comparing the USE values in Tables 12 and 13, note also there was excellent agreement between the ASTM E 185-82 definitions of

USE and the USE values obtained from the hyperbolic tangent curve fits. The largest difference between the two determinations of USE was only 1.2 ft-lb for plate C-505-3.

Table 14 provides a comparison of the initial and predicted EOL USE values for the intermediate and lower shell plates. The EOL values were conservatively estimated assuming a 38% to 38.9% decrease for the plates based on method 2.2 of Regulatory Guide 1.99 (Ref. 11), which uses the surveillance capsule data to establish a new curve for determining decrease in USE. Comparison of the predicted EOL values in Table 14 shows a significant advantage to having the transverse specimen data available. The advantage is that the estimated EOL USE values for plates C-505-1, 2 and 3 are predicted to fall below the required 50 ft-lb level (Ref. 9) when longitudinal data are converted by MTEB 5-2 (Ref. 12). The actual transverse USE based on test data is significantly higher than the converted value and the predicted EOL USE for the intermediate shell course plates does not fall below 50 ft-lb.

6.0 SUMMARY

Transverse oriented Charpy impact test specimens were machined from archive plate materials from ABB-CENS storage. Testing was performed over the temperature range of -80°F to 300°F to develop the full Charpy impact energy curve. These data may now be used in the evaluation of the Millstone Unit 2 intermediate shell plates for prediction of irradiation damage. The test results demonstrated that the actual USE for the transverse orientation is significantly higher than that predicted from longitudinal data by Ref. 12. Based on the measured transverse USE, the predicted EOL USE energy is greater than 50 ft-lbs for each of the three intermediate shell plates.

7.0 REFERENCES

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7) ASTM E 185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels," American Society for Testing and Materials, Philadelphia, PA.

8) ASTM E 185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E 706(IF)," American Society for Testing and Materials, Philadelphia, PA.

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20) Drawing E-233-543, Revision 2, "Material Identification - Vessel," Combustion Engineering, Chattanooga, TN.

21) Drawing E-233-535, Revision 1, "Vessel Shells Forming and Fit-Up," Combustion Engineering, Chattanooga, TN.

22) Drawing E-233-798, Revision 3, "Surveillance Test Material Fabrication for Northeast Utilities," Combustion Engineering, Chattanooga, TN.

TABLE 1

CHARPY V-NOTCH IMPACT TEST RESULTS

BASE METAL PLATE C-505-1, TRANSVERSE ORIENTATION

DROP WEIGHT NDTT = -20°F   INITIAL RT_{NDT} = +20°F

UPPER SHELF ENERGY = 88.4 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
F04-6	-80	7.0	16.0	0
F04-20	-40	11.5	17.0	0
F04-10	0	38.0	35.5	5
F04-14	40	38.2	37.5	10
F04-8	65	48.0	54.5	30
F04-17	65	50.0	51.5	30
F04-4	66	54.2	55.0	30
F04-19	80	59.1	57.0	50
F04-24	80	60.8	61.0	60
F04-22	80	57.8	52.0	70
F04-23	100	68.0	66.0	80
F04-21	100	75.8	74.5	80
F04-9	120	79.2	77.5	90
F04-5	160	83.1	84.0	95
F04-15	160	82.5	77.5	100
F04-12	160	87.0	75.5	100
F04-18	200	85.1	78.0	100
F04-2	200	84.0	78.5	100
F04-13	200	91.0	82.0	100
F04-7	240	90.2	81.0	100
F04-1	240	84.0	80.5	100
F04-11	240	90.0	81.0	100
F04-3	300	88.0	85.0	100
F04-16	300	81.8	81.0	100

TABLE 2

CHARPY V-NOTCH IMPACT TEST RESULTS

BASE METAL PLATE C-505-1, LONGITUDINAL ORIENTATION

DROP WEIGHT NDTT = -20°F   INITIAL RT_{NDT} = +20°F

UPPER SHELF ENERGY = 116.6 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
1	-40	9.0	4.0	0
2	-40	15.0	8.0	1
3	-40	10.0	3.0	0
4	10	40.0	27.0	15
5	10	44.0	30.0	20
6	10	25.0	16.0	10
7	40	67.0	47.0	30
8	40	49.0	35.0	20
9	40	60.0	42.0	25
10	110	95.0	67.0	70
11	110	98.0	69.0	80
12	110	92.0	63.0	70
13	160	124.0	82.0	100
14	160	108.0	75.0	100
15	160	118.0	76.0	100

TABLE 3

CHARPY V-NOTCH IMPACT TEST RESULTS

BASE METAL PLATE C-505-2, TRANSVERSE ORIENTATION

DROP WEIGHT NDTT = -10°F   INITIAL RT_{NDT} = +20°F

UPPER SHELF ENERGY = 89.3 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
F05-9	-80	5.0	14.0	0
F05-2	-40	10.8	21.0	0
F05-12	0	23.5	34.5	5
F05-18	40	36.2	43.5	15
F05-14	65	48.0	50.0	20
F05-20	65	35.2	41.0	30
F05-19	66	52.0	53.5	30
F05-23	80	56.0	57.0	40
F05-7	80	54.8	52.5	40
F05-21	80	53.0	51.5	50
F05-24	100	81.2	78.0	70
F05-22	100	70.0	55.0	60
F05-11	120	74.0	71.0	100
F05-15	160	87.0	81.0	100
F05-3	160	77.0	71.0	100
F05-17	160	89.8	82.0	100
F05-13	200	85.2	82.0	100
F05-8	200	95.8	88.0	100
F05-1	200	86.8	82.0	100
F05-4	240	83.5	79.0	100
F05-16	240	84.8	76.0	100
F05-5	240	86.5	75.5	100
F05-6	300	87.5	76.0	100
F05-10	300	87.5	76.5	100

TABLE 4

CHARPY V-NOTCH IMPACT TEST RESULTS

BASE METAL PLATE C-505-2, LONGITUDINAL ORIENTATION

DROP WEIGHT NDTT = -10°F   INITIAL RT_{NDT} = +20°F

UPPER SHELF ENERGY = 122.0 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
1	-40	9.0	3.0	0
2	-40	8.0	3.0	0
3	-40	11.0	4.0	0
4	10	49.0	33.0	20
5	10	38.0	27.0	15
6	10	40.0	26.0	15
7	40	49.0	35.0	25
8	40	43.0	33.0	20
9	0	36.0	28.0	15
10	110	115.0	75.0	80
11	110	99.0	72.0	90
12	110	100.0	72.0	80
13	160	127.0	75.0	100
14	160	116.0	74.0	100
15	160	123.0	80.0	100

TABLE 5

CHARPY V-NOTCH IMPACT TEST RESULTS

BASE METAL PLATE C-505-3, TRANSVERSE ORIENTATION

DROP WEIGHT NDTT = -10°F INITIAL RT_{NDT} = +5°F

UPPER SHELF ENERGY = 94.6 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
F06-20	-80	4.0	13.5	0
F06-17	-40	10.2	21.0	0
F06-11	0	24.2	33.0	5
F06-2	40	41.8	44.0	10
F06-5	65	55.2	59.0	25
F06-7	65	55.0	58.5	30
F06-4	66	52.2	54.0	20
F06-24	80	60.0	58.0	30
F06-22	80	56.2	52.5	40
F06-18	80	68.5	59.0	50
F06-23	100	66.0	62.5	40
F06-21	100	59.0	62.5	40
F06-13	120	77.1	67.0	60
F06-15	160	92.8	80.0	100
F06-3	160	91.0	86.0	100
F06-16	160	96.0	74.0	100
F06-19	200	97.0	80.0	100
F06-14	200	88.0	75.0	100
F06-9	200	88.0	80.0	100
F06-1	240	92.8	79.0	100
F06-10	240	93.0	83.0	100
F06-6	240	98.0	87.0	100
F06-8	300	89.0	82.0	100
F06-12	300	92.0	81.0	100

TABLE 6

CHARPY V-NOTCH IMPACT TEST RESULTS

BASE METAL PLATE C-505-3, LONGITUDINAL ORIENTATION

DROP WEIGHT NDTT = -10°F   INITIAL RT_{NDT} = +5°F

UPPER SHELF ENERGY = ~~177.7~~ 117.7 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
1	-40	12.0	5.0	0
2	-40	12.0	6.0	0
3	-40	8.0	3.0	0
4	10	30.0	22.0	15
5	10	49.0	36.0	25
6	10	26.0	19.0	10
7	40	57.0	41.0	30
8	40	61.0	41.0	30
9	40	57.0	41.0	30
10	110	101.0	74.0	80
11	110	91.0	66.0	80
12	110	92.0	61.0	80
13	160	115.0	79.0	100
14	160	123.0	80.0	100
15	160	115.0	78.0	100

TABLE 7

CHARPY V-NOTCH IMPACT TEST RESULTS - SURVEILLANCE BASELINE

BASE METAL PLATE C-506-1, TRANSVERSE ORIENTATION

DROP WEIGHT NDTT = -10°F INITIAL RT_{NDT} = 6°F

UPPER SHELF ENERGY = 108 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
22M	-80	4.0	3.0	0
235	-40	15.5	16.0	15
265	0	32.5	31.0	25
264	0	36.0	32.0	25
233	40	40.0	38.0	35
221	60	42.0	38.0	35
22P	60	50.0	46.0	45
261	70	53.5	49.0	50
23D	70	58.5	56.0	60
24A	70	66.0	58.0	65
246	80	66.5	59.0	65
23C	120	91.5	76.0	90
25B	120	94.5	73.0	80
22C	160	106.5	80.0	100
24D	160	113.0	85.0	100
256	180	112.5	82.0	100
22Y	210	96.0	76.0	100
236	210	112.0	82.0	100

TABLE 8

CHARPY V-NOTCH IMPACT TEST RESULTS - SURVEILLANCE BASELINE

BASE METAL PLATE C-506-1, LONGITUDINAL ORIENTATION

DROP WEIGHT NDTT = -10°F   INITIAL RT_{NDT} = +6°F

UPPER SHELF ENERGY = 129.6 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
11M	-80	4.5	3.0	0
161	-40	7.0	9.0	10
12E	0	13.5	16.0	20
163	40	32.0	33.0	35
13U	60	45.5	44.0	45
15K	60	56.0	48.0	45
12C	80	45.0	42.0	45
11D	80	77.0	66.0	60
12D	90	62.5	54.0	65
13E	90	79.5	67.0	70
13K	90	89.0	67.0	70
15L	120	116.0	87.0	85
11E	120	119.0	86.0	90
14Y	160	124.5	89.0	100
15P	160	134.5	91.0	100
13J	210	130.0	90.0	100
152	210	136.5	89.0	100

TABLE 9

CHARPY V-NOTCH IMPACT TEST RESULTS - MANUFACTURING CMTR

BASE METAL PLATE C-506-1, LONGITUDINAL ORIENTATION

DROP WEIGHT NDTT = -10°F   INITIAL RT_{NDT} = +6°F

UPPER SHELF ENERGY = 112 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
1	-40	14.0	15.0	0
2	-40	17.0	12.0	0
3	-40	24.0	20.0	5
4	10	33.0	29.0	20
5	10	50.0	41.0	25
6	10	37.0	31.0	20
7	40	50.0	40.0	25
8	40	49.0	40.0	25
9	40	46.0	36.0	25
10	110	73.0	62.0	60
11	110	79.0	69.0	65
12	110	81.0	70.0	65
13	160	116.0	89.0	99
14	160	94.0	80.0	95
15	212	114.0	88.0	100
16	212	110.0	85.0	100

TABLE 10

CHARPY V-NOTCH IMPACT TEST RESULTS - MANUFACTURING CMTR

BASE METAL PLATE C-506-2, LONGITUDINAL ORIENTATION

DROP WEIGHT NDTT = -40°F INITIAL RT_{NDT} = -30°F

UPPER SHELF ENERGY = 132.5 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
1	-40	12.0	11.0	0
2	-40	17.0	14.0	0
3	-40	35.0	23.0	10
4	10	59.0	43.0	30
5	10	53.0	40.0	30
6	10	64.0	47.0	30
7	40	85.0	63.0	40
8	40	80.0	60.0	40
9	40	76.0	55.0	35
10	110	116.0	81.0	90
11	110	118.0	83.0	90
12	110	115.0	83.0	90
13	160	130.0	85.0	100
14	160	138.0	90.0	100
15	212	127.0	86.0	100
16	212	135.0	91.0	100

TABLE 11

CHARPY V-NOTCH IMPACT TEST RESULTS - MANUFACTURING CMTR

BASE METAL PLATE C-506-3, LONGITUDINAL ORIENTATION

DROP WEIGHT NDTT = -30°F INITIAL RT_{NDT} = 0°F

UPPER SHELF ENERGY = 135.5 ft-lbs.

SPECIMEN NUMBER	TEST TEMPERATURE (°F)	IMPACT ENERGY (ft-lb)	LATERAL EXPANSION (mils)	PERCENT SHEAR (%)
1	-40	30.0	22.0	10
2	-40	12.0	11.0	0
3	-40	14.0	12.0	0
4	10	41.0	30.0	20
5	10	56.0	38.0	25
6	10	65.0	45.0	30
7	40	96.0	69.0	50
8	40	87.0	61.0	45
9	40	66.0	49.0	30
10	110	104.0	76.0	80
11	110	103.0	72.0	80
12	110	89.0	66.0	60
13	160	135.0	88.0	100
14	160	134.0	87.0	100
15	212	139.0	86.0	100
16	212	134.0	85.0	100

TABLE 12

PR-EDB TANH CURVE FITTING OF CHARPY V-NOTCH IMPACT TEST DATA

PLATE I.D.	ORIENT.	USE (ft-lb)	LSE (ft-lb)	CVT(1/2) (°F)	SLOPE
C-505-1	TL	122.2	2.2	50.0	0.00865
C-505-1	LT	88.7	2.2	46.4	0.00804
C-505-2	TL	136.5	2.2	64.4	0.00840
C-505-2	LT	88.3	2.3	59.0	0.01008
C-505-3	TL	123.6	2.2	51.8	0.00865
C-505-3	LT	93.4	2.2	55.4	0.00881
C-506-1	TL	133.9	2.3	73.4	0.01424
C-506-1	LT	116.5	2.3	68.0	0.00783
C-506-2	LT	132.7	2.2	24.8	0.00922
C-506-3	LT	136.6	2.1	35.6	0.00730

TABLE 13

UPPER SHELF ENERGY VALUES FOR MILLSTONE 2

INTERMEDIATE SHELL PLATES

MATERIAL I.D.	160°F	200°F	240°F	ASTM E 185 USE VALUE	GL 92-01 USE VALUE
C-505-1	87.0	91.0	91.0		
	82.5	85.1	84.0		
	83.1	84.0	90.2		
AVERAGE	84.2	86.7	88.4	88.4	75.8
C-505-2	89.8	85.2	84.8		
	77.0	95.8	83.5		
	87.0	86.8	86.5		
AVERAGE	84.6	89.3	84.9	89.3	79.3
C-505-3	91.0	88.0	93.0		
	92.8	88.0	92.8		
	96.0	97.0	98.0		
AVERAGE	93.3	91.0	94.6	94.6	76.5

TABLE 14

COMPARISON OF INITIAL & EOL USE VALUES

PLATE I.D.	ORIENT.	COPPER CONTENT (%)	INITIAL USE (ft-lb)	CALC. INITIAL USE-T (ft-lb)	CALC. EOL USE (ft-lb)
C-505-1	TL	0.13	88.4		54.8
C-505-1	LT	0.13	116.6	75.8	47.0
C-505-2	TL	0.13	89.3		55.4
C-505-2	LT	0.13	122.0	79.3	49.2
C-505-3	TL	0.13	94.6		57.8
C-505-3	LT	0.13	117.7	76.5	46.8
C-506-1	TL	0.14	108.0		66.5
C-506-1	LT	0.14	129.6	84.2	51.8
C-506-2	LT	0.14	132.5	86.1	53.0
C-506-3	LT	0.13	135.5	88.1	54.3

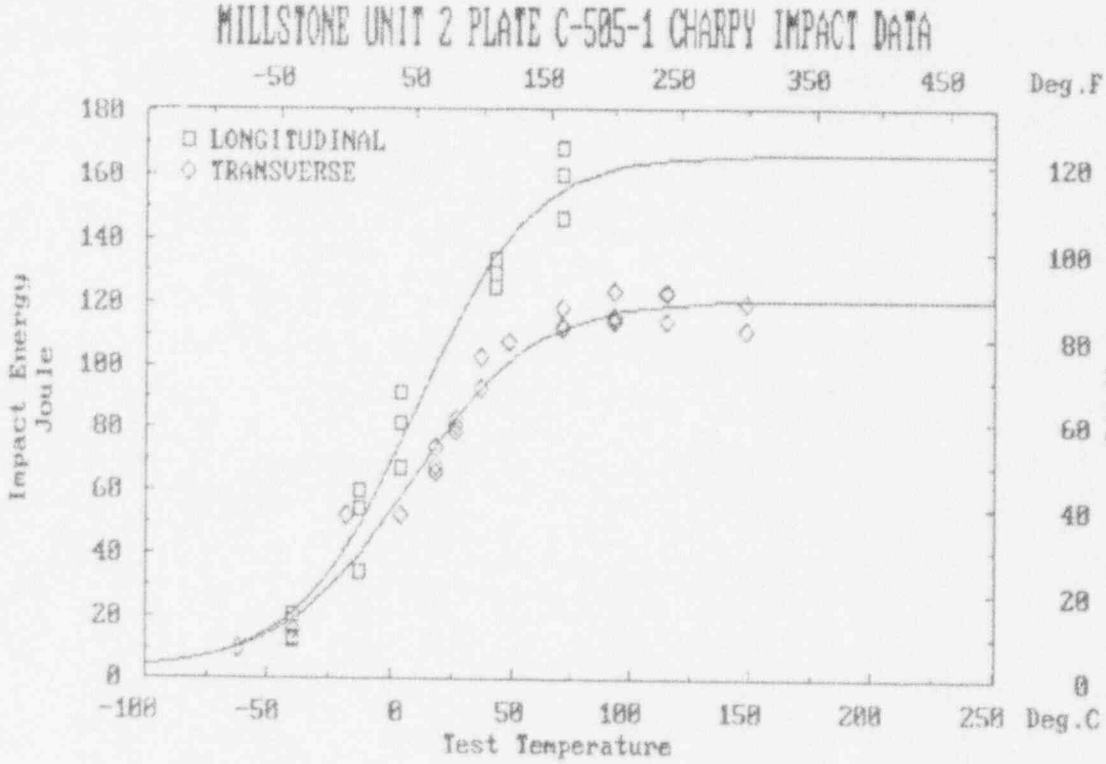


FIGURE 1 - CHARPY IMPACT TEST DATA FOR PLATE C-505-1

MILLSTONE UNIT 2 PLATE C-505-2 CHARPY IMPACT DATA

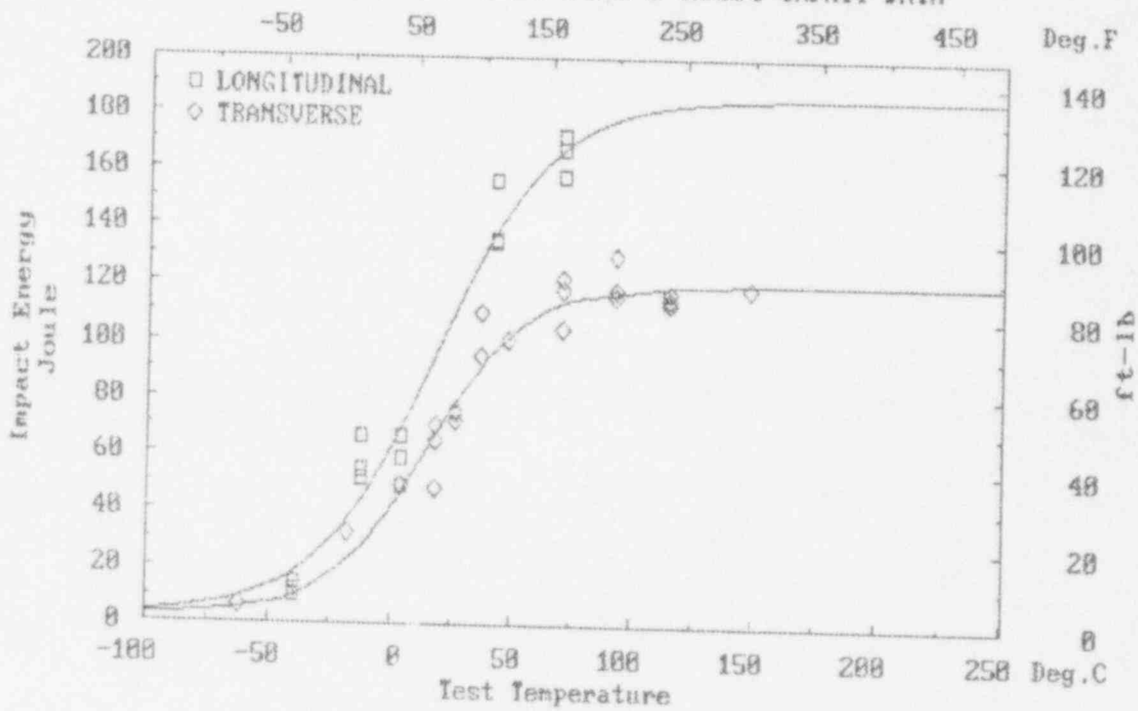


FIGURE 2 - CHARPY IMPACT TEST DATA FOR PLATE C-505-2

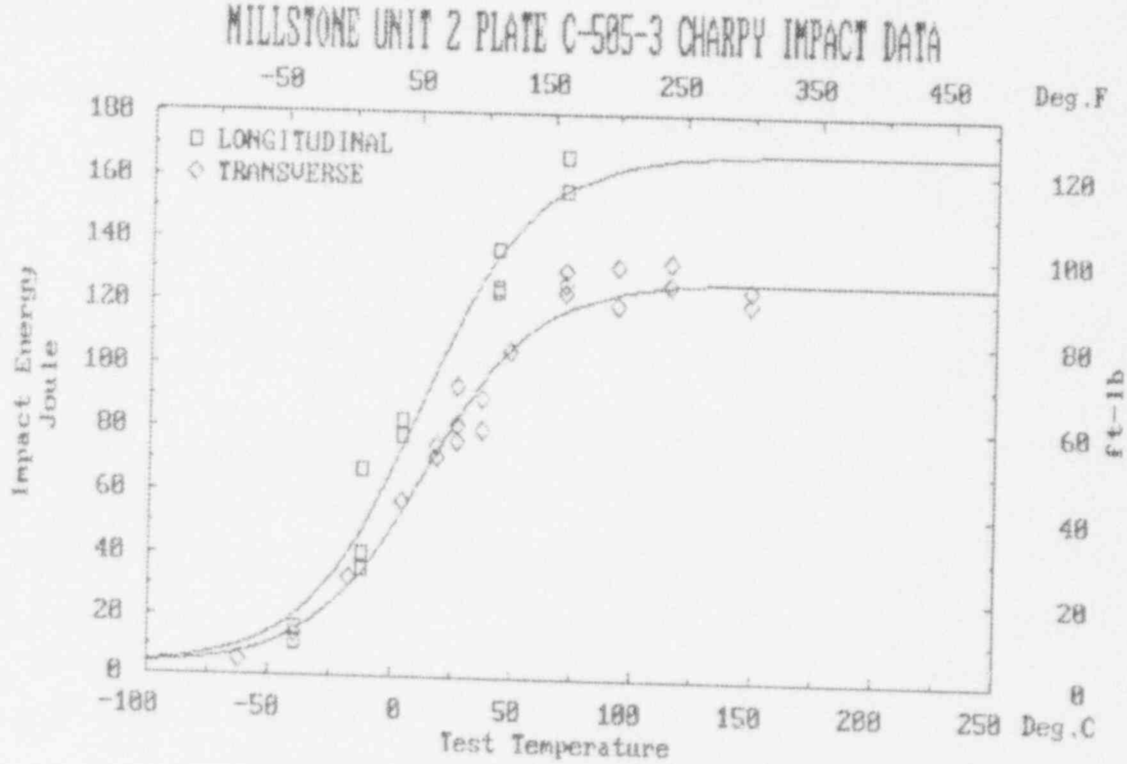


FIGURE 3 - CHARPY IMPACT TEST DATA FOR PLATE C-505-3

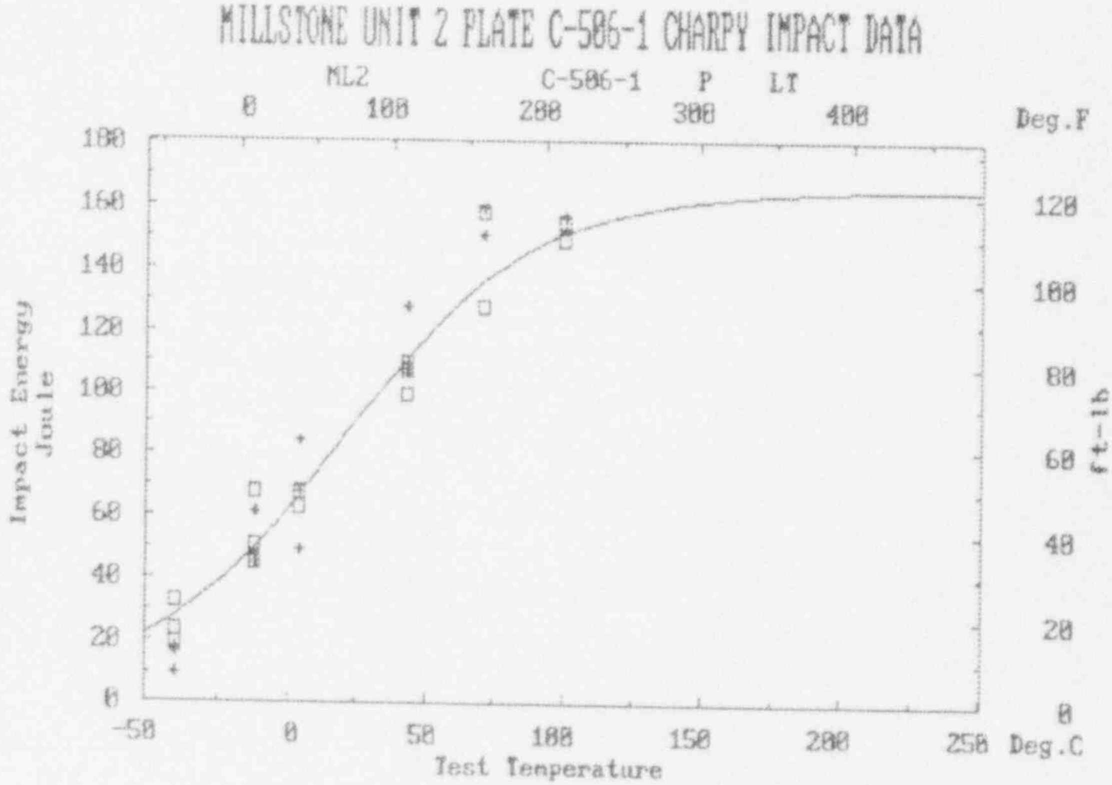


FIGURE 4 - CHARPY IMPACT TEST DATA FOR PLATE C-506-1
DATA FROM MANUFACTURING CMTR FOR PLATE
LONGITUDINAL TEST DATA ONLY AT 1/4T AND 1/2T LOCATIONS

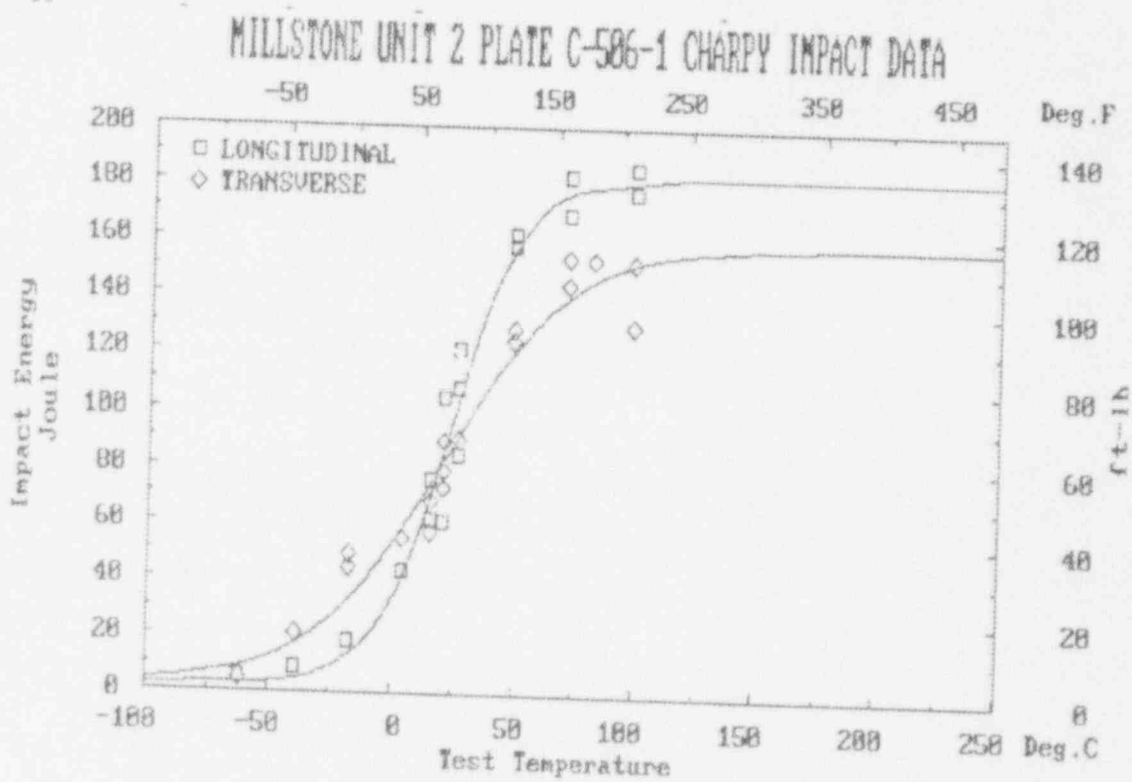


FIGURE 5 - CHARPY IMPACT TEST DATA FOR PLATE C-506-1
DATA FROM BASELINE TEST RESULTS FROM SURVEILLANCE PROGRAM

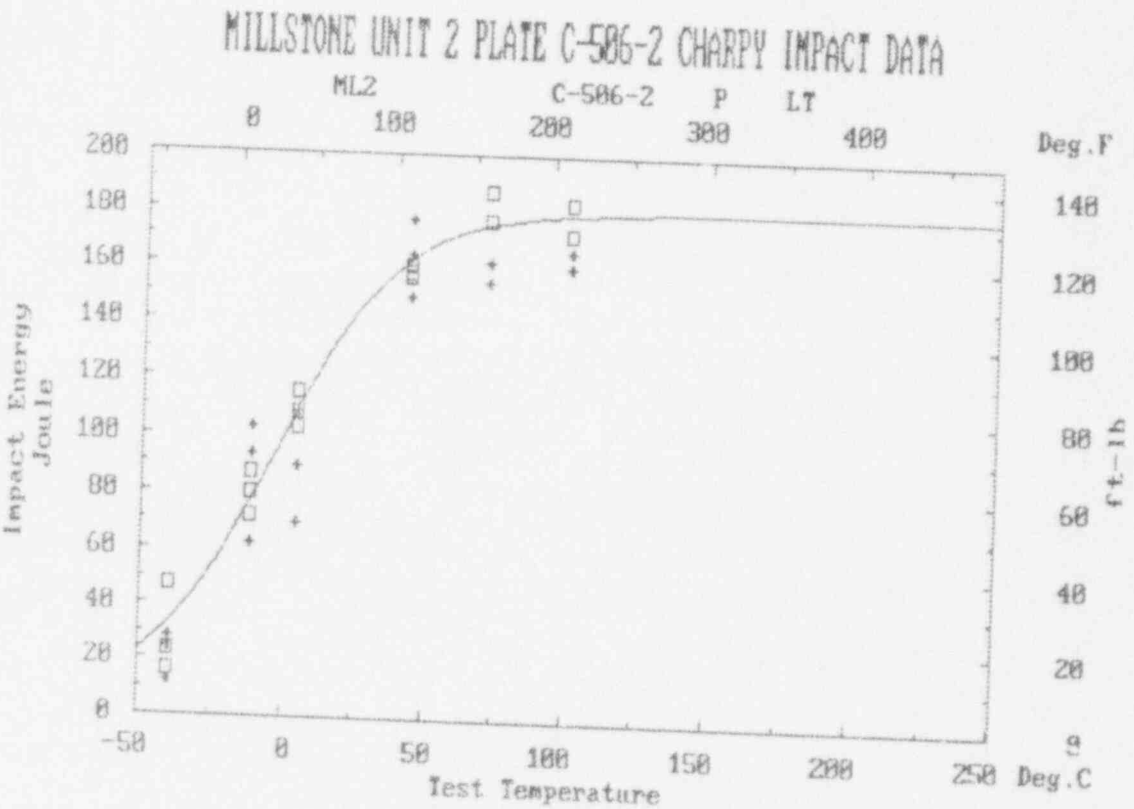


FIGURE 6 - CHARPY IMPACT TEST DATA FOR PLATE C-506-2
LONGITUDINAL TEST DATA ONLY AT 1/4T AND 1/2T LOCATIONS

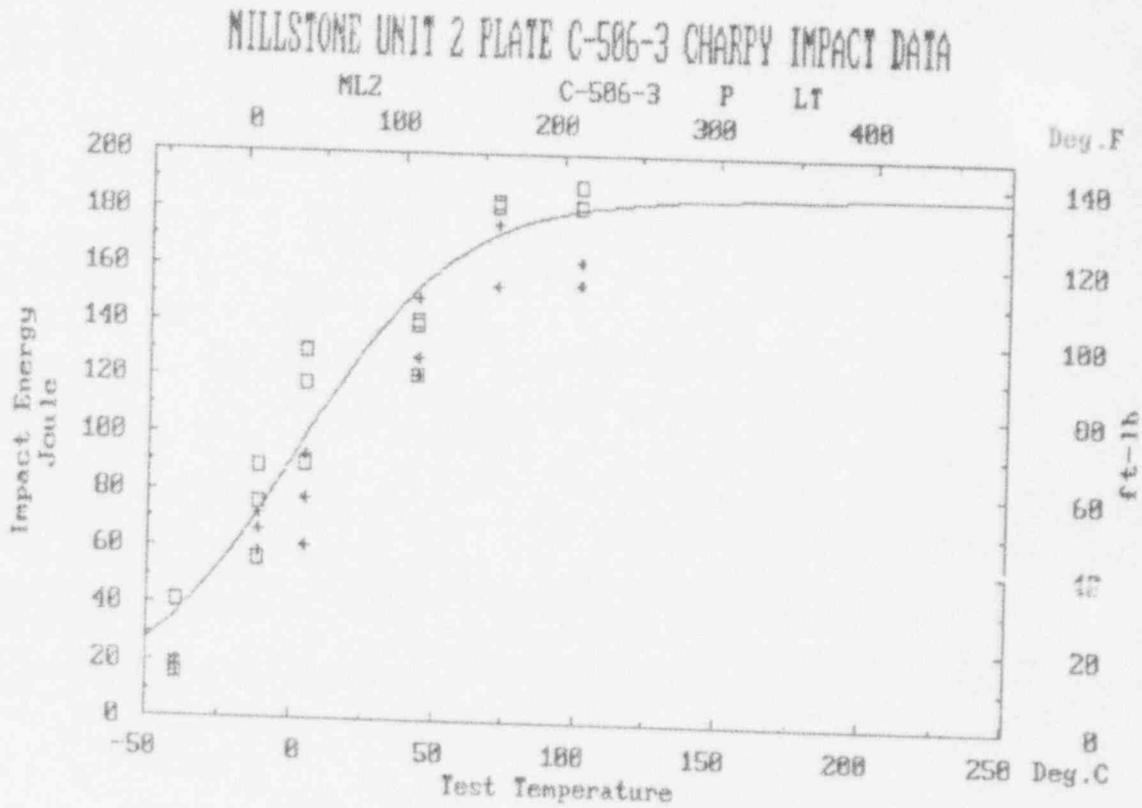
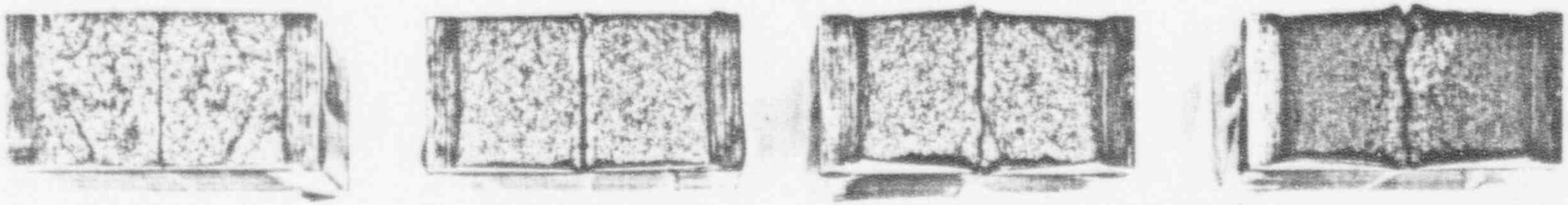
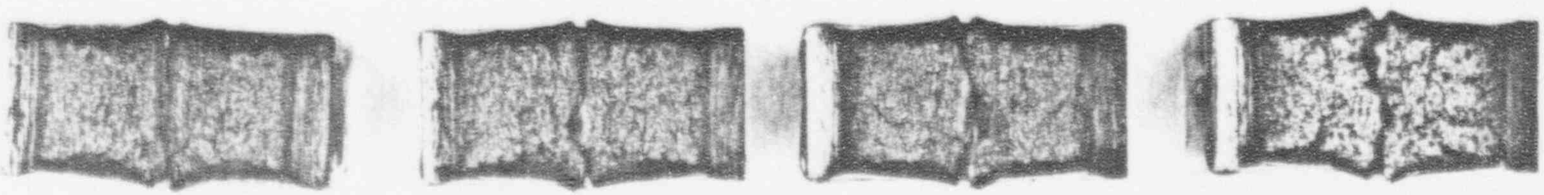


FIGURE 7 - CHARPY IMPACT TEST DATA FOR PLATE C-506-3
LONGITUDINAL TEST DATA ONLY AT 1/4T AND 1/2T LOCATIONS

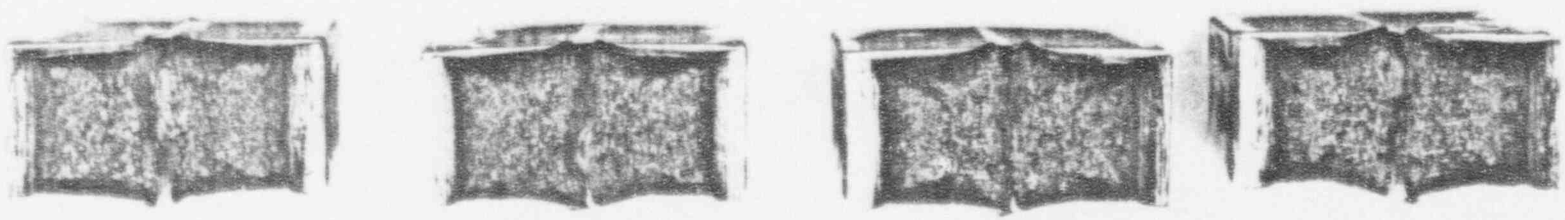
FIGURE 8



SPECIMEN NO.:	FO4-6	FO4-20	FO4-10	FO4-14
TEMPERATURE:	-80°F	-40°F	0°F	40°F

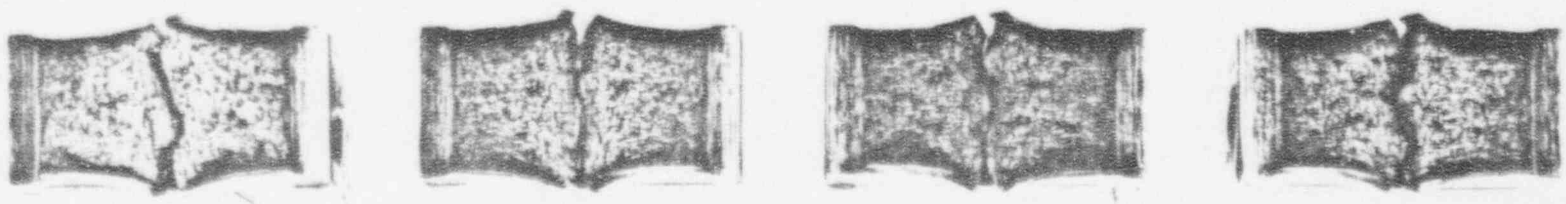


SPECIMEN NO.:	FO4-8	FO4-17	FO4-4	FO4-19
TEMPERATURE:	65°F	65°F	66°F	80°F

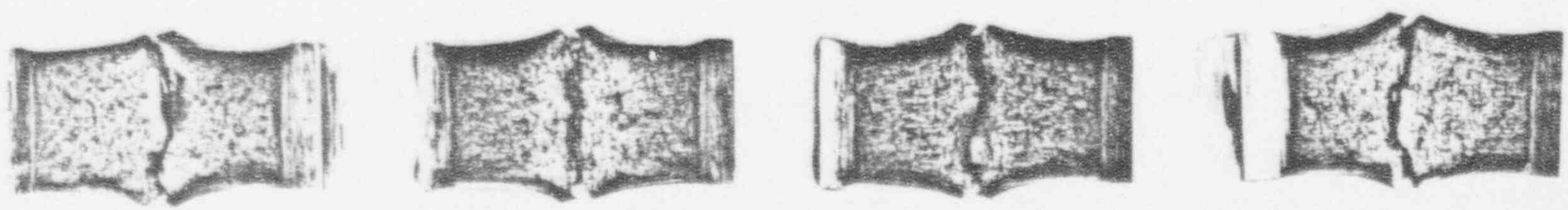


SPECIMEN NO.:	FO4-24	FO4-22	FO4-23	FO4-21
TEMPERATURE:	80°F	80°F	100°F	100°F

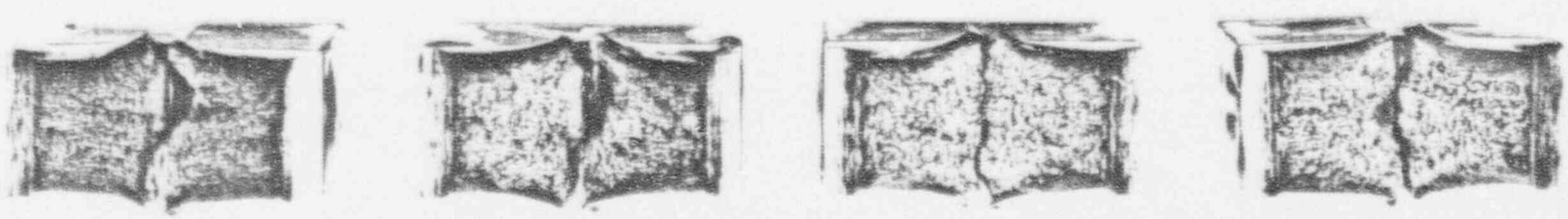
FIGURE 8 (Cont.)



SPECIMEN NO.: F04-9 F04-5 F04-15 F04-12
TEMPERATURE: 120°F 160°F 160°F 160°F

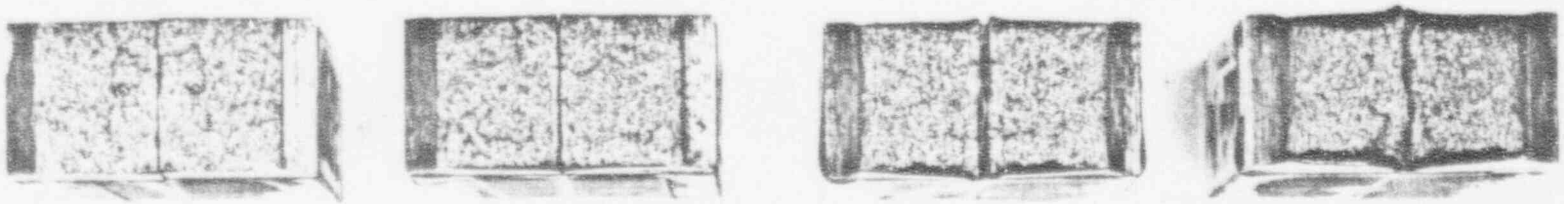


SPECIMEN NO.: F04-18 F04-2 F04-13 F04-7
TEMPERATURE: 200°F 200°F 200°F 240°F

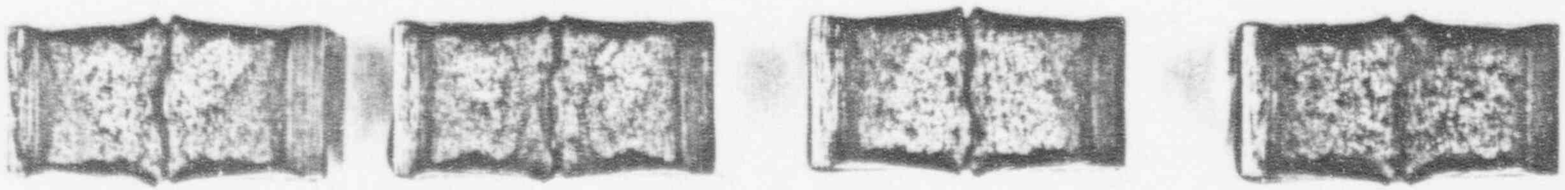


SPECIMEN NO.: F04-1 F04-11 F04-3 F04-16
TEMPERATURE: 240°F 240°F 300°F 300°F

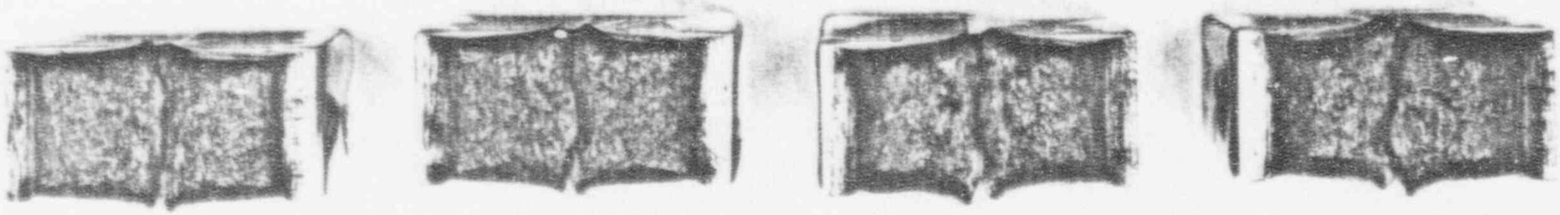
FIGURE 9



SPECIMEN NO.:	F05-9	F05-2	F05-12	F05-18
TEMPERATURE:	-80°F	-40°F	0°F	40°F

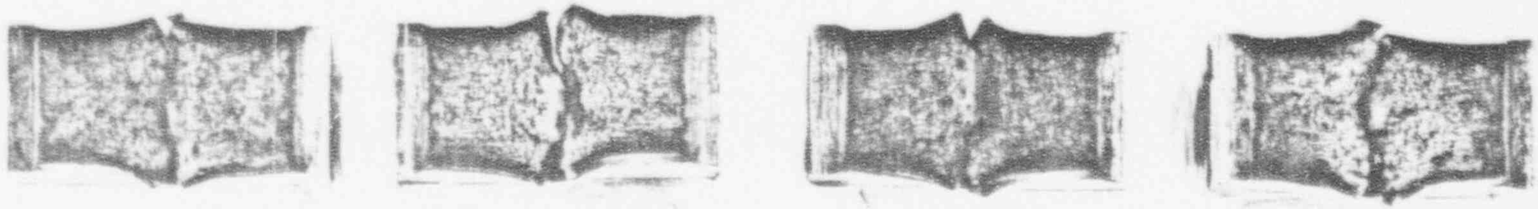


SPECIMEN NO.:	F05-19	F05-20	F05-14	F05-7
TEMPERATURE:	65°F	65°F	66°F	80°F

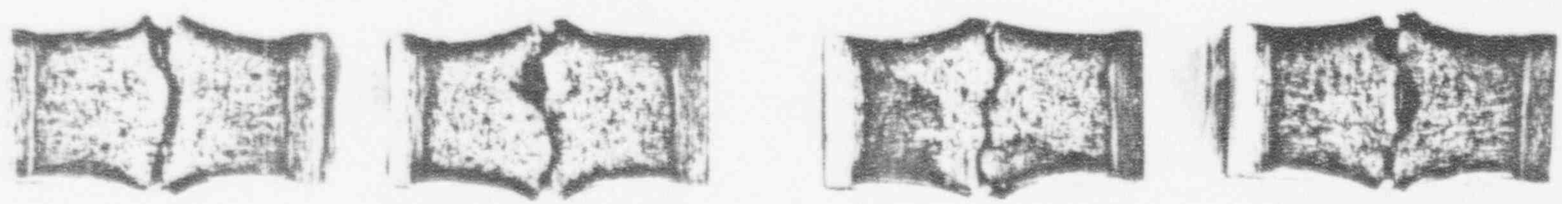


SPECIMEN NO.:	F05-21	F05-23	F05-22	F05-24
TEMPERATURE:	80°F	80°F	100°F	100°F

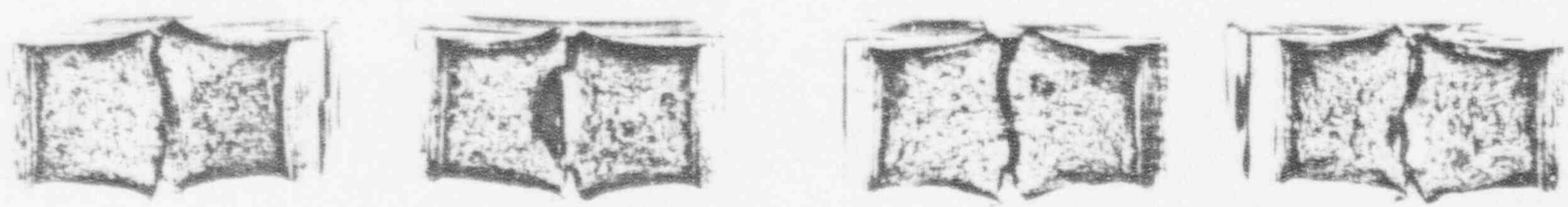
FIGURE 9 (Cont.)



SPECIMEN NO.:	FO5-11	FO5-3	FO5-17	FO5-15
TEMPERATURE:	120°F	160°F	160°F	160°F

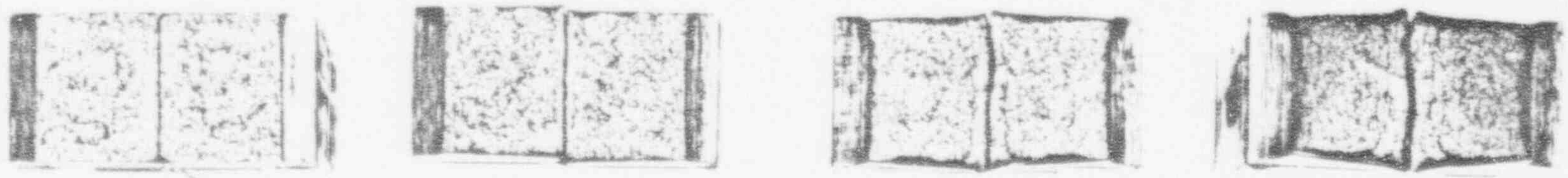


SPECIMEN NO.:	FO5-13	FO5-1	FO5-8	FO5-5
TEMPERATURE:	200°F	200°F	200°F	240°F

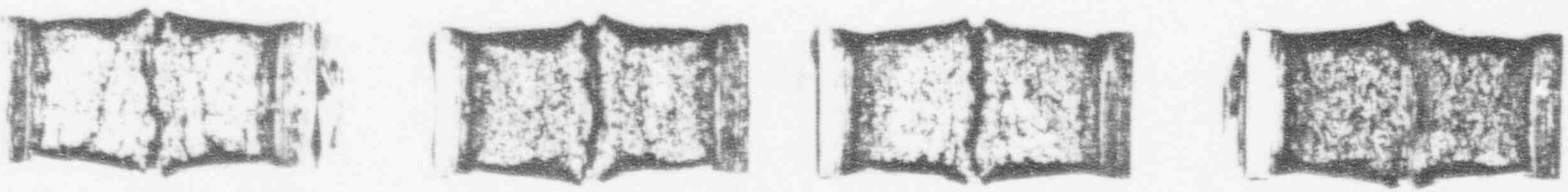


SPECIMEN NO.:	FO5-4	FO5-16	FO5-6	FO5-10
TEMPERATURE:	240°F	240°F	300°F	300°F

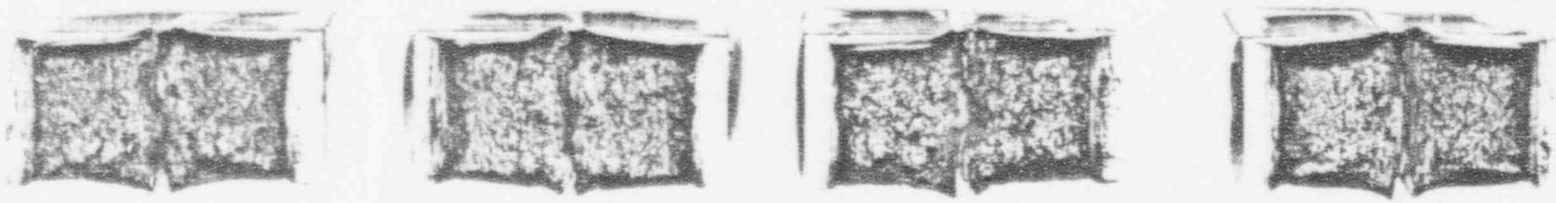
FIGURE 10



SPECIMEN NO.: F06-20 F06-17 F06-11 F06-2
TEMPERATURE: -80°F -40°F 0°F 40°F

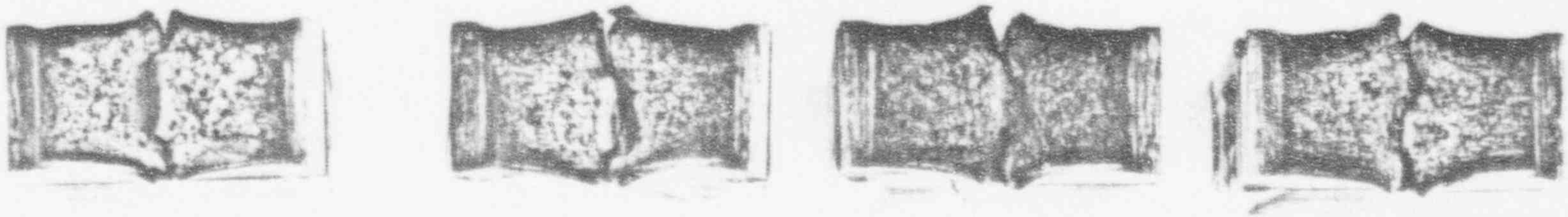


SPECIMEN NO.: F06-7 F06-5 F06-4 F06-18
TEMPERATURE: 65°F 65°F 66°F 80°F

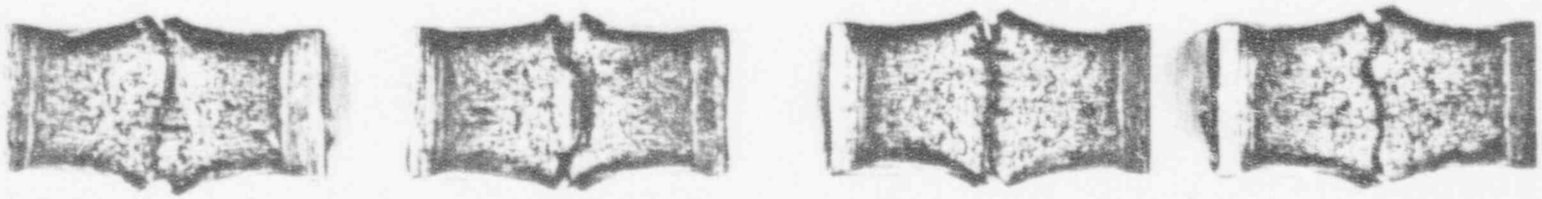


SPECIMEN NO.: F06-22 F06-24 F06-21 F06-23
TEMPERATURE: 80°F 80°F 100°F 100°F

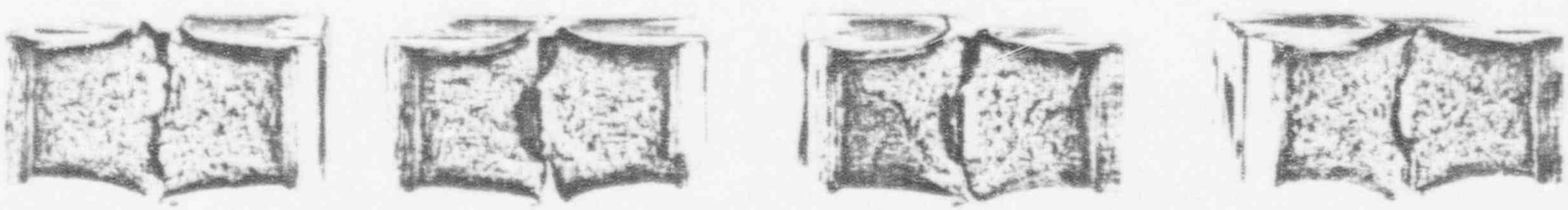
FIGURE 10 (Cont.)



SPECIMEN NO.:	F06-13	F06-16	F06-15	F06-3
TEMPERATURE:	120°F	160°F	160°F	160°F



SPECIMEN NO.:	F06-19	F06-14	F06-9	F06-10
TEMPERATURE:	200°F	200°F	200°F	240°F



SPECIMEN NO.:	F06-6	F06-1	F06-12	F06-8
TEMPERATURE:	240°F	240°F	300°F	300°F

APPENDIX A-1

CERTIFICATION OF NDT & PWHT

OF MILLSTONE UNIT 2

SURVEILLANCE PROGRAM MATERIALS

COMBUSTION DIVISION, COMBUSTION ENGINEERING, INC.
911 W. MAIN ST., CHATTANOOGA, TENN. 37401 615-265-4631

APPENDIX A-1

COMBUSTION DIVISION
CHATTANOOGA WORKS

January 26, 1972

TO WHOM IT MAY CONCERN:

This is to certify that all required nondestructive testing on Contract X-96351, Northeast Surveillance Test Program was satisfactorily completed.

The one (1) test plate coded C-504-1 received a total of 40-1/4 hours at a temperature range of 1100° F. - 1175° F. The five (5) test plates coded C-504-2 and -3, and C-505-1, -2, and -3 received a total of 40 hours at a temperature range of 1100° F. - 1175° F. The one (1) test plate containing code numbers C-506-1, -2, and -3 received a total of 44-1/4 hours at a temperature range of 1100° F. - 1175° F. The heat-up and cool-down rate was in accordance with M&P 4.3.8.5(b).

Very truly yours,

COMBUSTION ENGINEERING, INC.

H. N. Dinwiddie

H. N. Dinwiddie
Chief Inspector
Nuclear Components Department

HND/rr