Enclosure 1

MPR ASSOCIATES, INC.

# REPORT OF THE EXAMINATION, TESTING, AND EVALUATION OF IRRADIATED REACTOR VESSEL SURVEILLANCE SPECIMENS FROM NINE MILE POINT UNIT 1

## TABLE OF CONTENTS

# I. INTRODUCTION

In accordance with the Code of Federal Regulations (10CFR50), Niagara Mohawk Power Corporation has instituted a reactor vessel materials surveillance program for Nine Mile Point Unit 1 (NMP-1). The program is described in reports issued by the General Electric Company (GE),[1,2] and consists of the periodic testing of samples installed in the reactor vessel to monitor irradiation embrittlement of the reactor vessel material. Three surveillance capsules, each containing Charpy and tensile mechanical property test specimens and iron, copper and nickel dosimeter wires, were inserted in the reactor vessel prior to initial start-up. One of these capsules was removed in March 1979 after having been irradiated for 5.80 effective full power years. A second capsule, the one of primary interest, was removed in March 1982 after an exposure of 7.98 effective full power years (approximately one-fourth of the expected reactor vessel lifetime). This report describes mechanical and physical tests performed on test specimens removed from both capsules at Battelle Columbus Laboratories in accordance with the surveillance testing requirements of 10CFR50.

## II. SUMMARY

Both 300-degree and 30-degree azimuthal reactor vessel surveillance capsule assemblies were removed from the Nine Mile Point Unit 1 vessel and sent to Battelle Columbus Laboratories for testing. The 300-degree capsule was irradiated for 7.98 effective full power years (efpy) and was removed from the reactor after shutdown on March 19, 1982. The 30-degree capsule was removed in March, 1979 and sent to Battelle in November, 1984 for a series of limited tests to confirm results from the 300-degree capsule. This capsule was irradiated for 5.80 efpy. Both capsules were visually examined, opened, and the specimens inventoried. Both baskets contained a complete compliment of six tensile specimens and 24 Charpy specimens.

Two iron, two copper, and two nickel neutron monitor wires from Charpy packets P7 and P8 in the 300-degree capsule were analyzed. The capsule specimens received a fast neutron fluence ($E > 1$ MeV) of $4.78 \times 10^{17}$ n/cm$^2$. The calculated maximum fast neutron fluence at the 1/4-T pressure vessel wall position occurred at about 286-degree azimuthal and was $4.93 \times 10^{17}$ n/cm$^2$ at the time the capsule was removed from the reactor vessel. The lead factor from the capsule to the wall surface was 0.66 which indicates that the flux at the capsule lags the flux at certain vessel wall positions. The lead factors at the 1/4-T and 3/4-T position were calculated to be 0.97 and 3.62, respectively.

Iron and copper neutron monitor wires were also removed from the 30-degree capsule to determine the fast neutron fluence received by the specimens in that capsule. The capsule specimens received a fast neutron fluence of $3.6 \times 10^{17}$ nvt

(E > 1MeV). Lead factors were not calculated for this capsule since the limited tests performed were only intended to confirm results from the 300-degree capsule.

Charpy impact specimens were tested to determine the impact behavior, including the impact energy, lateral expansion, fracture appearance, and upper shelf energies for irradiated base metal, weld metal, and heat affected zone (HAZ) metal. The base metal exhibited the largest 30 ft-lb shift and therefore is the limiting material for the Nine Mile Point Unit 1 reactor pressure vessel. The measured change in the 30 ft-lb and 50 ft-lb transition temperatures from the 300-degree capsule are 114°F and 113°F, respectively, for the base metal Charpy specimens.

Limited Charpy tests were also performed on six base material specimens removed from the 30-degree capsule. These tests were performed to confirm the large measured shifts in the 300-degree capsule. The 30 ft-lb and 50 ft-lb shifts were 89 and 86°F, respectively. Both the shifts measured for this capsule and the 300-degree capsule are considerably larger than would have been predicted from current USNR Regulatory guidelines based on measured-specimen fluence and chemistry.

The halves of five broken weld metal Charpy V-notch specimens from the 300-degree capsule and five specimens from the 30-degree capsule were analyzed for copper (Cu), nickel (Ni), and phosphorus (P) using the method of X-ray fluorescence. The base metal from both capsules averaged 0.25 weight percent Cu, 0.52 weight percent Ni, and 0.041 weight percent P, while the weld metal (tested only from the 300-degree capsule) averaged 0.17 weight percent Cu, 0.07 weight percent Ni, and 0.022 weight percent P.

Because the adjusted RTNDT for the vessel beltline region enters the pressure-temperature (P-T) calculations directly via the stress intensity factor relation, it is necessary to provide reasonable and conservative estimates of the shift in the adjusted RTNDT over the period of time for which the P-T calculations are performed. The shift in RTNDT at 20 efpy for the 1/4-T position was conservatively estimated to be 183°F based on an extrapolation of Charpy test data from the 300-degree capsule. This value is greater than would be predicted from base metal chemistry and fluence measurements and the guidelines of Regulatory Guide 1.99, Revisions 1 or 2.

Selected capsule Charpy specimens from both the 30-degree and 300-degree capsules are being reconstituted for re-insertion in the reactor vessel. It is planned to adjust the re-inserted capsule position to be somewhat closer to the core for future irradiation. This action will increase the specimen lead factor to make up for time out of core, and, if possible, to achieve end-of-life fluence levels in advance of the reactor vessel.

# III. DESCRIPTION OF THE TEST SPECIMENS

The 300-degree and 30-degree azimuthal surveillance capsule assemblies from the NMP-1 reactor were examined at Battelle Columbus Laboratories. The baskets contained a complete compliment of six tensile specimens and 24 Charpy specimens each, representing reactor vessel beltline base metal, weld metal and heat affected zone material. Only base metal specimens from the 30-degree capsule were examined.

The base metal for the NMP-1 reactor pressure vessel is A302 Grade B, Class 1 steel. Charpy V-notch and tensile specimens were prepared from actual beltline plates (shell plates G-8-3 and G-8-4). The specimens were prepared from A302 steel plate (Heat No. P2130) provided by Lukens Steel Corporation in 1964. Both plates G-8-3 and G-8-4 were fabricated from this heat. Base metal specimens were taken from flat slabs cut parallel to both plate surfaces at a depth of one-quarter and three-quarter plate thickness. The Charpy and tensile base metal specimens were machined with their longitudinal axes parallel to the plate rolling direction, and the Charpy specimen notches were cut perpendicular to the plate surface. Both Charpy and tensile base metal specimens were designated longitudinal specimens.

The weld metal for the NMP-1 reactor pressure vessel was welded in accordance with Combustion Engineering Welding Specifications SAA-33A(3) and MA-33A(7) using the submerged arc process. The Charpy weld metal specimens were machined in a direction transverse to the weld direction; thus, only the notched section of the specimen would necessarily be composed of weld-deposited metal. Charpy specimens were taken throughout the weld section to a depth of 1-1/16 inch

from the weld root. The Charpy weld metal specimens' long axes were therefore parallel to the plate surface, and the notches were cut perpendicular to the plate surface. The tensile weld metal specimens were composed entirely of weld metal and were obtained by machining the specimens parallel to the weld length and parallel to the plate surface.

The Charpy HAZ metal specimens were machined in a direction transverse to the weld length and parallel to the plate surface. The axes of the notches were then cut perpendicular to the plate surfaces, with the notch located at the intersection of the base metal and weld deposit. The tensile HAZ metal specimens were machined transverse to the weld length and parallel to the plate surface. The joint between the base metal and weld deposit was located at the center of the tensile specimen gage length.

# IV. EXPERIMENTAL PROCEDURES

## A. Neutron Dosimetry Measurements

Flux monitor wires of iron, copper, and nickel, were recovered from the surveillance capsules, cleaned, sampled, weighed and counted for specific activity using a 50cc high purity germanium detector. ASTM procedures[3-8] were followed in the measurement of the specific activities and in the calculation of neutron fluence for the two capsules.

The integrated neutron fluence at the surveillance location was determined from the radioactivity induced in the irradiated detector materials. The gamma radiation from the dosimeter was measured and used to calculate the flux required to produce this level of activity. The fluence was then calculated from the integrated power output of the reactor during the exposure interval.

In order to determine the effective cross section to be used in the fluence calculations, the cross section as a function of energy must be known and the neutron flux intensity as a function of energy must be known. A cross section library of this nature is available[9] and a computer code DETAN[10] was used to retrieve the cross sections desired from this library. The neutron flux and spectrum was calculated with computer code DOT.[11] This code solves the two-dimensional Boltzmann transport equation using the method of discrete ordinates. The reactor geometrical configuration design was modeled to simulate the core structure, the relative power level of

important fuel bundles, intervening structures, and the pressure vessel. This is shown in Figure 1.

Calculations were performed in the $S_8P_3$ approximation using 47 neutron group cross sections from the DLC-75 library.[12] The effective cross sections were generated by the DOT calculation. Coincidental with the calculation of the effective cross sections in the DOT run, the lead factor and neutron flux profile in the reactor vessel wall were also determined. Based on core symmetry, the 300-degree and 30-degree capsules occupied equivalent azimuthal positions.

The neutron fluence was calculated by multiplying the flux (neutrons per square centimeter per second) by the time of operation at full power (using effective full power seconds). To perform the computations, the following information was used:

(1) A description or sketch of the fuel bundle arrangement making up the core, the structures between the core and the pressure vessel, and the pressure vessel itself. This descripion included materials, thicknesses, and distances between components. The cladding material properties and thickness were also included.

(2) The average fast flux distribution in the core. These data included the fuel bundles in one octant of the core and covered the entire time span during which the capsule was in the reactor.

(3) Detailed capsule and capsule holder drawings and the exact position of the capsule relative to other structures.

(4) A complete energy generation history by month ($MWH_t$ per month) for the time during which the capsule was in the reactor, plus a value considered to be full power.

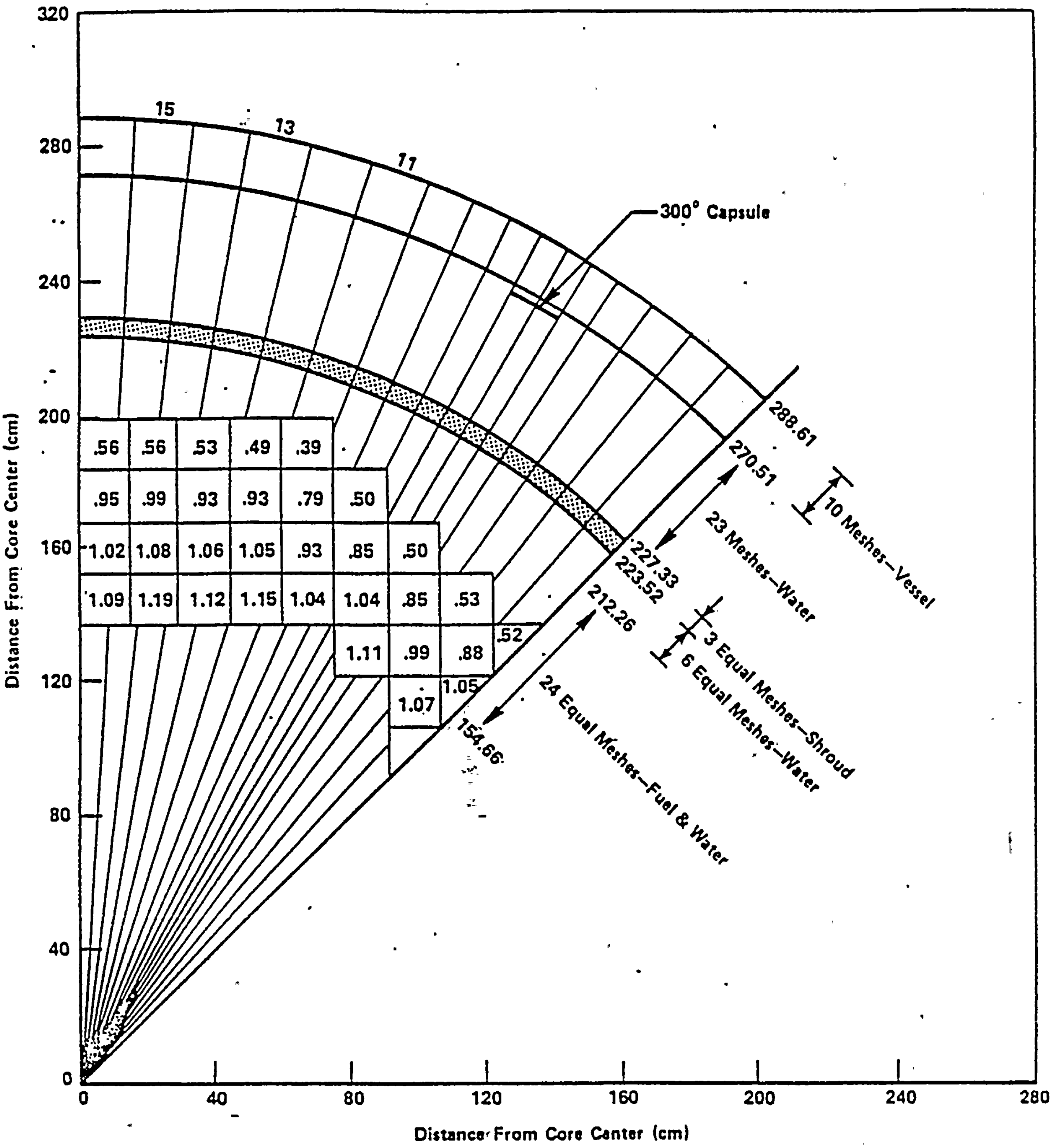

FIGURE 1 - NINE MILE POINT CORE, INTERNAL VESSEL STRUCTURES, AND VESSEL WALL GEOMETRY USED IN THE DOT CALCULATION

### B. Charpy Impact Tests

Charpy impact tests were conducted using a 264 ft-lb Tinius-Olsen Model 74 impact machine in accordance with ASTM specifications.[13,14] Testing of the irradiated Charpy V-notch specimens followed the general recommendations of General Electric Service Information Letter No. 14, Supplement 1.

ASTM Procedure E23-82 for specimen temperature control was utilized. The low temperature bath consisted of a refrigeration unit containing methyl alcohol. Tests above room temperature were conducted in a similar manner using a heated oil bath.

The Battelle's Columbus Laboratory approach was to test each type specimen (base, weld, and HAZ metal) in the approximate temperature range of -50°F to 400°F with the actual test temperature mutually agreed upon prior to testing. The data generated was used to construct conventional Charpy transition curves. Emphasis was placed on establishing 30 ft-lb, 50 ft-lb, and 35 mil lateral expansion index temperatures. Because of the current concern regarding the upper shelf energy level of pressure vessel materials, tests were also conducted in a manner such that the upper shelf was well-defined. Items reported include test temperature, energy absorbed by the specimen in breaking, lateral expansion, percent ductile fracture, upper shelf energy, 30 ft-lb level nil-ductility transition (NDT) temperature, and the 50 ft-lb level NDT temperature. The Charpy impact data were prepared and reported in accordance with ASTM E185-82.[15]

Six additional samples from the 300-degree capsule were tested which were reconstituted from broken halves of

tested Charpy bars. The fracture surfaces of the broken halves are first machined to obtain a smooth end surface for welding. Machining stud ends of the same material are then welded to both ends of the machined halves. The arc welding is done using a stud gun and alignment fixture. The bar was then machined to the approximate length. Previous studies have shown that arc stud welding successfully produces reconstituted Charpy specimens under hot laboratory conditions. It was also shown that no welding-induced annealing occurs in the notch area as a result of the welding.

## C. Tensile Tests

Tensile tests were conducted using a screw-driven Instron machine having a 20,000 pound capacity. The tensile properties of base metal, weld metal, and HAZ metal specimens were determined following ASTM procedures.[13,16,17] Prior to testing, each tensile specimen diameter was measured using a blade micrometer, and an initial cross-sectional area was calculated for each specimen. The samples of each material were tested at room temperature (∿ 80°F) and 550°F. Tensile specimens were heated by means of a hot air-furnace.

Load-elongation data were recorded on the testing machine strip chart. Yield strength, ultimate tensile strength, uniform elongation, and total elongation were determined from these charts. The reduction in area was determined from specimen measurements made using a blade micrometer. Total elongation was also determined from the increase in distance between two punch marks (originally one-inch apart) which were made in the gage section prior to testing.

## D. Chemical Analysis

The method of X-ray fluorescence (XRF) was used to determine copper (Cu), phosphorus (P), and nickel (Ni) contents. Each sample consisted of a separate half of a broken weld metal Charpy specimen which was polished through 600 grit grinding paper to provide a satisfactory surface for analysis. The samples and NBS standards (with known amounts of each element) were bombarded with primary X-rays to produce measurable characteristic or secondary X-rays of the desired elements. Qualification and calibration was achieved by comparing the accumulated intensity and wavelengths of the X-rays from the sample to those from NBS standards possessing a known concentration range for each element.

# V. RESULTS OF TESTS

## A. Dosimetry Results

The primary surveillance capsule was located at the 300-degree azimuthal position at approximately the core midplane position and at 7/16 inch from the inner pressure vessel wall. This capsule was in the reactor for 2913 equivalent full power days or about 7.98 equivalent full power years. The second capsule tested was located at the 30-degree azimuthal position at the same radial and axial position as the first. This capsule was in the reactor for 2117.8 equivalent full power days, or about 5.80 equivalent full power years.

The neutron monitor wires from Charpy packets P7 and P8 in the 300-degree capsule and packets P1, P2, and P3 from the 30-degree capsule were counted to determine their specific activity. The fast flux and fluence was calculated using the count rate from each wire. The results represent an average over the 4-inch length of each wire. The $E > 0.1$ MeV and $E > 1.0$ MeV full power flux and fluence calculated from initial startup to March 1982 for the 300-degree capsule are given in Tables 1a and 2a, respectively, for each of the dosimeter wires, along with the average of the flux and fluence derived from the Fe, Cu, and Ni wire pairs. In addition, the grand average values of the results for Fe and Cu are given. The Ni results were not used in the grand average because the very short half life makes its results dependent on only the latest operating history. Similar flux and fluence results for the 30-degree capsule are shown in Tables 1b and 2b,

respectively. Nickel results are not available for the 30-degree capsule because of the short half-life of Co-58. Flux and fluence results for this capsule were not used for calculating reactor vessel lead factors. These were calculated solely on the basis of the 300-degree dosimetry results.

Using the average fluxes of 3.32 x $10^9$ n/cm$^2$/sec for E > 0.1 MeV and 1.90 x $10^9$ n/cm$^2$/sec for E > 1.0 MeV for the 300-degree capsule, the fluxes at full power at the inside of the pressure vessel wall, at 1/4 T and at 3/4 T directly behind the capsule (300-degree orientation), and at the maximum position (285.66-degree orientation) were calculated. The flux results are tabulated in Table 3. The end of life (EOL) fluences were also calculated and tabulated in Table 3 assuming a reactor pressure vessel lifetime of 40 years and a capacity factor of 80 percent. The fine mesh and time integrated relative power values shown in Figure 1 for each fuel assembly was used in the DOT 4.3 code to generate the values in Table 3. A plot of neutron flux (E > 1.0 MeV) as a function of azimuthal angle (in degrees) is shown in Figure 2. The fluence values at the maximum position for inner vessel wall, 1/4 T and 3/4 T are plotted as a function of time in equivalent full power years (efpy) for the NMP-1 pressure vessel in Figure 3. The lead factor, i.e., the ratio of the flux (E > 1.0 MeV) at the surveillance capsule to the largest flux (E > 1.0 MeV) received by the vessel wall at any azimuthal location, is approximately 0.66 (1.90 x $10^9$/2.86 x $10^9$) at the vessel surface. This result indicates that the flux at the capsule actually lags the flux at certain vessel wall positions. The lead

### TABLE 1a FLUX AND FLUENCE VALUES WITH ENERGY GREATER THAN 0.1 MeV AT THE NINE MILE POINT UNIT 1 SURVEILLANCE CAPSULE (300-DEGREE AZIMUTHAL POSITION)

| Energy | Dosimeter Material | Full Power Flux $(n/cm^2/sec) \times 10^9$ | Fluence* $(n/cm^2) \times 10^{17}$ |
|---|---|---|---|
| 0.1 MeV | Fe (P7)[a] | 3.549 | 8.933 |
| | (P8)[b] | 3.210 | 8.078 |
| | Average of Fe | 3.380 | 8.506 |
| | Cu (P7)[a] | 3.253 | 8.188 |
| | (P8)[b] | 3.253 | 8.188 |
| | Average of Cu | 3.253 | 8.188 |
| | Ni (P7)[a] | 3.230 | 8.130 |
| | (P8)[b] | 3.117 | 7.844 |
| | Average of Ni | 3.174 | 7.987 |
| | Average of Fe and Cu | 3.32 | 8.35 |

*Fluence based on 2913.1 equivalent full power days of operation.

a) P7 refers to bottom packet
b) P8 refers to top packet

## TABLE 1b FLUX AND FLUENCE VALUES WITH ENERGY GREATER THAN 0.1 MeV AT THE NINE MILE POINT UNIT 1 SURVEILLANCE CAPSULE (30-DEGREE AZIMUTHAL POSITION)

| Energy | Dosimeter Material | Full Power Flux $(n/cm^2/sec) \times 10^9$ | Fluence* $(n/cm^2) \times 10^{17}$ |
|---|---|---|---|
| 0.1 MeV | Fe (P1-Fe) | 3.8 | 6.9 |
| | (P2-Fe) | 3.6 | 6.6 |
| | (P3-Fe) | 3.5 | 6.4 |
| | Average of Fe | 3.6 | 6.6 |
| | Cu (P2-Cu) | 3.3 | 6.1 |
| | (P3-Cu) | 3.1 | 5.7 |
| | Average of Cu | 3.2 | 5.9 |
| | Average of Cu and Fe | 3.4 | 6.3 |

*Fluence based on 2117.8 equivalent full power days of operation.

## TABLE 2a FLUX AND FLUENCE VALUES WITH ENERGY GREATER THAN 1.0 MeV AT THE NINE MILE POINT UNIT 1 SURVEILLANCE CAPSULE (300-DEGREE AZIMUTHAL POSITION)

| Energy | Dosimeter Material | Full Power Flux $(n/cm^2/sec) \times 10^9$ | Fluence* $(n/cm^2) \times 10^{17}$ |
|---|---|---|---|
| 1.0 MeV | Fe (P7)[a] | 2.033 | 4.118 |
| | (P8)[b] | 1.839 | 4.629 |
| | Average of Fe | 1.936 | 4.874 |
| | Cu (P7)[a] | 1.864 | 4.691 |
| | (P8)[b] | 1.864 | 4.691 |
| | Average of Cu | 1.864 | 4.691 |
| | Ni (P7)[a] | 1.851 | 4.659 |
| | (P8)[b] | 1.786 | 4.494 |
| | Average of Ni | 1.819 | 4.577 |
| | Average of Fe and Cu | 1.90 | 4.78 |

*Fluence based on 2913.1 equivalent full power days of operation.

a) P7 refers to bottom packet
b) P8 refers to top packet

## TABLE 2b FLUX AND FLUENCE VALUES WITH ENERGY GREATER THAN 1.0 MeV AT THE NINE MILE POINT UNIT 1 SURVEILLANCE CAPSULE (30-DEGREE AZIMUTHAL POSITION)

| Energy | Dosimeter Material | Full Power Flux $(n/cm^2/sec) \times 10^9$ | Fluence* $(n/cm^2) \times 10^{17}$ |
|---|---|---|---|
| 1.0 MeV | Fe (P1-Fe) | 2.2 | 4.0 |
| | (P2-Fe) | 2.0 | 3.8 |
| | (P3-Fe) | 2.0 | 3.7 |
| | Average of Fe | 2.1 | 3.8 |
| | Cu (P2-Cu | 1.9 | 3.5 |
| | (P3-Cu) | 1.8 | 3.3 |
| | Average of Cu | 1.9 | 3.4 |
| | Average of Cu and Fe | 2.0 | 3.6 |

*Fluence based on 2117.8 equivalent full power days of operation.

TABLE 3 FLUX AND FLUENCE IN THE PRESSURE VESSEL WALL OF THE NINE MILE POINT UNIT 1 REACTOR - BEHIND THE SURVEILLANCE CAPSULE (300-DEGREE) AND AT THE PEAK FLUX LOCATION IN THE VESSEL WALL (285.66-DEGREE)

| | | Full Power Flux in Vessel Wall | | Fluence in Vessel Wall | | | |
|---|---|---|---|---|---|---|---|
| | | | | Behind Capsule (300°) | | Maximum (285.66°) | |
| Energy (MeV) | Location | Behind Capsule (300°) $(n/cm^2/sec) \times 10^9$ | Maximum (285.66°) $(n/cm^2/sec) \times 10^9$ | March 82 (1) $(n/cm^2 \times 10^{17})$ | EOL (2) $(n/cm^2 \times 10^{18})$ | March 82 (1) $(n/cm^2 \times 10^{18})$ | EOL (2) $(n/cm^2 \times 10^{18})$ |
| 0.1 | Surface | 3.26 | 5.68 | 8.20 | 3.29 | 1.43 | 5.73 |
| 0.1 | 1/4 T | 2.91 | 5.12 | 7.32 | 2.94 | 1.29 | 5.19 |
| 0.1 | 3/4 T | 1.34 | 2.30 | 3.37 | 1.35 | 0.582 | 2.33 |
| 1.0 | Surface | 1.54 | 2.86 | 3.88 | 1.55 | 0.721 | 2.89 |
| 1.0 | 1/4 T | 1.04 | 1.95 | 2.63 | 1.05 | 0.492 | 1.97 |
| 1.0 | 3/4 T | 0.287 | 0.525 | 0.722 | 0.290 | 0.132 | 0.521 |

(1) Fluence based on 7.98 effective full power years of operation.

(2) Fluence based on 32 effective full power years of operation.

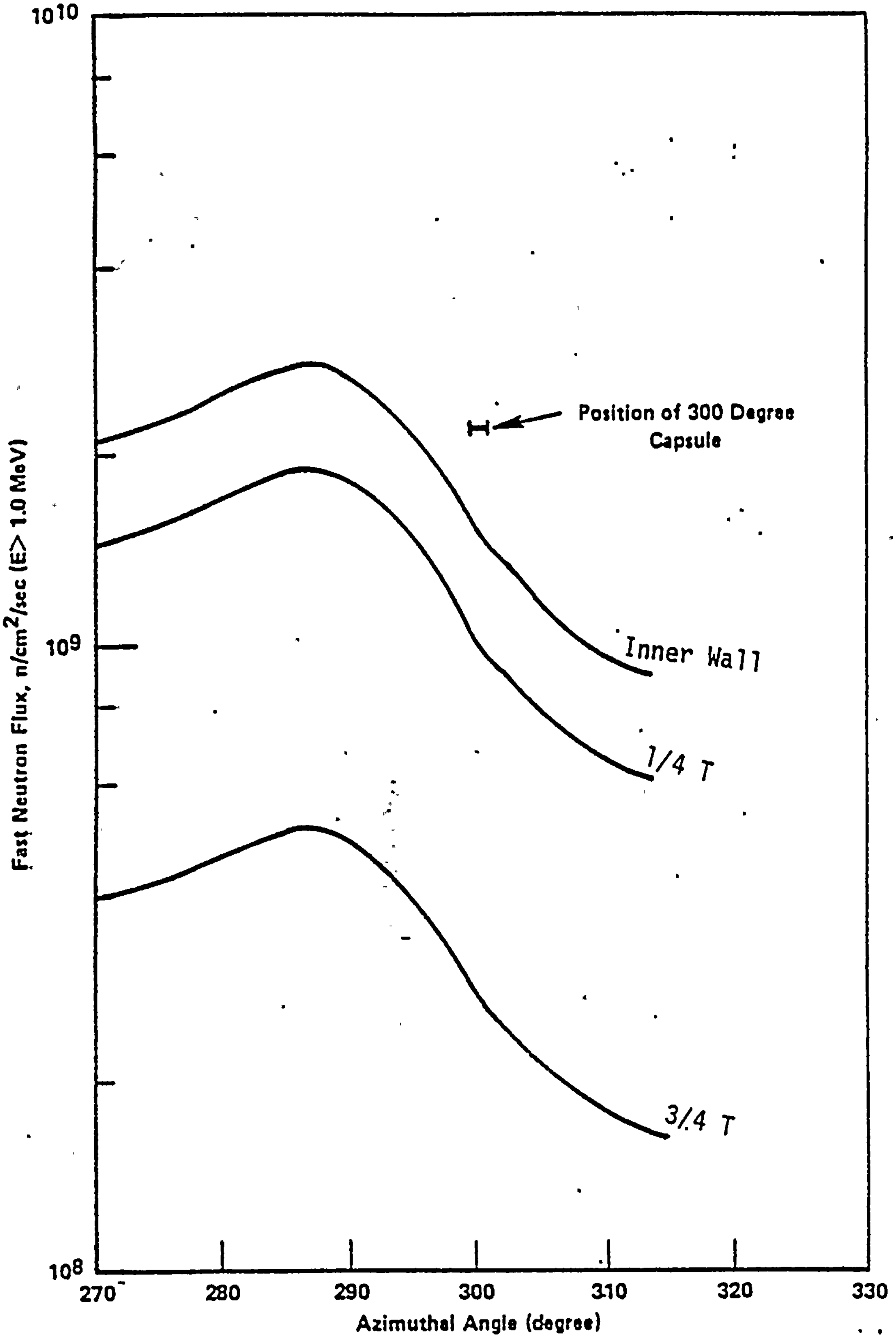

FIGURE 2 - CALCULATED FLUX AT PRESSURE VESSEL INNER WALL, 1/4 T THICKNESS AND 3/4 T THICKNESS AS A FUNCTION OF AZIMUTHAL ANGLE

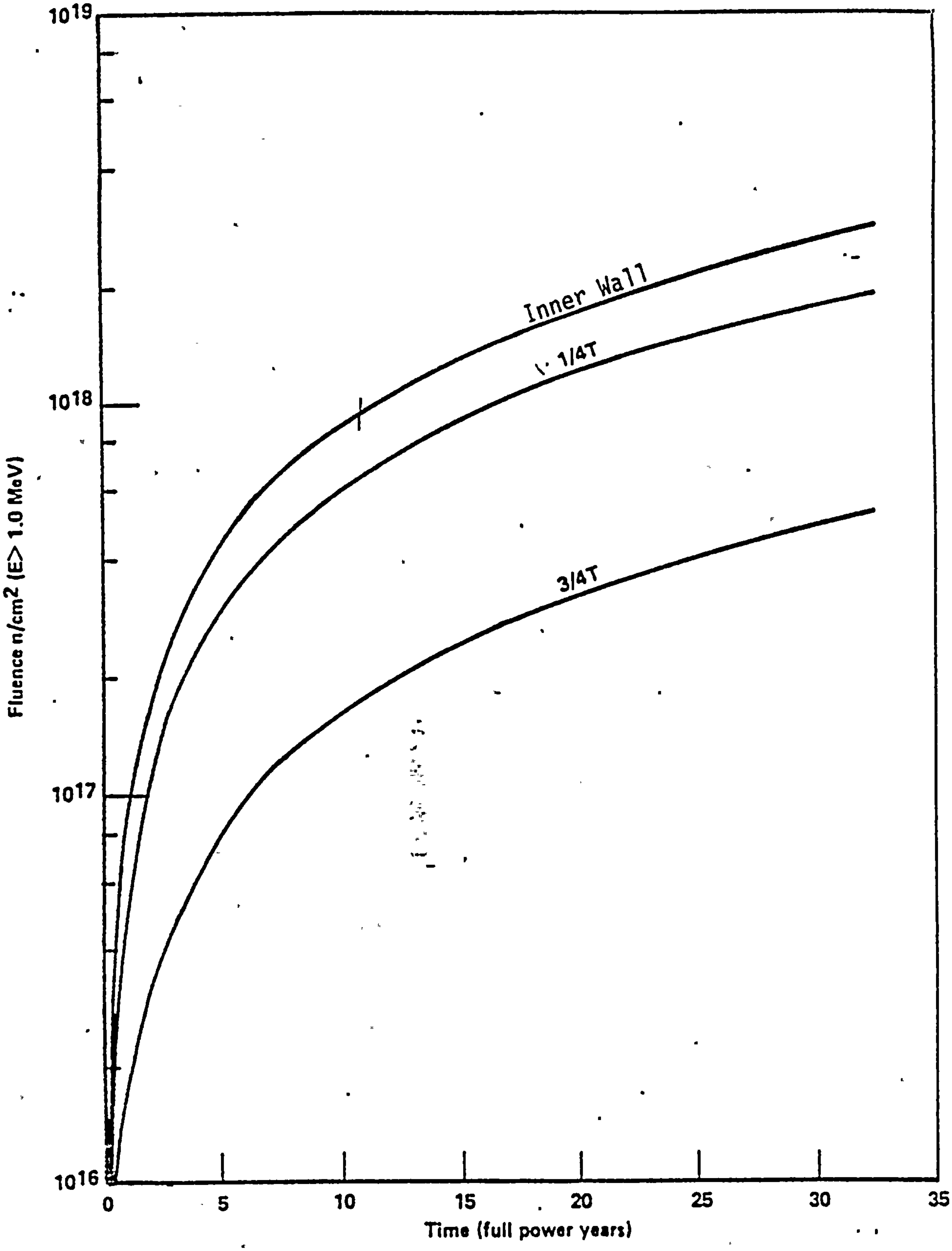

FIGURE 3 - FLUENCE AT INNER WALL 1/4 T AND 3/4 T POSITIONS AS A FUNCTION OF TIME FOR THE NINE MILE POINT UNIT 1 REACTOR VESSEL

factors at the pressure vessel 1/4 T and 3/4 T positions were calculated to be 0.97 ($1.90 \times 10^9/1.95 \times 10^9$) and 3.62 ($1.90 \times 10^9/5.25 \times 10^8$), respectively.

The accuracy of the fluence values generated at BCL is estimated by BCL to be ± 20 percent. Although the specific activity of fluence monitor wires can be determined to ± 5 percent, uncertainties in neutron spectrum and spectrum averaged across sections result in the large variances in the computed flux and fluence values.

The rate of displacements per atom was also calculated using the cross sections for displacement available with the DETAN code. Table 4 shows calculated values of displacements per atom per second at full power in the pressure vessel wall behind the capsule and in the pressure vessel wall at the angle of peak fluence in the wall. Table 4 also shows calculated values of displacements per atom at these same positions in the wall for 7.98 effective full power years of operation (to time of capsule removal) and for 32 effective full power years of operation.

## B. Charpy Impact Test Results

### 1. 300-Degree Capsule Results

Eight irradiated base metal Charpy V-notch impact specimens, eight irradiated weld metal Charpy V-notch impact specimens, and eight irradiated HAZ metal Charpy V-notch specimens from the 300-degree capsule with 7.98 efpy of exposure were tested. Four additional base and weld metal specimens which were reconstituted from the halves of broken

## TABLE 4 ATOM DISPLACEMENTS IN THE PRESSURE VESSEL WALL OF THE NINE MILE POINT UNIT I REACTOR

| | Displacement per Atom per Second | | Displacement per Atom | | | |
|---|---|---|---|---|---|---|
| | | | Behind Capsule | | Maximum (285.66°) | |
| Location | Behind Capsule | Maximum (285.66°) | March 82 (1) | EOL (2) | March 82 (1) | EOL (2) |
| Surface | $2.56\times10^{-9}$ | $4.82\times10^{-9}$ | 0.644 | 2.582 | 1.214 | 4.868 |
| 1/4 T | $1.79\times10^{-9}$ | $3.28\times10^{-9}$ | 0.452 | 1.813 | 0.825 | 3.308 |
| 3/4 T | $6.19\times10^{-10}$ | $1.10\times10^{-9}$ | 0.156 | 0.626 | 0.277 | 1.111 |

(1) Fluence based on 7.98 effective full power years of operation.

(2) Fluence based on 32 effective full power years of operation.

Charpy bars were also tested. The results of tests conducted between -40 and 320°F for the base metal specimens are shown in Figures 4-6. The results of tests conducted between -120 and 320°F for the weld metal specimens are shown in Figures 7-9 and the results of tests conducted between -40 and 280°F for the HAZ metal specimens are shown in Figures 10-12. In addition to the total impact energy values, the measured lateral expansion values and the estimated fracture appearance for each specimen are also shown in the figures noted above.

The total impact energy is the amount of energy absorbed by the specimen tested at the indicated temperature. Lateral expansion is a measure of the plastic "shear lip" deformation produced by the striking edge of the impact machine hammer when it impacts the specimen. Lateral expansion is determined by the change of specimen thickness directly adjacent to the notch location. Fracture appearance is a visual estimate of the amount of shear (ductile type of fracture) appearing on the specimen fracture surface.

### 2. 30-Degree Capsule Results

As a means of confirming the Charpy impact tests results from the 300-degree capsule reported above, Niagara Mohawk authorized limited Charpy tests on specimens removed from the 30-degree capsule which was removed from the reactor vessel in 1979. Testing was limited to six Charpy tests on base material (which appears to be limiting) in order to determine 30 and 50 ft-lb temperature

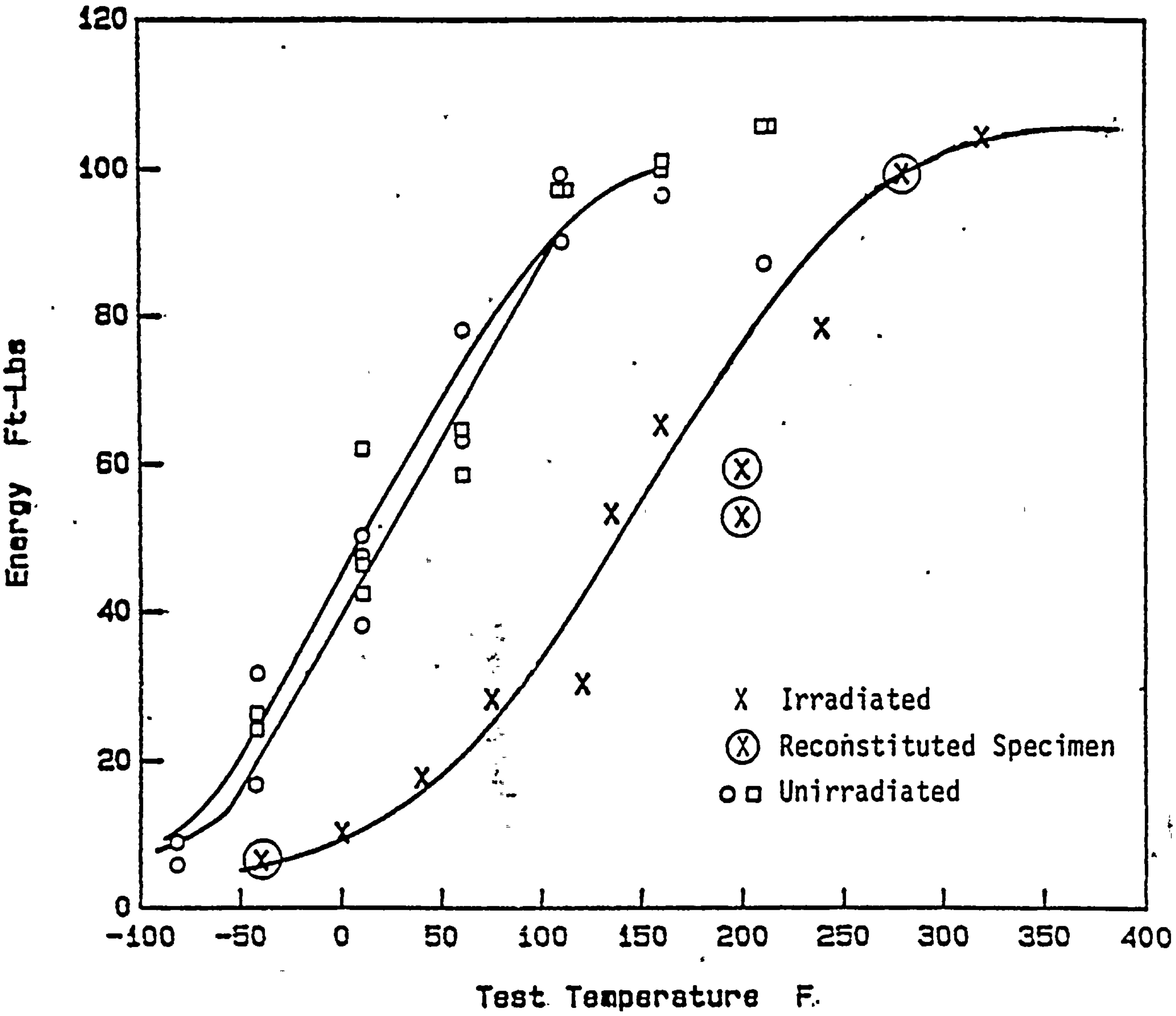

FIGURE 4 - CHARPY V-NOTCH IMPACT ENERGY VERSUS TEST TEMPERATURE FOR THE IRRADIATED BASE METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

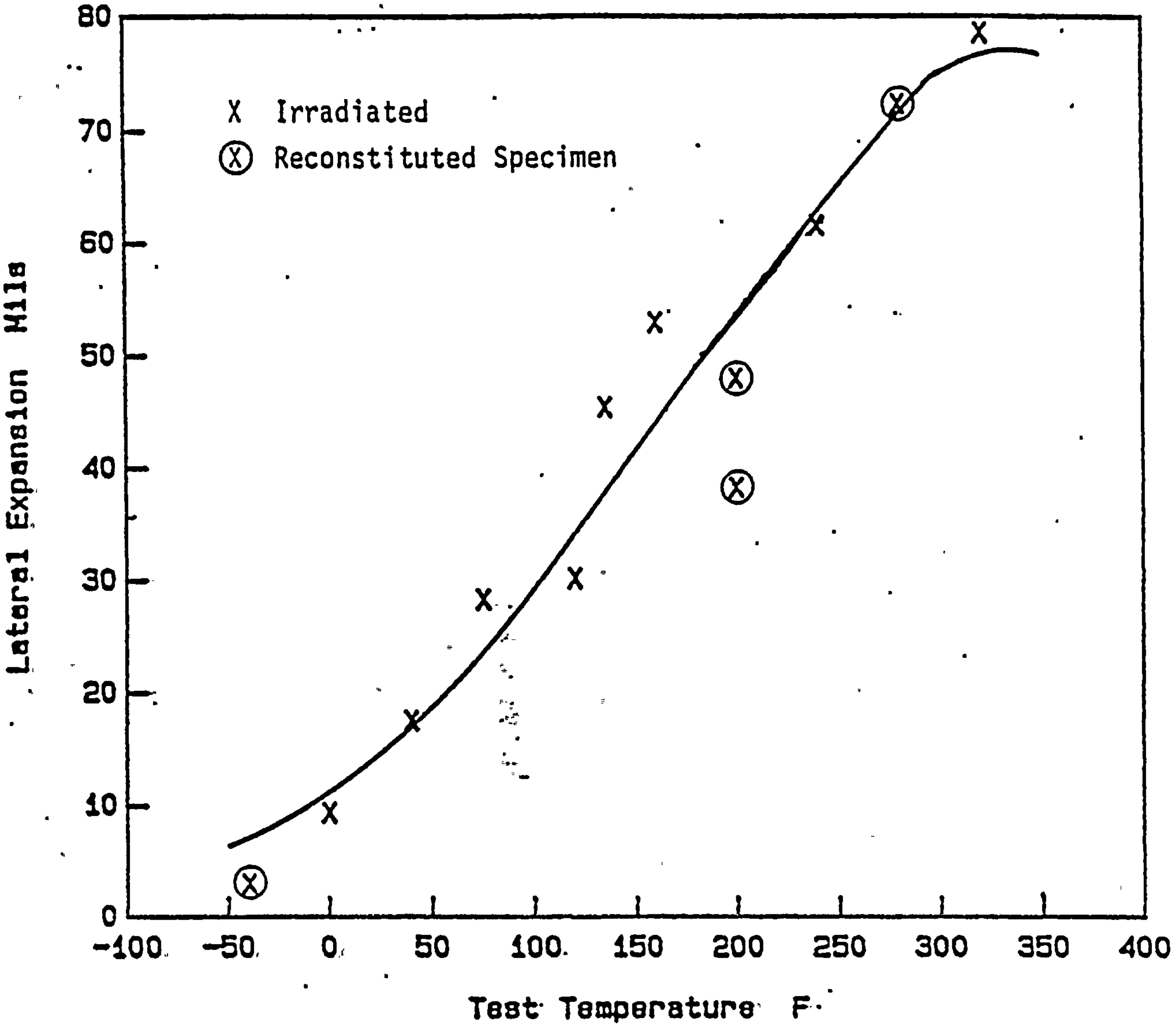

FIGURE 5 - CHARPY V-NOTCH EXPANSION VERSUS TEST TEMPERATURE FOR THE IRRADIATED BASE METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

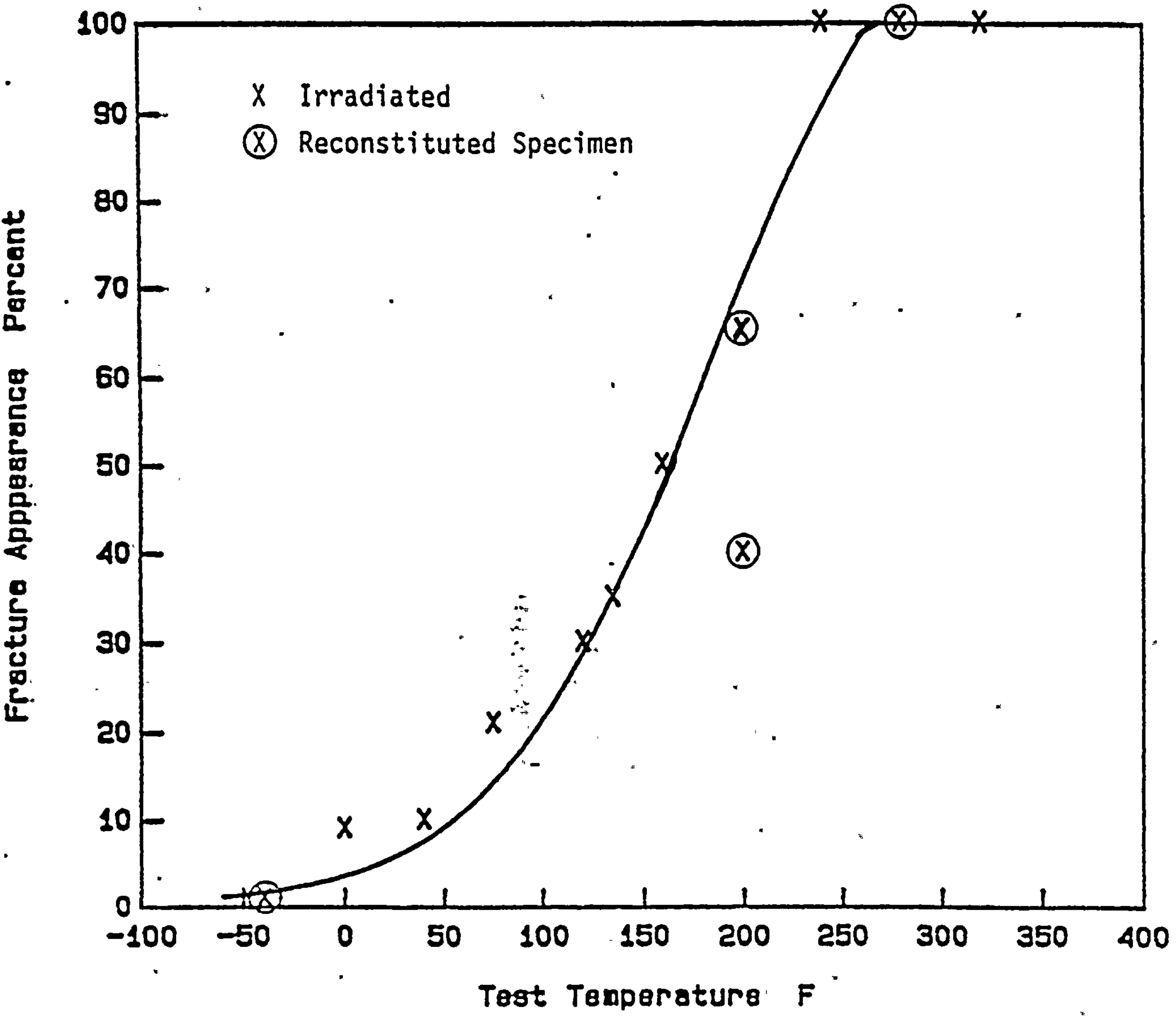

FIGURE 6 - CHARPY V-NOTCH PERCENT DUCTILE SHEAR VERSUS TEST TEMPERATURE FOR THE IRRADIATED BASE METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

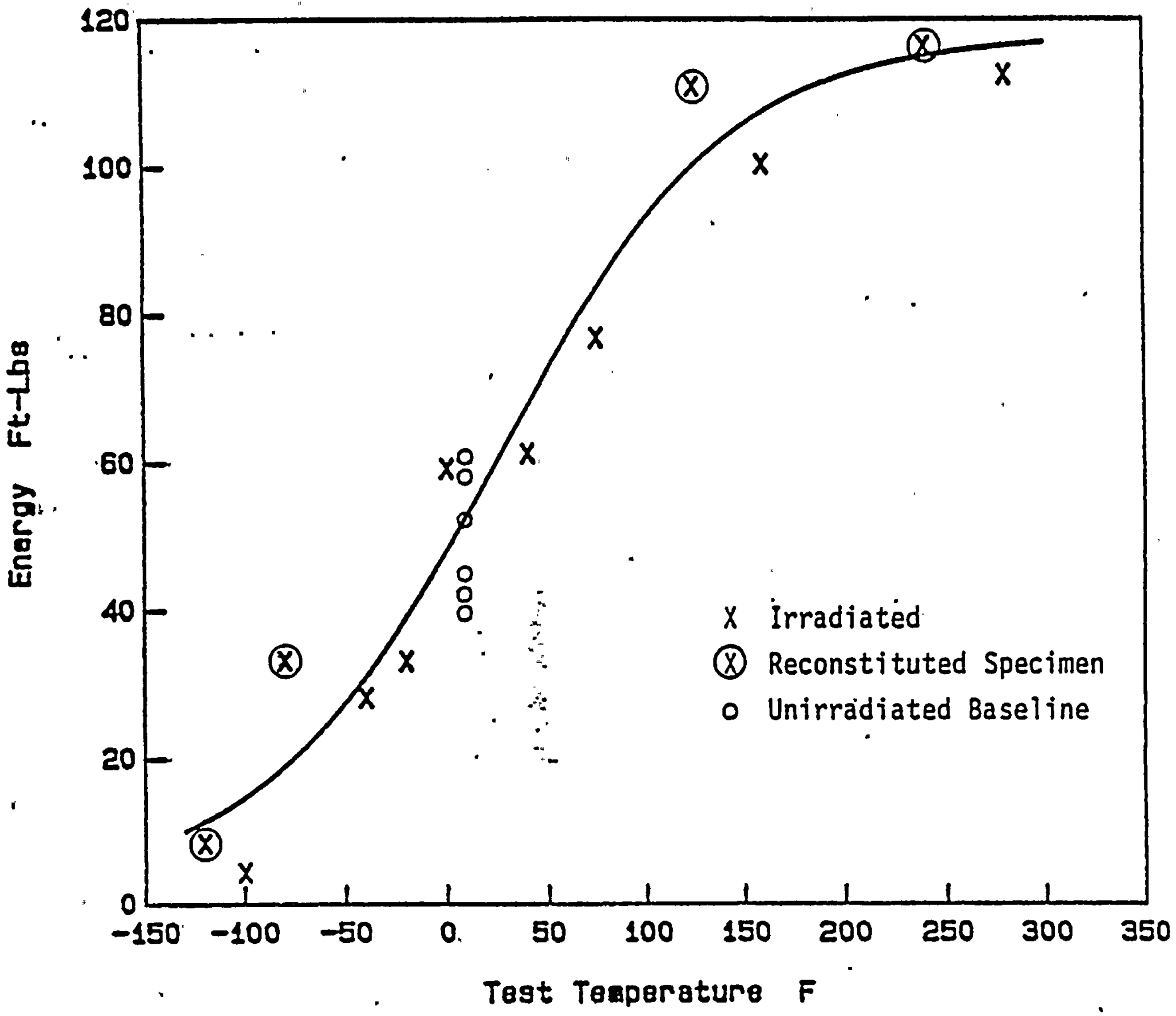

FIGURE 7 - CHARPY V-NOTCH IMPACT ENERGY VERSUS TEST TEMPERATURE FOR THE IRRADIATED WELD METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

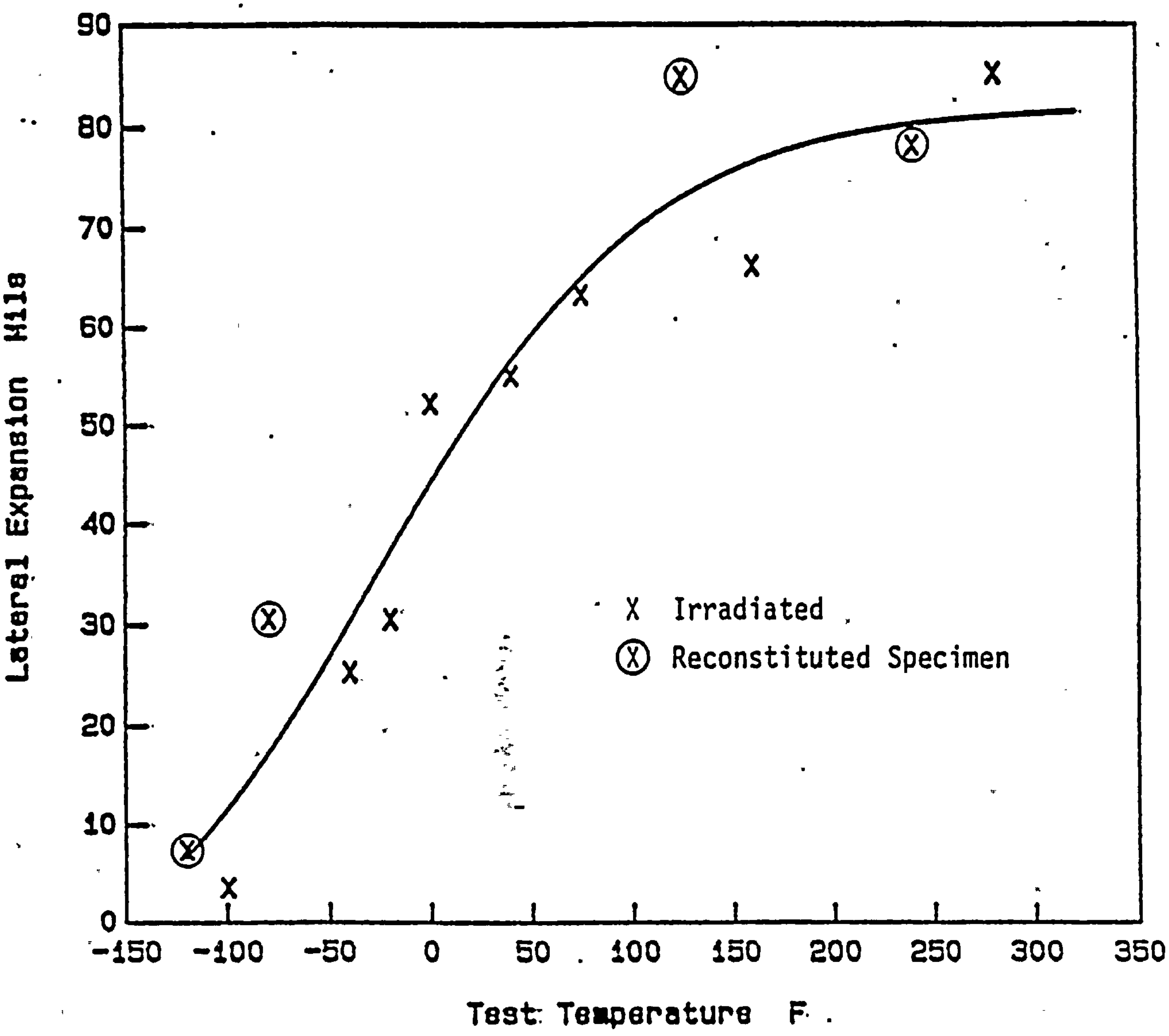

FIGURE 8 - CHARPY V-NOTCH LATERAL EXPANSION VERSUS TEST TEMPERATURE FOR THE IRRADIATED WELD METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

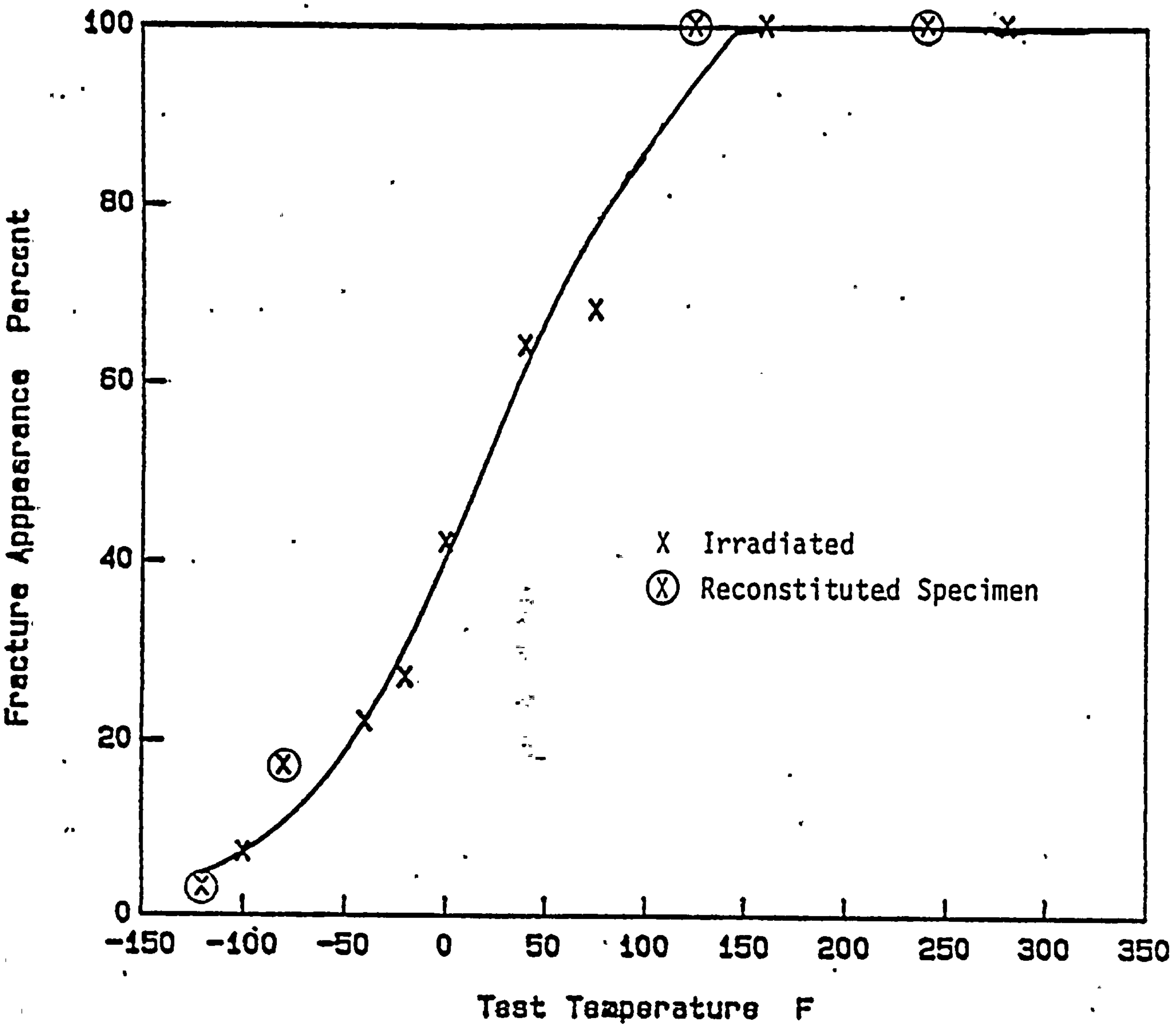

FIGURE 9 - CHARPY V-NOTCH PERCENT DUCTILE SHEAR VERSUS TEST TEMPERATURE FOR THE IRRADIATED WELD METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

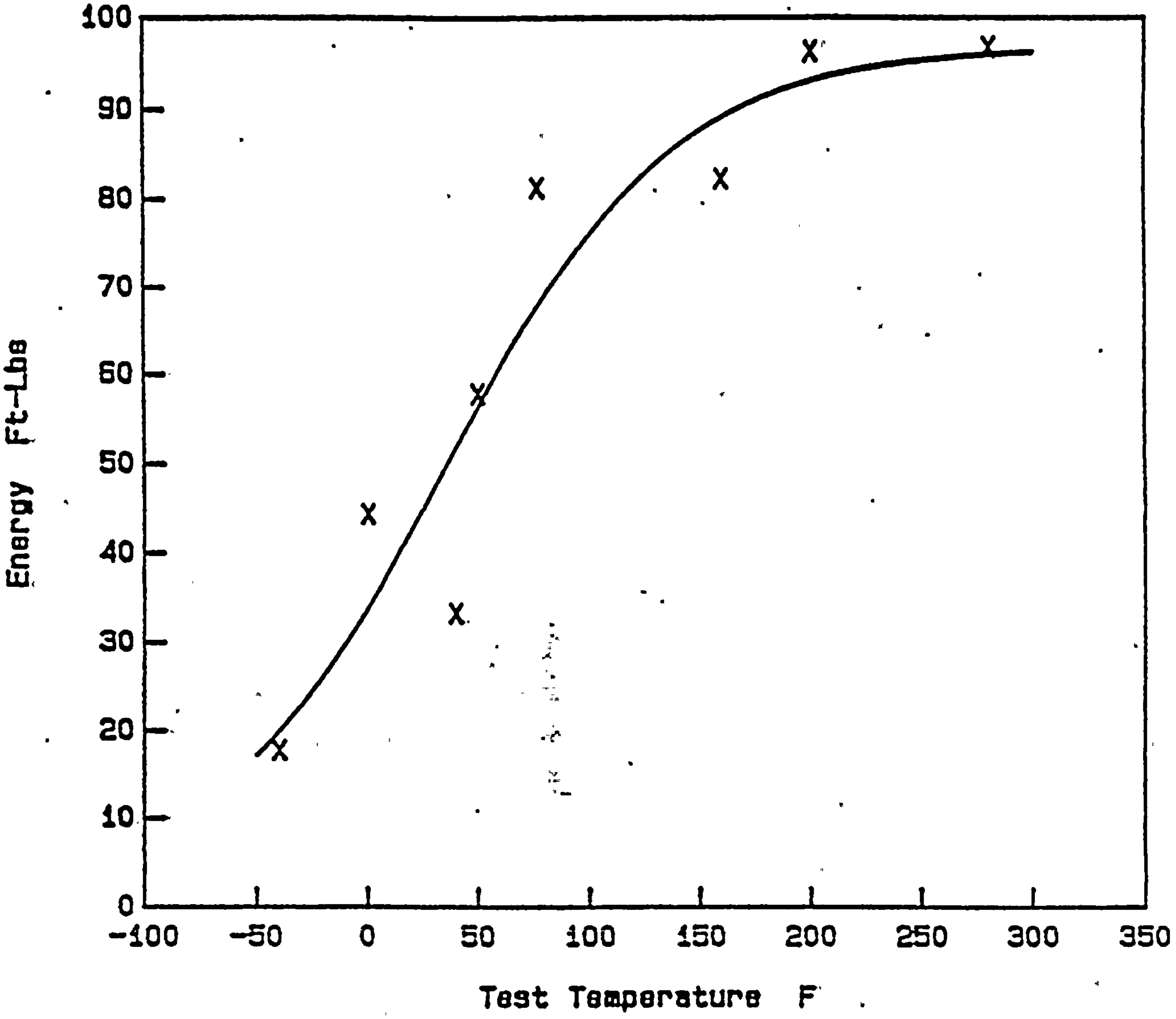

FIGURE 10 - CHARPY V-NOTCH IMPACT ENERGY VERSUS TEST TEMPERATURE FOR THE IRRADIATED HAZ METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

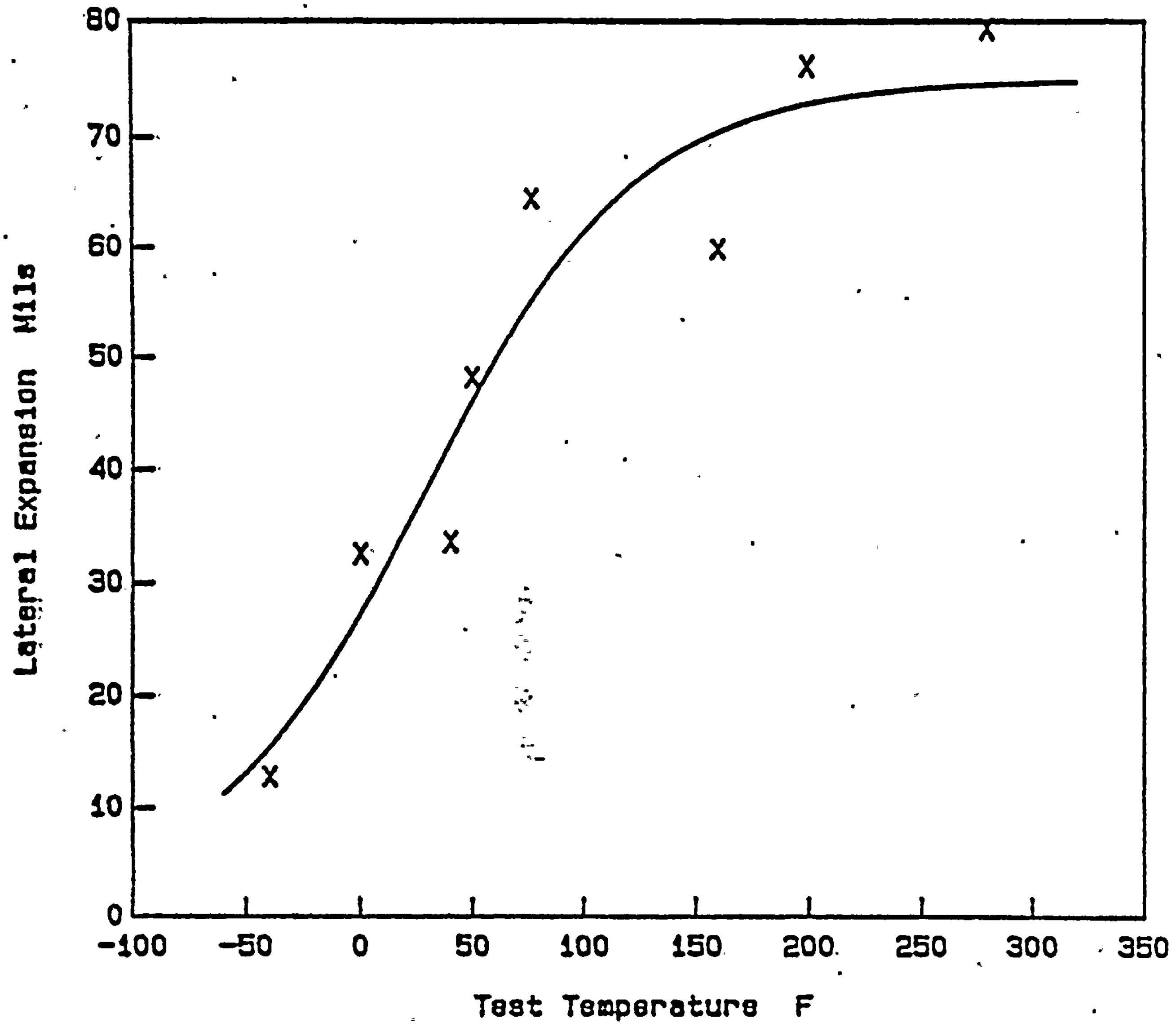

FIGURE 11 - CHARPY V-NOTCH LATERAL EXPANSION VERSUS TEST TEMPERATURE FOR THE IRRADIATED HAZ METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

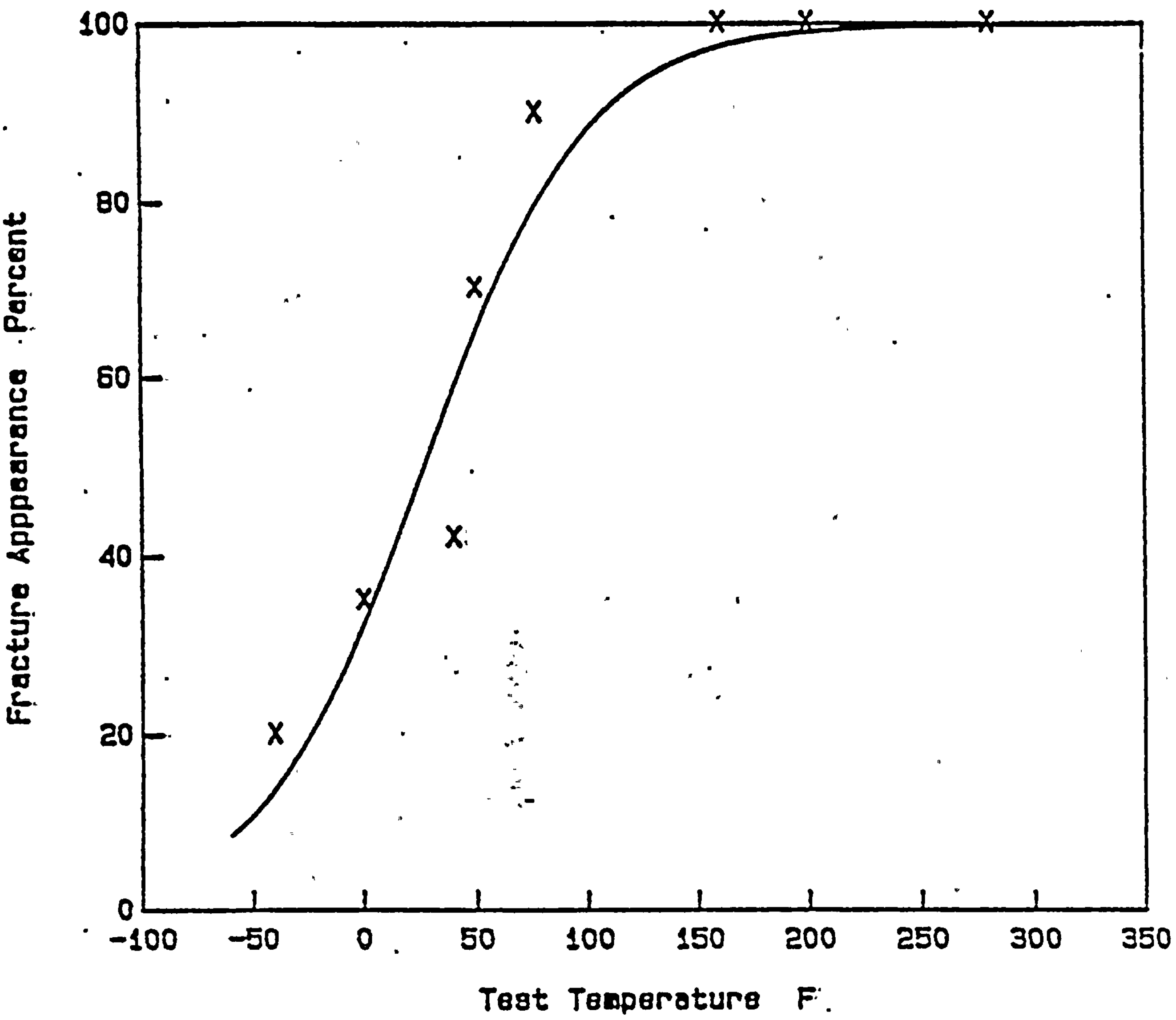

FIGURE 12 - CHARPY V-NOTCH PERCENT DUCTILE SHEAR VERSUS TEST TEMPERATURE FOR THE IRRADIATED HAZ METAL SPECIMENS FROM THE NINE MILE POINT 300-DEGREE SURVEILLANCE CAPSULE

shifts. Unirradiated baseline data and irradiated results for the tests are shown in Figure 13.

A summary of the 300-degree and the 30-degree NMP-1 surveillance capsule Charpy V-notch impact test data, including the 30 and 50 ft-lb transition temperatures, the 35-mil lateral expansion temperature and the upper shelf energy, is given in Table 5.

Unirradiated archive baseline Charpy V-notch data come from Combustion Engineering Mechanical Test Reports for tests on material taken from the same heat of the pressure vessel steel as was used to fabricate the Charpy specimens and heat treated in like fashion.[18] These data are plotted in Figures 4 and 13. From these data, the 30 and 50 ft-lb unirradiated transition temperatures and the upper shelf energy were obtained. By difference, the shift or change in transition temperatures and upper shelf energy were calculated for the base material, as shown in Table 5. The upper shelf energy is essentially unchanged from the base metal. In all cases, (base, weld, and HAZ) the upper shelf energy values are well above the minimum allowable EOL value of 50 ft-lb specified in 10CFR50 Appendix G.

There are no archive data for HAZ metal and only limited (10°F) data for weld metal.[18] The archive weld data are plotted in Figure 7, and show that all values are above 30 ft-lb at 10°F, and the average energy is above 45 ft-lb. It also suggests that only a negligible shift occurs as a result of irradiation. This is consistent with the low nickel and copper content of the weld metal as determined by chemical analysis of the irradiated Charpy specimens. The General Electric design specification calls for a vessel $RT_{NDT}$ of $< 10°F$

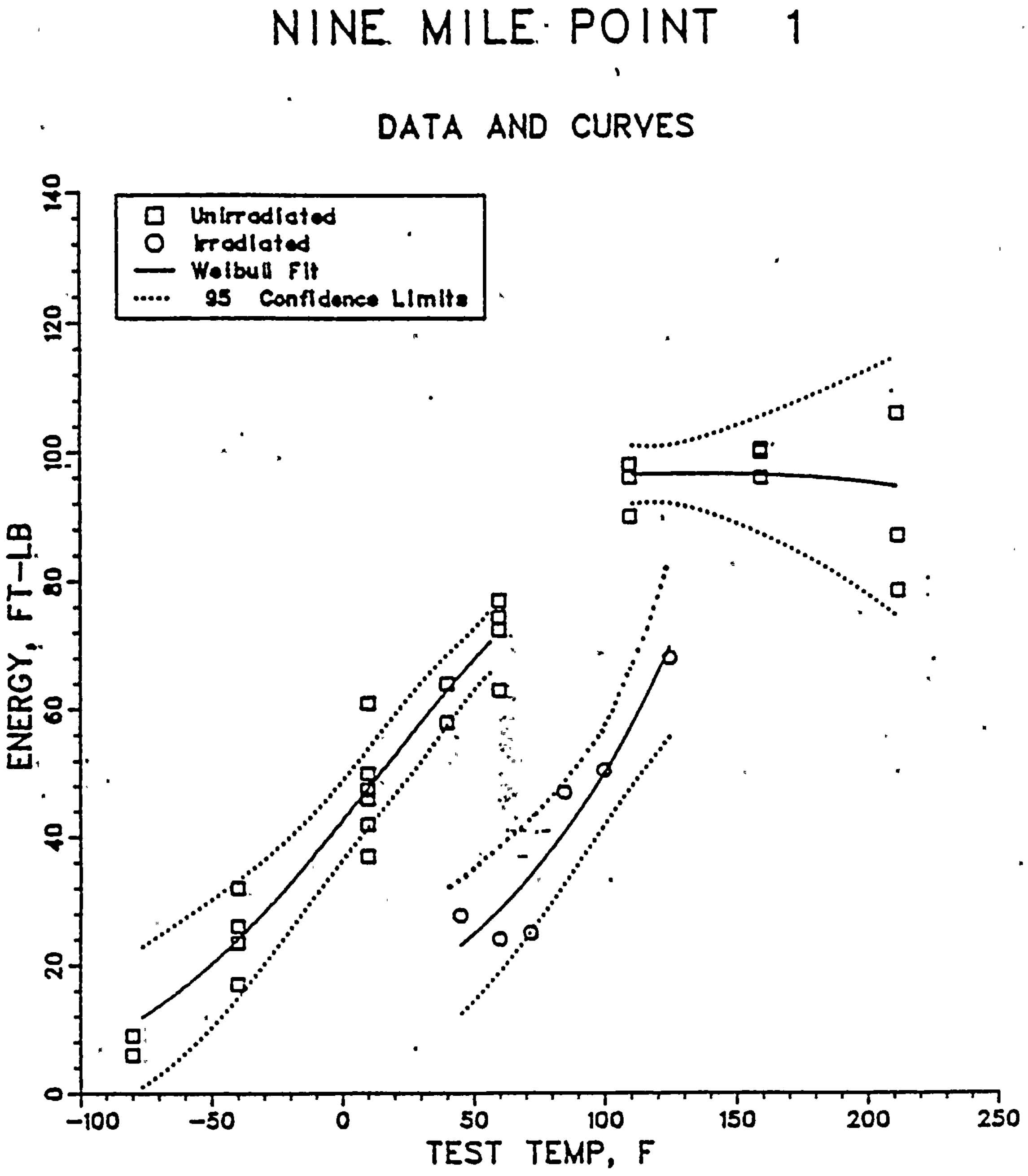

FIGURE 13. COMPARISON OF THE CHARPY V-NOTCH IMPACT ENERGY VERSUS TEST TEMPERATURE FOR THE UNIRRADIATED AND IRRADIATED BASE METAL SPECIMENS FROM THE 30-DEGREE CAPSULE

## TABLE 5 SUMMARY OF CHARPY IMPACT PROPERTIES FOR IRRADIATED MATERIALS FROM THE NINE MILE POINT UNIT 1 300-DEGREE SURVEILLANCE CAPSULE

| Capsule | Material | E > 1.0 MeV Fluence, n/cm$^2$ | 30 ft-lb Transition Temperature, F | 50 ft-lb Transition Temperature, F | 35-Mil Lateral Expansion Temperature, F | Upper Shelf Energy, ft-lb |
|---|---|---|---|---|---|---|
| 300-degree | Base | 0 | -24 | 10-25 | --- | 100 |
| 300-degree | Base | $4.78 \times 10^{17}$ | 90 | 139 | 130 | 102 |
| 300-degree | Weld | $4.78 \times 10^{17}$ | -43 | 4 | -22 | 116 |
| 300-degree | HAZ | $4.78 \times 10^{17}$ | -10 | 37 | 20 | 96 |
| 300-degree | Base | Change | 114 | 113 | 0 | 2 |
| 30-degree | Base | $3.6 \times 10^{17}$ | 63 | 100 | 79 | --- |
| 30-degree | Base | Change | 89 | 86 | --- | --- |

for all material in the core beltline region.[18] Since the 30 ft-lb value for the irradiated HAZ metal is < 10°F, it is again suggested that only a negligible shift occurs for that material as well. Since the shifts in weld and HAZ metal are small, the shift for the base metal at higher neutron exposure will probably be the limiting criterion for pressure vessel operation.

## C. Tensile Test Results

The tensile test parameters and irradiated specimen tensile properties are listed in Table 6. All tests were performed on specimens removed from the 300-degree capsule. Table 6 lists the specimen number, material, and test temperature. Also listed are the 0.2 percent offset yield strength, ultimate tensile strength, fracture strength, fracture stress, reduction in area, uniform elongation, and total elongation for each specimen tested.

Tensile tests were conducted at room temperature (75°F), and 550°F. All three materials, base metal, weld metal, and HAZ metal exhibited decreases in yield strength and ultimate strength when the test temperature was increased from room temperature to 550°F. Fracture strength was the same or slightly higher at 550°F than at room temperature. The percent reduction in area for the three materials are relatively constant at test temperatures of 75°F (room temperature), but decreased slightly (8 to 13 percent) at a test temperature of 550°F. The uniform and total elongation also decreased when the test temperature was increased from 75°F to 550°F.

TABLE 6 TENSILE PROPERTIES FOR THE IRRADIATED MATERIALS FROM THE NINE MILE POINT UNIT 1 300-DEGREE SURVEILLANCE CAPSULE

| Specimen No. | Material Type | Test Temp.(1) (F) | Strength, psi Yield | Strength, psi Ultimate | Strength, psi Fracture | Fracture Stress (psi) | Reduction in Area (percent) | Elogation, percent(2) Uniform | Elogation, percent(2) Total |
|---|---|---|---|---|---|---|---|---|---|
| UUA | Base | RT | 79,170 | 99,700 | 66,060 | 192,300 | 65.7 | 12.5 | 27.7 |
| JDB | Base | 550 | 69,410 | 92,890 | 68,090 | 161,800 | 58.0 | 8.9 | 19.7 |
| G-8-3 | Base(3) | RT | 65,000 | 86,200 | 0 | 0 | 65.4 | - | 26.0 |
| G-8-4 | Base(3) | RT | 59,300 | 85,500 | - | - | 68.0 | - | 29.0 |
| JLB | Weld | RT | 73,680 | 90,240 | 59,450 | 186,300 | 68.1 | 13.0 | 23.2 |
| JL7 | Weld | 550 | 67,760 | 84,690 | 59,180 | 157,600 | 62.4 | 10.5 | 20.9 |
| JUD | HAZ | RT | 63,720 | 85,060 | 54,880 | 181,200 | 69.7 | 7.5 | 19.8 |
| JTU | HAZ | 550 | 59,960 | 81,500 | 56,910 | 145,100 | 60.8 | 7.1 | 18.4 |

(1) Room temperature (RT) is approximately 75°F.

(2) The elongation is for a 1-inch gauge length, except for the baseline, which is 2 inches.

(3) Unirradiated baseline material reported by Lukens Steel.

Archive base line tensile data are limited to two tests at room temperature, as shown in Table 6.[18] From these data one can see that there is an increase in yield and ultimate strengths and a decrease in (1-in) total elongation as a result of the irradiation. However, the reduction in area is essentially unchanged. The data for the irradiated base and weld metal compare favorably. The HAZ metal ductility is somehwat reduced; however, this is consistent with data from other BWR surveillance capsules.

## D. Chemical Analysis Results

The method of X-ray fluorescence (XRF) was used to determine the copper (Cu), nickel (Ni), and phosphorus (P) contents of the base and weld metal specimens. Five irradiated base metal and five irradiated weld metal samples from the 300-degree capsule consisting of broken halves of tested Charpy V-notch specimens were analyzed for Cu, Ni, and P content. Five irradiated base metal samples (with two duplicate tests) were taken from the 30-degree capsule as well. The analytical results for all the samples are listed in Table 7.

The calculated accuracy for this X-ray fluorescence chemical analysis is ± 15% for copper, ± 6.0% for nickel, and ± 10% for phosphorus. The estimated detection limit is 0.02 weight percent for copper and 0.01 weight percent for both nickel and phosphorus.

The average Cu and Ni contents for the 30-degree capsule Charpy base specimens are 0.30 and 0.56 weight percent, respectively. The average Cu and Ni contents for the 300-degree capsule Charpy base specimens are 0.23 and 0.46 weight percent, respectively. These differences

## TABLE 7 CHEMICAL ANALYSIS RESULTS FOR NINE MILE POINT UNIT 1 BASE AND WELD MATERIAL SPECIMENS

| Capsule | Specimen No. | Material Type | Elements, Weight Percent(a) | | |
|---|---|---|---|---|---|
| | | | Cu | Ni | P |
| 300-degree | G-8-3(b) | Base (U) | 0.18 | 0.56 | 0.012 |
| 300-degree | G-8-4 | Base (U) | 0.18 | 0.56 | 0.012 |
| 300-degree | E1U | Base (I) | 0.21 | 0.48 | 0.017 |
| 300-degree | E1U | Base (I) | 0.22 | 0.47 | 0.020 |
| 300-degree | EIM | Base (I) | 0.22 | 0.46 | 0.021 |
| 300-degree | E42 | Base (I) | 0.22 | 0.48 | 0.022 |
| 300-degree | E7E | Base (I) | 0.23 | 0.45 | 0.021 |
| 300-degree | E3T | Base (I) | 0.25 | 0.46 | 0.024 |
| 300-degree | E3T | Base (I) | 0.23 | 0.45 | 0.027 |
| 300-degree | EDK | Weld (I) | 0.17 | 0.05 | 0.020 |
| 300-degree | EDK | Weld (I) | 0.18 | 0.05 | 0.022 |
| 300-degree | EJD | Weld (I) | 0.16 | 0.06 | 0.020 |
| 300-degree | EJC | Weld (I) | 0.17 | 0.08 | 0.022 |
| 300-degree | EDT | Weld (I) | 0.16 | 0.09 | 0.022 |
| 300-degree | EDL | Weld (I) | 0.16 | 0.08 | 0.023 |
| 300-degree | EDL | Weld (I) | 0.17 | 0.08 | 0.022 |
| 30-degree | E1C | Base (I) | 0.26 | 0.57 | 0.06 |
| 30-degree | E1C | Base (I) | 0.30 | 0.59 | 0.06 |
| 30-degree | EBK | Base (I) | 0.30 | 0.51 | 0.08 |
| 30-degree | EBK | Base (I) | 0.34 | 0.54 | 0.07 |
| 30-degree | E71 | Base (I) | 0.33 | 0.58 | 0.05 |
| 30-degree | E2U | Base (I) | 0.28 | 0.52 | 0.03 |
| 30-degree | E31 | Base (I) | 0.28 | 0.61 | 0.07 |

---

(a) Estimated analysis accuracy is ±30 percent for P, ± 60 percent for Ni, and ± 10 percent for Cu.

(b) From Lukens Test Certificates, (U) - Unirradiated, (I) - Irradiated.

are not believed to be inconsistent with compositional variations in thick-section steel. The average Cu and Ni contents for all the data are 0.25 and 0.52 percent, respectively.

The chemical analysis results of unirradiated base metal samples reported in the Lukens test certificates for the same heat from which the surveillance specimens were fabricated are also listed for comparison. The results for the base metal are similar, as expected, within the error band noted above. The weld metal samples showed low copper and very low nickel. Unfortunately, no archive weld and HAZ metal samples were available for chemical analysis.

# VI. DISCUSSION

The shifted nil ductility reference temperature (RTNDT) for the vessel beltline enters reactor vessel pressure-temperature (P-T) calculations directly via the reference stress intensity factor-temperature relation. Therefore, it is necessary to determine conservative estimates of RTNDT for the period of time during which P-T operating limits are in effect. Without surveillance capsule data, estimates of RTNDT are calculated based on the methods of Regulatory Guide 1.99,[19] which take into account material chemistry, estimated fluence and initial values of RTNDT. An assessment shall be made here of the expected value of RTNDT for 10 and 20 efpy of plant service based on Regulatory Guide 1.99 methods and material chemistry only, draft Regulatory Guide 1.99 (Revision 2) methods[20] and material chemistry only, and on surveillance capsule data extrapolated to 10 and 20 efpy.

## A. Predicted Fluence

Based on the flux wire data presented in Section III.A and calculated lead factors, the expected fluence at the 1/4-T location of highest fluence at core midplane is as follows:

Table 8

Expected 1/4-T Fluence (> 1 MeV)

| Exposure Time | 1/4-T Fluence |
|---|---|
| 10 efpy | $6.16 \times 10^{17}$ nvt |
| 20 efpy | $12.32 \times 10^{17}$ nvt |

## B. Initial RTNDT Value

The measured or calculated shift in RTNDT must be added to some initial value determined from unirradiated reactor vessel belt material samples. Charpy impact data for all heats of shell material in the core region of the vessel are available as shown in Table 9. As can be seen from the table, the plate in the lower shell course has a 30 ft-lb temperature (equivalent to RTNDT) of 8°F. The next highest initial RTNDT plate lies in the intermediate shell course opposite the core mid-plane and has a 30 ft-lb temperature of -4°F. It is assumed that the fast flux (>1 MeV) peak will lie in the core mid-plane region or higher due to the increased void fraction higher in the core. Therefore, the limiting initial RTNDT for Nine Mile Point Unit 1 is taken as -4°F.

## C. 30-Degree and 300-Degree Capsule Comparison

Limited Charpy tests were performed on specimens removed from the 30-degree capsule to confirm the large shifts observed in the 300-degree capsule specimens. Measured shifts in the 30 ft-lb temperature for both sets of specimens exceed the expected shifts predicted by references 19 and 20 by considerable margins, as shown in Table 10. The 30-degree capsule exceeds the Reg. Guide 1.99 (Rev. 2) expected shift by over three standard deviations, and the 300-degree specimens exceed the expected shift by about four standard deviations. Therefore, the 30-degree capsule results confirm the large measured shifts in the 300-degree capsule specimens.

## TABLE 9 UNIRRADIATED BASELINE CHARPY TEST RESULTS FOR VESSEL HEATS IN CORE REGION AT NINE MILE POINT UNIT 1

| PLATE NO. | HEAT NO. | SHELL COURSE* | 30 FT-LB TEMPERATURE | 50 FT-LB TEMPERATURE | UPPER SHELF ENERGY |
|---|---|---|---|---|---|
| G-8-1 | P2112 | Lower | + 8°F | +52°F | 90 ft-lbs |
| G-8-3 | P2130 | Lower | -24°F | +24°F | 96 ft-lbs |
| G-8-4 | P2130 | Lower | -26°F | +12°F | 106 ft-lbs |
| G-307-3 | P2074 | Intermediate | - 4°F | +36°F | 104 ft-lbs |
| G-307-10 | P2091 | Intermediate | -12°F | +40°F | 100 ft-lbs |
| G-307-4 | P2076 | Intermediate | - 4°F | +44°F | 80 ft-lbs |

---

* The lower sheel course extends from the bottom head to a level 33.7" above the bottom of the active fuel. The intermediate course covers the remainder of the core elevations.

## Table 10

## Measured and Predicted Charpy 30 ft-lb Temperature Shifts for the 30-Degree and 300-Degree Capsules

| Capsule[a] | Fluence ( > 1MeV) | Measured Shift (30 ft-lb) | Reg. Guide 1.99 (Rev. 1) Shift | Reg. Guide 1.99 (Rev. 2) Shift[b] |
|---|---|---|---|---|
| 30-Degree | $3.6 \times 10^{17}$ | 89°F | 63°F | 74°F |
| 300-Degree | $4.78 \times 10^{17}$ | 114°F | 79°F | 81°F |

---

a) Assumed chemistry is the average for all specimens tested: .25% Cu, .52% Ni, .04% P.

b) This predicted shift includes the two standard deviation "margin" required by the Reg. Guide.

## Table 11

## Predicted 1/4-T RTNDT Shifts

| Method | 10 efpy Shift | 20 efpy Shift |
|---|---|---|
| Extrapolated Capsule Data* | 130°F | 183°F |
| Reg. Guide 1.99** (Revision 1) | 82°F | 116°F |
| Reg. Guide 1.99*** (Revision 2) | 88°F | 110°F |

---

* Based on a measured shift of 114°F after 7.98 efpy of exposure.

** Based on .25% Cu and 0.04% P (average of all samples).

*** Based on .25% Cu and 0.52% Ni (average of all samples).

## D. RTNDT Shift Prediction

Three methods were used to determine the expected shift in RTNDT for 10 and 20 efpy: (1) 300-degree surveillance capsule impact data were extrapolated to 10 and 20 efpy using a square-root-of-fluence extrapolation (which is consistent with Reg. Guide 1.99); (2) Regulatory Guide 1.99 (Revision 1) analytical methods were used with material chemistry (copper and phosphorous) and fluence data; and (3) Regulatory Guide 1.99 (Draft Revision 2) analytical methods were used with chemistry (copper and nickel) and fluence data only. For the last case, a temperature of 34°F was included in the temperature shift to cover the "two-sigma" uncertainty in shift data required by Regulatory Guide 1.99 (Revision 2). Results of these calculations are shown in Table 11.

As can be seen from Table 11, the extrapolated shift of RTNDT for 10 and 20 efpy is considerably greater when based on capsule data than when calculated by Regulatory Guide 1.99 (Revisions 1 or 2) methods.

Table 12 shows that the expected values of 1/4-T RTNDT at 10 and 20 efpy, based on the three methods discussed above, and based on an initial RTNDT of -4°F.

## Table 12

### Expected RTNDT Values at 10 and 20 efpy*

| Method | 10 efpy Shift | 20 efpy Shift |
|---|---|---|
| Extrapolated Capsule Data | 126°F | 179°F |
| Reg. Guide 1.99 (Revision 1) | 78°F | 112°F |
| Reg. Guide 1.99 (Revision 2) | 84°F | 106°F |

---

* Based on an initial RTNDT of -4°F and the temperature shifts shown in Table 10.

# VII. CONCLUSIONS

Evaluation of the fast neutron dosimetry, chemical analysis, and mechanical property test (Charpy V-notch and tensile) results for specimens from the Nine Mile Point Unit 1 surveillance capsules leads to the following conclusions:

## A. Neutron Dosimetry

The Nine Mile Point capsule and surveillance specimens at the 300-degree azimuthal location received a fast neutron fluence ($E > 1.0$ MeV) of $4.8 \times 10^{17}$ n/cm$^2$ as a result of operation from initial startup to March, 1982 (7.98 efpy). The 30-degree capsule received a fast neutron fluence of $3.6 \times 10^{17}$ nvt ($E > 1.0$ MeV).

The Nine Mile Point pressure vessel azimuthal fluence (or flux) varied by as much as a factor of 3. The maximum fast neutron exposure occurred at about the 286-degree aximuthal position and the lead factor was 0.66 for the pressure vessel inside surface, 0.97 for the 1/4-T, and 3.62 for the 3/4-T positions at the 286-degree azimuth.

The maximum fast neutron fluence ($E > 1.0$ MeV) at the pressure vessel 1/4-T position was $4.92 \times 10^{17}$ n/cm$^2$ as a result of operation from initial startup to March, 1982 (7.98 efpy).

## B. Charpy

After a fast neutron fluence ($E > 1.0$ MeV) of $4.78 \times 10^{17}$ n/cm$^2$, the irradiated Charpy V-notch specimens from the Nine Mile Point 300° surveillance capsule indicate a base metal upper shelf energy of 102 ft-lb,

a weld metal upper shelf energy of 116 ft-lb, and a HAZ metal upper shelf energy of 96 ft-lb. The base metal value is actually slightly higher than that obtained with the unirradiated baseline materials. Because of the limited number of tests, Charpy results for the 30-degree capsule did not include tests at temperatures appropriate to obtain upper shelf energies. All values from the 300-degree capsule are well above the minimum allowable upper shelf energy of 50 ft-lb specified in 10 CFR 50 Appendix G.

## C. Tensile

All tensile test specimens exhibited ductile failures as evidenced by the cup-and-cone type fracture shape. The tensile properties were essentially the same as those given for the available unirradiated baseline materials.

## D. Chemistry

The copper, nickel, and phosphorus content obtained at BCL for irradiated specimens from the 300-degree capsule compare well (within about 15 percent) to the content reported for the available base metal specimens.

For the 300-degree capsule, the base metal averaged 0.23 weight percent Cu, 0.46 weight percent Ni and 0.022 weight percent P, while the weld metal averaged 0.17 weight percent Cu. 0.07 weight percent Ni, and 0.022 weight percent P.

For the 30-degree capsule, base metal averaged 0.30 percent Cu and 0.56 percent Ni. The differences are

believed by Battelle to be within the normal compositional variation expected for thick section steel. The average Cu and Ni contents for all data from both capsules are 0.25 and 0.52 weight percent, respectively.

## E. Measured and Calculated RTNDT Shifts

Measured 30 and 50 ft-lb Charpy energy shifts for the 300-degree capsule specimens with 7.98 efpy were approximately 114°F. This same shift is expected for the 1/4-T location in the reactor vessel wall since the lead factor between capsule specimens and the 1/4-T location is essentially unity (0.97). The measured shift for the 30-degree capsule with 5.80 efpy exposure is 89°F. Both capsules display shifts considerably larger than would be predicted on the basis of fluence and chemistry alone, using the methods of Reg. Guide 1.99 (Rev. 1 or 2). Extrapolated RTNDT shifts for 10 and 20 efpy of operation, based on 300-degree capsule data, are also larger than would be calculated from material chemistry and fluence and Regulatory Guide 1.99, Revision 1 or Revision 2 methods.

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Enclosure 2

# PRESSURE-TEMPERATURE LIMITS FOR ELEVEN EFPY

MPR ASSOCIATES
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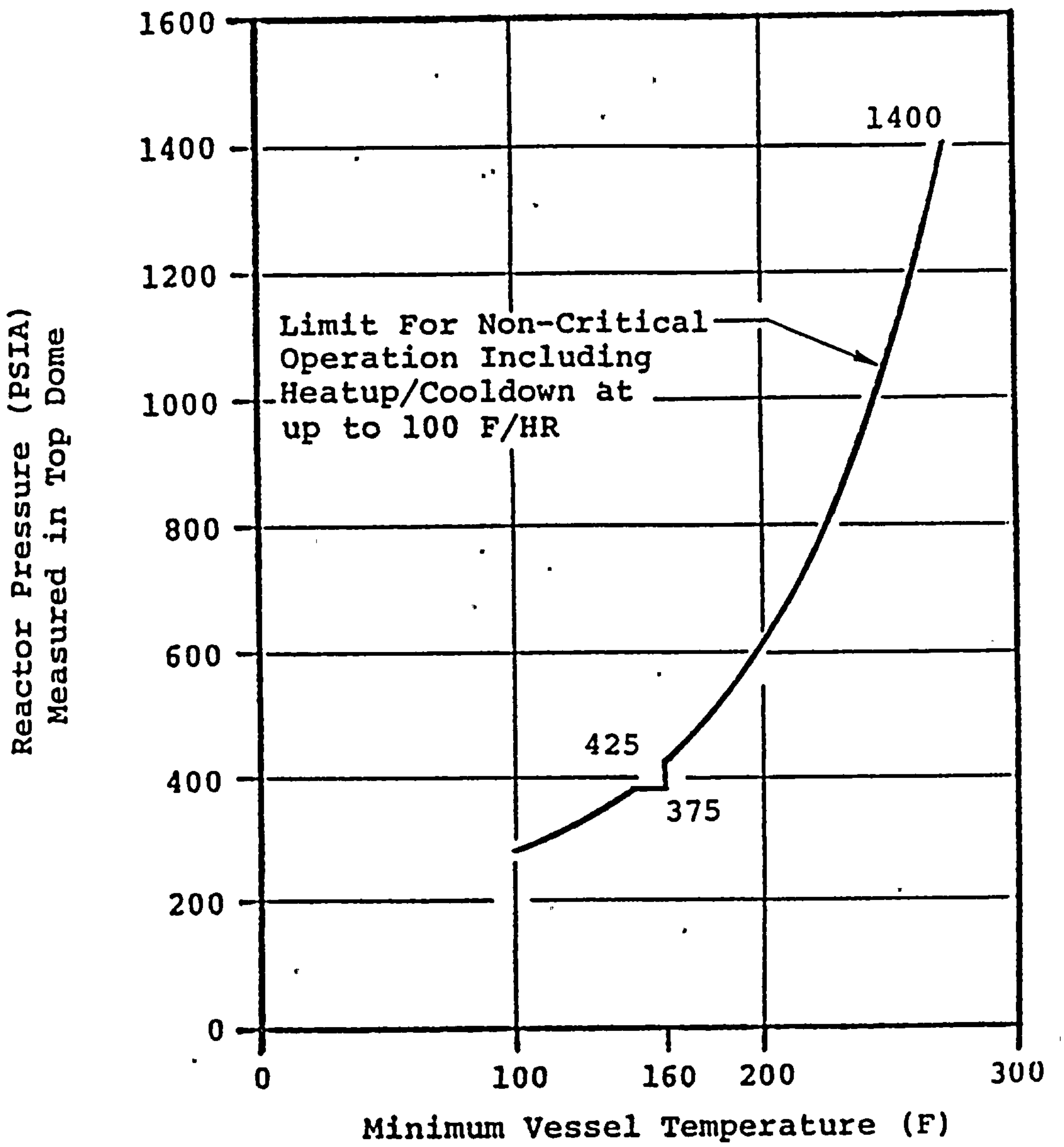

MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR NOT CRITICAL) (HEATING OR COOLING RATE ≤ 100 F/HR) FOR UP TO ELEVEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

FIGURE 1

# MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR NOT CRITICAL) (HEATING OR COOLING RATE ≤ 100 F/HR) FOR UP TO ELEVEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

| TEMPERATURE (°F) | PRESSURE (psia) | TEMPERATURE (°F) | PRESSURE (psia) |
|---|---|---|---|
| 100 | 0 | 223 | 800 |
| 100 | 279 | 225 | 820 |
| 105 | 287 | 227 | 840 |
| 110 | 295 | 229 | 860 |
| 115 | 304 | 231 | 880 |
| 120 | 314 | 233 | 900 |
| 125 | 324 | 235 | 920 |
| 130 | 336 | 237 | 940 |
| 135 | 348 | 239 | 960 |
| 140 | 361 | 240 | 980 |
| 145 | 375 | 242 | 1000 |
| 150 | 375 | 244 | 1020 |
| 160 | 375 | 245 | 1040 |
| 160 | 425 | 247 | 1060 |
| 164 | 440 | 249 | 1080 |
| 169 | 460 | 250 | 1100 |
| 174 | 480 | 251 | 1120 |
| 178 | 500 | 253 | 1140 |
| 182 | 520 | 254 | 1160 |
| 186 | 540 | 256 | 1180 |
| 190 | 560 | 257 | 1200 |
| 193 | 580 | 258 | 1220 |
| 196 | 600 | 260 | 1240 |
| 200 | 620 | 261 | 1260 |
| 203 | 640 | 262 | 1280 |
| 206 | 660 | 263 | 1300 |
| 208 | 680 | 265 | 1320 |
| 211 | 700 | 266 | 1340 |
| 214 | 720 | 267 | 1360 |
| 216 | 740 | 268 | 1380 |
| 218 | 760 | 269 | 1400 |
| 221 | 780 | | |

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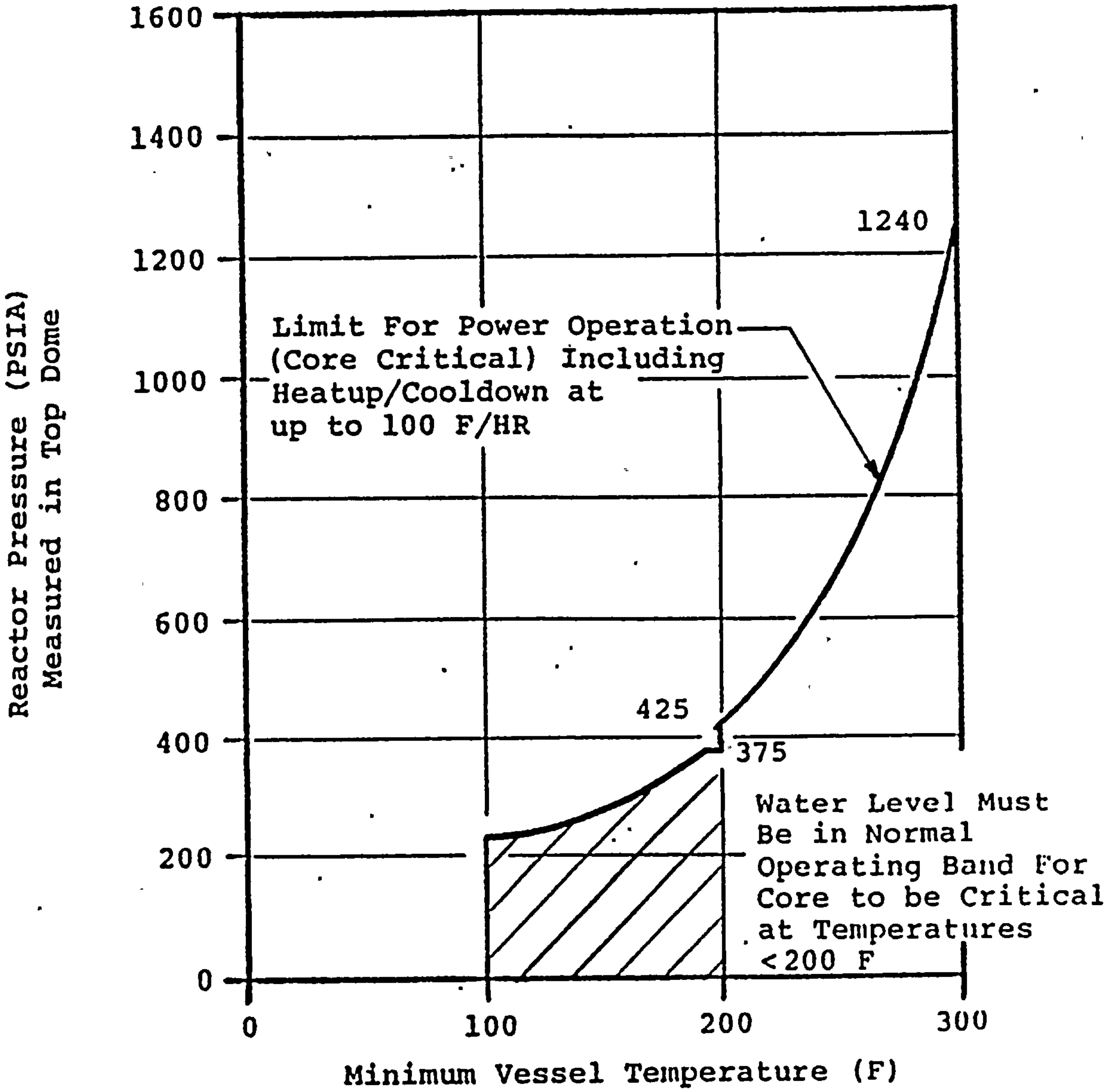

MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR CRITICAL) (HEATING OR COOLING RATE ≤ 100 F/HR) FOR UP TO ELEVEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

FIGURE 2

# MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR CRITICAL) (HEATING OR COOLING RATE $\leq$ 100 F/HR) FOR UP TO ELEVEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

| TEMPERATURE (°F) | PRESSURE (psia) | TEMPERATURE (°F) | PRESSURE (psia) |
|---|---|---|---|
| 100 | 0 | 263 | 800 |
| 100 | 233 | 265 | 820 |
| 109 | 241 | 267 | 840 |
| 118 | 250 | 269 | 860 |
| 127 | 261 | 271 | 880 |
| 136 | 273 | 273 | 900 |
| 145 | 287 | 275 | 920 |
| 154 | 302 | 277 | 940 |
| 163 | 320 | 279 | 960 |
| 172 | 340 | 280 | 980 |
| 181 | 363 | 282 | 1000 |
| 190 | 375 | 284 | 1020 |
| 200 | 375 | 285 | 1040 |
| 200 | 425 | 287 | 1060 |
| 204 | 440 | 289 | 1080 |
| 209 | 460 | 290 | 1100 |
| 214 | 480 | 291 | 1120 |
| 218 | 500 | 293 | 1140 |
| 222 | 520 | 294 | 1160 |
| 226 | 540 | 296 | 1180 |
| 230 | 560 | 297 | 1200 |
| 233 | 580 | 298 | 1220 |
| 236 | 600 | 300 | 1240 |
| 240 | 620 | 301 | 1260 |
| 243 | 640 | 302 | 1280 |
| 246 | 660 | 303 | 1300 |
| 248 | 680 | 305 | 1320 |
| 251 | 700 | 306 | 1340 |
| 254 | 720 | 307 | 1360 |
| 256 | 740 | 308 | 1380 |
| 258 | 760 | 309 | 1400 |
| 261 | 780 |  |  |

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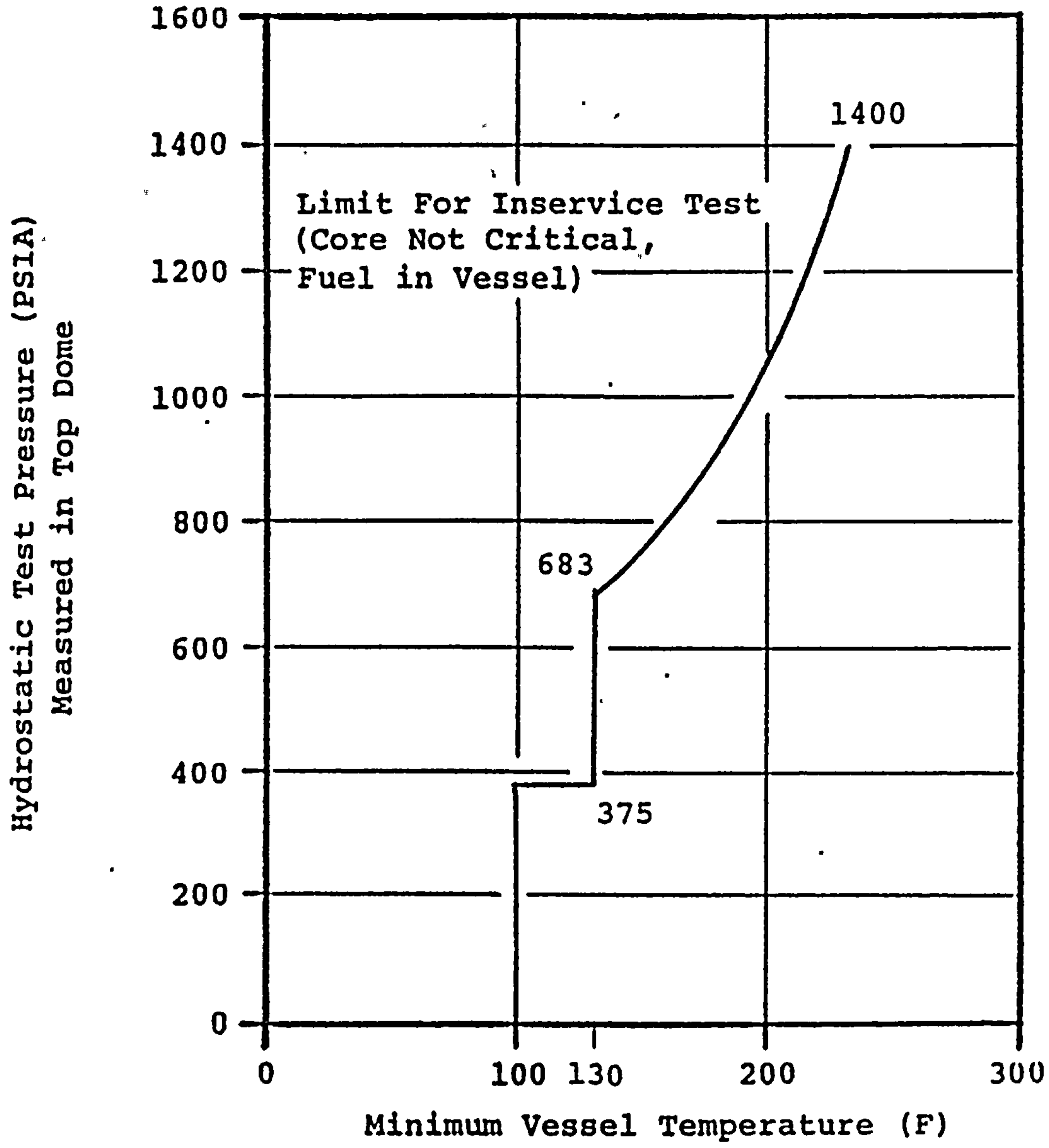

MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HYDROSTATIC TESTING (REACTOR NOT CRITICAL) FOR UP TO ELEVEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

FIGURE 3

## MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HYDROSTATIC TESTING (REACTOR NOT CRITICAL) FOR UP TO ELEVEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

| TEMPERATURE (°F) | PRESSURE (psia) | TEMPERATURE (°F) | PRESSURE (psia) |
|---|---|---|---|
| 100 | 0 | 195 | 1020 |
| 100 | 375 | 197 | 1040 |
| 130 | 375 | 200 | 1060 |
| 130 | 683 | 202 | 1080 |
| 135 | 700 | 204 | 1100 |
| 141 | 720 | 206 | 1120 |
| 146 | 740 | 208 | 1140 |
| 151 | 760 | 210 | 1160 |
| 156 | 780 | 212 | 1180 |
| 160 | 800 | 214 | 1200 |
| 164 | 820 | 216 | 1220 |
| 168 | 840 | 218 | 1240 |
| 171 | 860 | 220 | 1260 |
| 175 | 880 | 221 | 1280 |
| 178 | 900 | 223 | 1300 |
| 181 | 920 | 225 | 1320 |
| 184 | 940 | 226 | 1340 |
| 187 | 960 | 228 | 1360 |
| 190 | 980 | 229 | 1380 |
| 192 | 1000 | 231 | 1400 |

# PRESSURE-TEMPERATURE LIMITS FOR THIRTEEN EFPY

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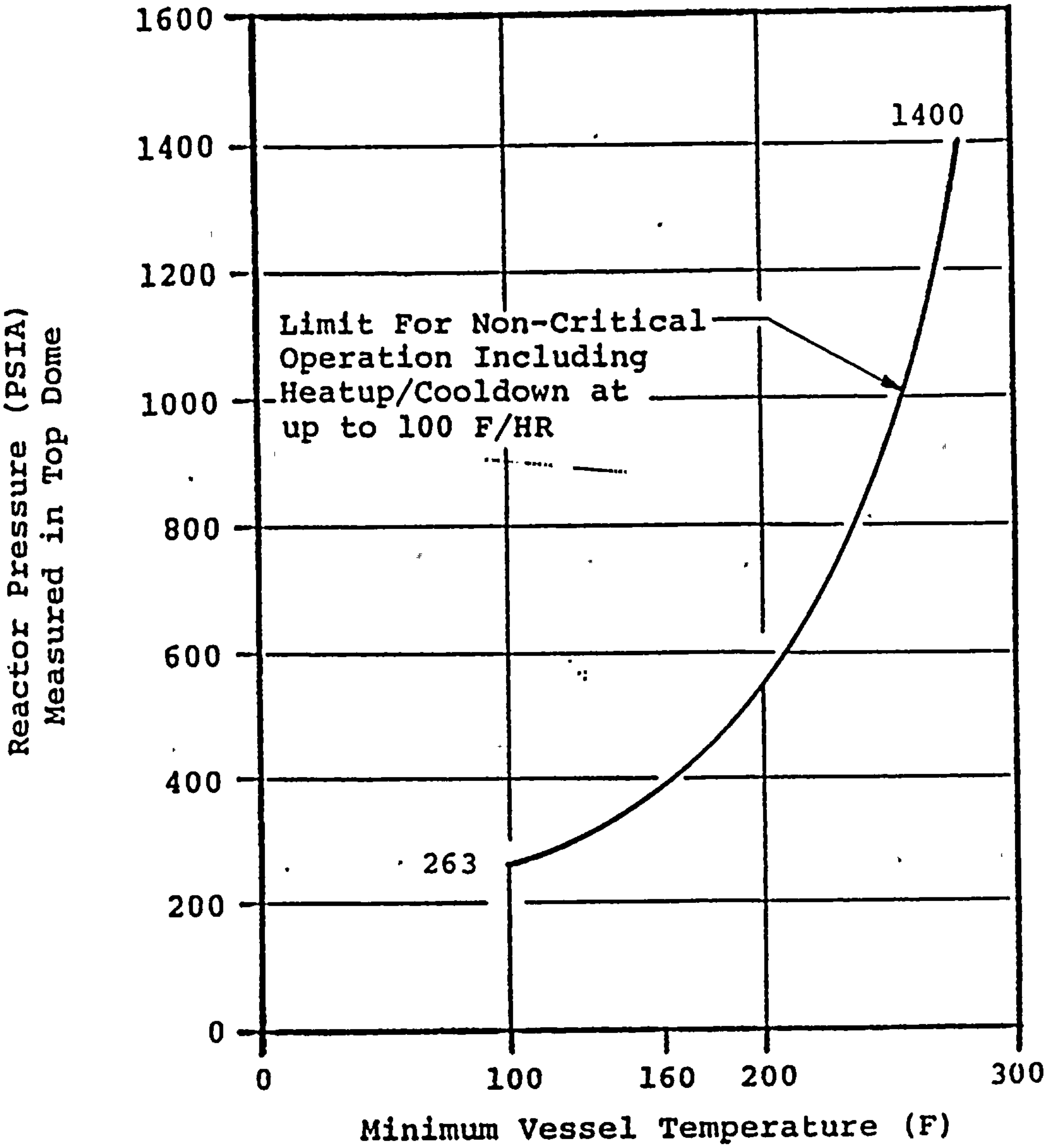

MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR NOT CRITICAL) (HEATING OR COOLING RATE ≤ 100 F/HR) FOR UP TO THIRTEEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

FIGURE 1

# MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR NOT CRITICAL) (HEATING OR COOLING RATE $\leq$ 100 F/HR) FOR UP TO THIRTEEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

| TEMPERATURE (°F) | PRESSURE (psia) | TEMPERATURE (°F) | PRESSURE (psia) |
|---|---|---|---|
| 100 | 0 | 232 | 780 |
| 100 | 263 | 235 | 800 |
| 106 | 271 | 237 | 820 |
| 112 | 280 | 239 | 840 |
| 118 | 290 | 241 | 860 |
| 125 | 300 | 243 | 880 |
| 131 | 312 | 245 | 900 |
| 137 | 325 | 247 | 920 |
| 143 | 339 | 249 | 940 |
| 149 | 355 | 250 | 960 |
| 155 | 371 | 252 | 980 |
| 161 | 375 | 254 | 1000 |
| 160 | 375 | 255 | 1020 |
| 160 | 386 | 257 | 1040 |
| 164 | 400 | 259 | 1060 |
| 170 | 420 | 260 | 1080 |
| 176 | 440 | 262 | 1100 |
| 181 | 460 | 263 | 1120 |
| 185 | 480 | 265 | 1140 |
| 190 | 500 | 266 | 1160 |
| 194 | 520 | 267 | 1180 |
| 198 | 540 | 269 | 1200 |
| 201 | 560 | 270 | 1220 |
| 205 | 580 | 271 | 1240 |
| 208 | 600 | 273 | 1260 |
| 211 | 620 | 274 | 1280 |
| 214 | 640 | 275 | 1300 |
| 217 | 660 | 276 | 1320 |
| 220 | 680 | 278 | 1340 |
| 223 | 700 | 279 | 1360 |
| 225 | 720 | 280 | 1380 |
| 228 | 740 | 281 | 1400 |
| 230 | 760 | | |

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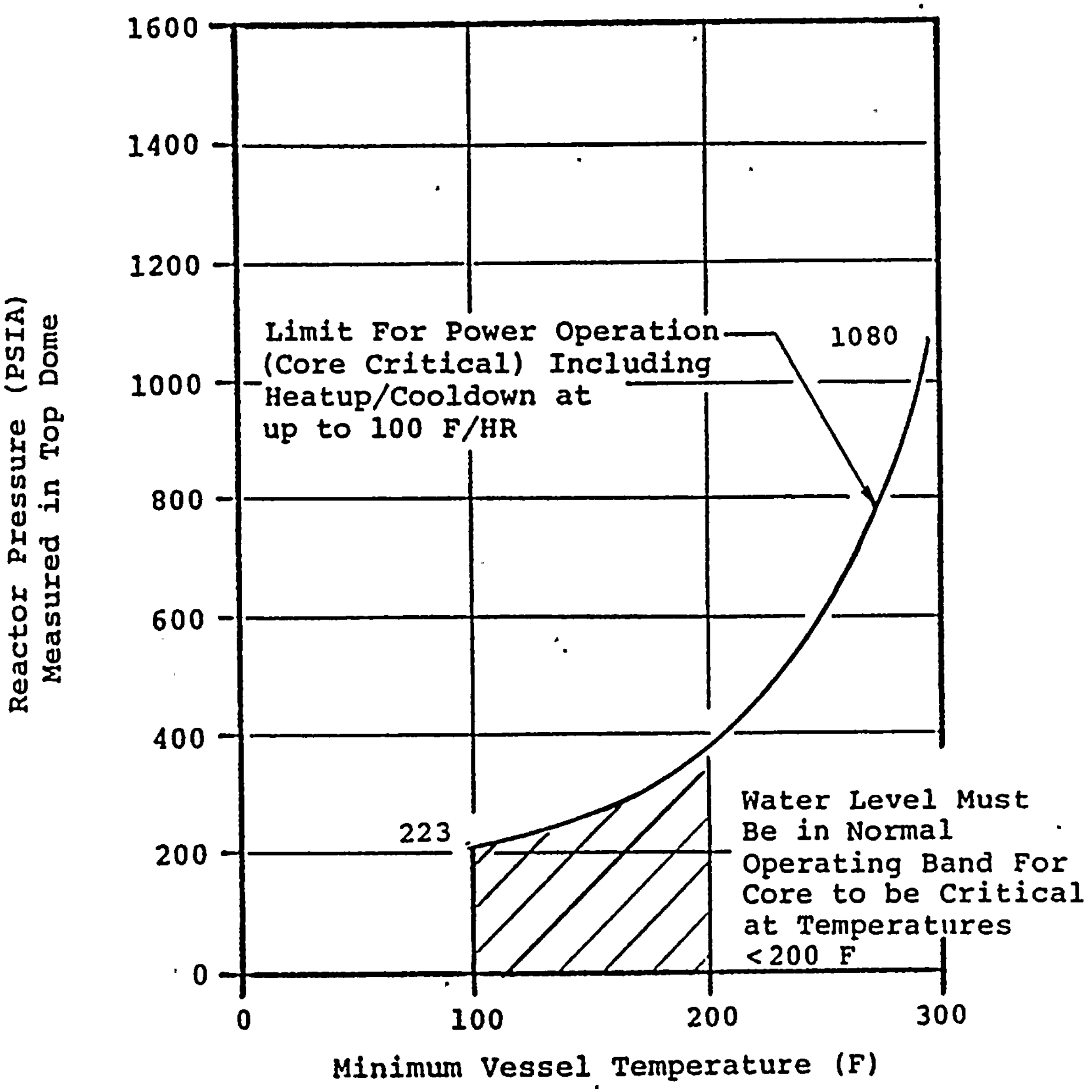

MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR CRITICAL) (HEATING OR COOLING RATE ≤ 100 F/HR) FOR UP TO THIRTEEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

FIGURE 2

# MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HEATUP OR COOLDOWN (REACTOR CRITICAL) (HEATING OR COOLING RATE ≤ 100 F/HR) FOR UP TO THIRTEEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

| TEMPERATURE (°F) | PRESSURE (psia) | TEMPERATURE (°F) | PRESSURE (psia) |
|---|---|---|---|
| 100 | 0 | 272 | 780 |
| 100 | 223 | 275 | 800 |
| 110 | 231 | 277 | 820 |
| 120 | 240 | 279 | 840 |
| 130 | 251 | 281 | 860 |
| 141 | 263 | 283 | 880 |
| 151 | 277 | 285 | 900 |
| 161 | 294 | 287 | 920 |
| 171 | 313 | 289 | 940 |
| 181 | 335 | 290 | 960 |
| 191 | 360 | 292 | 980 |
| 201 | 375 | 294 | 1000 |
| 200 | 375 | 295 | 1020 |
| 200 | 386 | 297 | 1040 |
| 204 | 400 | 299 | 1060 |
| 210 | 420 | 300 | 1080 |
| 216 | 440 | 302 | 1100 |
| 221 | 460 | 303 | 1120 |
| 225 | 480 | 305 | 1140 |
| 230 | 500 | 306 | 1160 |
| 234 | 520 | 307 | 1180 |
| 238 | 540 | 309 | 1200 |
| 241 | 560 | 310 | 1220 |
| 245 | 580 | 311 | 1240 |
| 248 | 600 | 313 | 1260 |
| 251 | 620 | 314 | 1280 |
| 254 | 640 | 315 | 1300 |
| 257 | 660 | 316 | 1320 |
| 260 | 680 | 318 | 1340 |
| 263 | 700 | 319 | 1360 |
| 265 | 720 | 320 | 1380 |
| 268 | 740 | 321 | 1400 |
| 270 | 760 | | |

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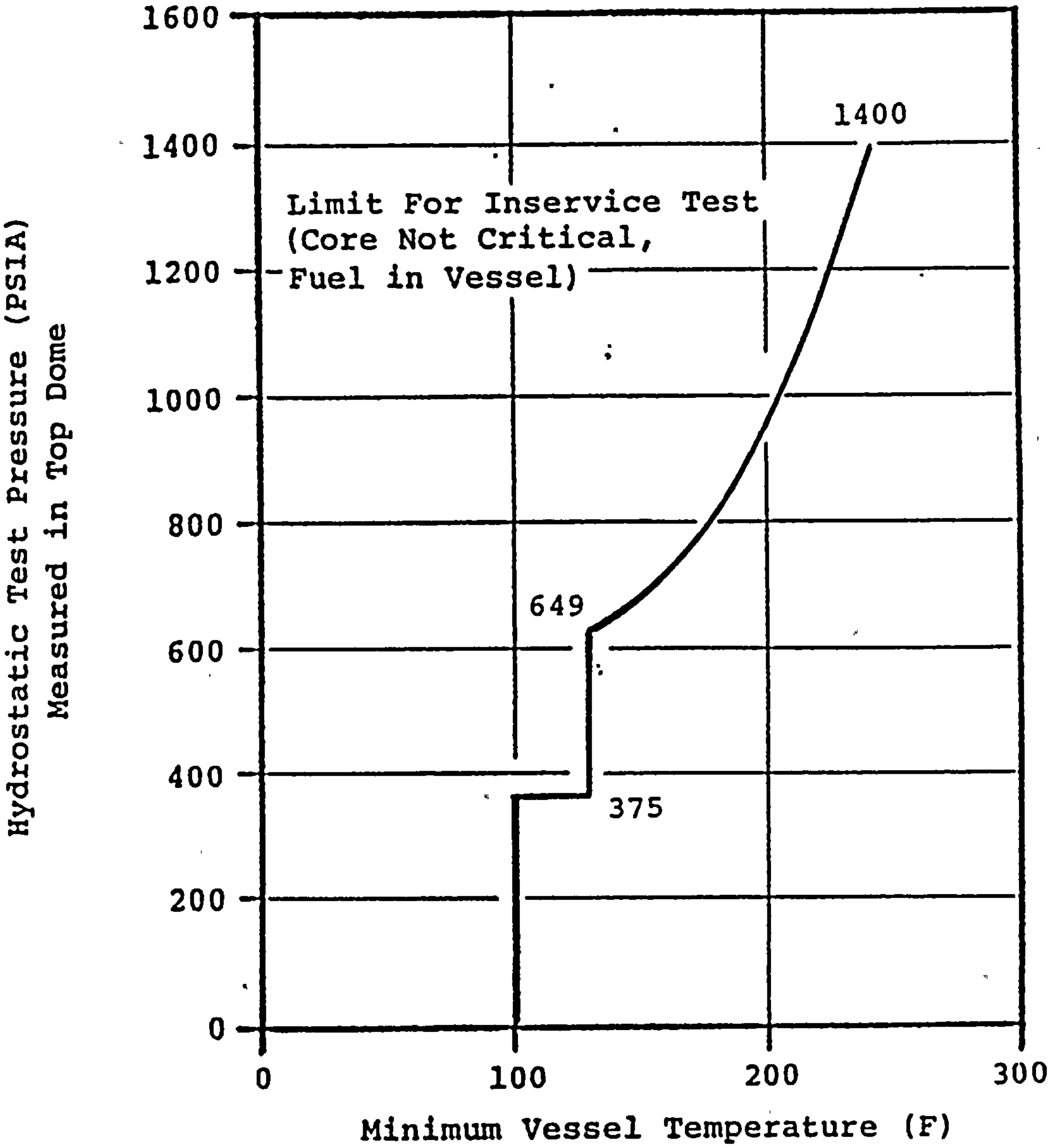

MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HYDROSTATIC TESTING (REACTOR NOT CRITICAL) FOR UP TO THIRTEEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

FIGURE 3

# MINIMUM TEMPERATURE FOR PRESSURIZATION DURING HYDROSTATIC TESTING (REACTOR NOT CRITICAL) FOR UP TO THIRTEEN EFFECTIVE FULL POWER YEARS OF CORE OPERATION

| TEMPERATURE (°F) | PRESSURE (psia) | TEMPERATURE (°F) | PRESSURE (psia) |
|---|---|---|---|
| 100 | 0 | 204 | 1000 |
| 100 | 375 | 206 | 1020 |
| 130 | 375 | 209 | 1040 |
| 130 | 649 | 211 | 1060 |
| 134 | 660 | 213 | 1080 |
| 141 | 680 | 216 | 1100 |
| 147 | 700 | 218 | 1120 |
| 153 | 720 | 220 | 1140 |
| 158 | 740 | 222 | 1160 |
| 163 | 760 | 224 | 1180 |
| 167 | 780 | 226 | 1200 |
| 171 | 800 | 228 | 1220 |
| 175 | 820 | 229 | 1240 |
| 179 | 840 | 231 | 1260 |
| 183 | 860 | 233 | 1280 |
| 186 | 880 | 235 | 1300 |
| 190 | 900 | 236 | 1320 |
| 193 | 920 | 238 | 1340 |
| 196 | 940 | 339 | 1360 |
| 198 | 960 | 241 | 1380 |
| 201 | 980 | 242 | 1400 |