Entergy

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Barbara E. Dotson
Licensing Manager

PNP 2011-044

May 24, 2011

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

SUBJECT: Response to Request for Additional Information for Pressurized Thermal Shock Evaluation (ME5263)

Palisades Nuclear Plant
Docket 50-255
License No. DPR-20

Reference:

1. Entergy Nuclear Operations, Inc. letter, "Updated Palisades Reactor Vessel Pressurized Thermal Shock Evaluation", dated December 20, 2010 (ADAMS Accession No. ML 110060692)

2. NRC e-mail dated April 7, 2011, Palisades - PTS Evaluation - ME5263 - Request for Additional Information

Dear Sir or Madam:

Entergy Nuclear Operations, Inc. (ENO) submitted an updated reactor vessel pressurized thermal shock evaluation for the Palisades Nuclear Plant on December 20, 2010 (Reference 1). ENO received an electronic request for additional information (RAI) from the Nuclear Regulatory Commission (NRC) concerning the submittal on April 7, 2011 (Reference 2). ENO and the NRC held a conference call on May 3, 2011, to clarify the RAI.

The enclosure contains the ENO response to the RAI. Attachment 1 of the enclosure contains BAW-2341, "Test Results Capsule SA-60-1," and Attachment 2 of the enclosure contains BAW-2398, "Test Results for Capsule SA-240-1." These two documents were requested by the NRC during the conference call.

A001
NRR

This letter contains no new or revised commitments.

Sincerely,

BE Dotson

bed/jse

Enclosure: RAI Response on Updated Palisades Reactor Vessel Pressurized Thermal Shock Evaluation

cc: Administrator, Region III, USNRC
Project Manager, Palisades, USNRC
Resident Inspector, Palisades, USNRC

ENCLOSURE

RAI RESPONSE ON UPDATED PALISADES REACTOR VESSEL PRESSURIZED THERMAL SHOCK EVALUATION

Request for additional information (RAI) received by electronic mail on April 7, 2011.

Nuclear Regulatory Commission (NRC) Request

Attachment 1: Report 0901132.401, "Evaluation of Surveillance Data for Weld Heat No. W5214 for Application to Palisades PTS Analysis"

1. *It is stated in Section 4.0 under Data Evaluation Results that, "[t]he new data survey was performed to gather all the unirradiated and irradiated capsule test results for the Palisades limiting weld material." Briefly describe this new data survey to demonstrate that no relevant data could have been missed during the survey.*

Entergy Nuclear Operations, Inc. (ENO) Response

1. The new data survey to gather all the unirradiated and irradiated capsule test results for the Palisades Nuclear Plant (PNP) limiting weld materials consisted of discussions with vendors and reviews of applicable databases and reports to ensure that all relevant data had been identified for the pressurized thermal shock evaluation. The focus of the surveying process was to identify and verify:

    - sister plants containing the same heats of weld material,
    - capsules containing weld metal heat W5214 and 27204 that have been removed and tested to date,
    - capsule initial properties,
    - capsule irradiation temperature, and
    - capsule fluence.

    The following sister plants, vendors, and consultants were contacted for information:

    - sister plants: Fort Calhoun, Indian Point Units 2 and 3, and Robinson
    - fabricating vendor: Combustion Engineering
    - testing vendor: The Babcock and Wilcox Company, AREVA, and Westinghouse Electric Company
    - fluence analysis vendor: Westinghouse Electric Company
    - consultant: ATI Consulting and Structural Integrity Associates, Inc.

The following documentation was reviewed during the initial information gathering process:

1. Reactor Vessel Integrity Database Version 2.0.1 (NRC database).

2. Reactor Vessel Materials Database (RPVDATA) Version 2 (EPRI database).

3. EPRI, Materials Reliability Program letter 2010-001, Technical Report 51-9107111-000, "Coordinated U.S. PWR Reactor Vessel Surveillance Program (DRAFT 2)," September 2010.

4. "Best Estimate Copper and Nickel Values in CE Fabricated Reactor Vessel Welds," CE NPSD-1039, Revision 2, Combustion Engineering Owners Group, June 1997 [referenced in Structural Integrity Associates, Inc. (SIA) Report No. 1000915.401, Revision 1].

5. "Updated Analysis for Combustion Engineering Fabricated Reactor Vessel Welds Best Estimate Copper and Nickel Content," Combustion Engineering Owners Group, CEOG Task 1054, CE NPSD-1119, Revision 1, July 1998 [referenced in SIA Report No. 0901132.401, Revision 0, and SIA Report No. 1000915.401, Revision 1].

6. Letter from NRC to Palisades Plant, "Palisades Plant – Pressurized Thermal Shock Safety Evaluation (TAC No. M83227)," April 12, 1995.

7. CNS-04-02-01, Constellation Nuclear Services Report, Revision 1, June 2004, "Evaluation of Palisades Nuclear Plant Reactor Pressure Vessel Through the Period of Extended Operation" [referenced in SIA Report No. 0901132.401, Revision 0, and SIA Report No. 1000915.401, Revision 1].

8. WCAP and BAW/BWXT reports referenced in SIA Report No. 0901132.401, Revision 0, and SIA Report No. 1000915.401, Revision 1.

9. EPRI, Reactor Vessel Embrittlement Management Handbook, Volume 6, "Vessel Design and Fabrication," EPRI TR-101975-T2, December 1993.

Through discussions with Westinghouse Electric Company and AREVA, ENO was able to confirm which surveillance capsules containing weld metal heats W5214 and 27204 have been removed and tested to date.

In addition, ENO retained Westinghouse Electric Company to review Structural Integrity Associates (SIA), Inc. Report No. 0901132.401 and Report No. 1000915.401 prior to transmittal of the pressurized thermal shock evaluation to the NRC to ensure that the reports contain all relevant information.

In summary, an exhaustive search confirmed that all reactor vessels made by Combustion Engineering containing these weld metal heats were identified. For the sister plants containing these same heats of weld material in surveillance capsules, the most up-to-date information had been gathered and there was no additional relevant data available.

NRC Request

2. *It is stated in Section 4.0 that, "there are two capsules from the Palisades supplemental surveillance program that were previously unreported."*

- *A review of the BAW-2398 report, "Test Results of Capsule SA-240-1," indicated that the upper shelf energy values were determined in accordance with American Society for Testing and Materials (ASTM) Standard E 185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels." However, it did not mention whether the two supplemental capsules also comply with other aspects of the ASTM E 185-82. Discuss whether the supplemental capsule weld test data were obtained in accordance with the ASTM E 185-82 regarding test specimens, irradiation requirements, measurement of mechanical properties, and determination of irradiation effects.*

ENO Response

The PNP supplemental surveillance capsules SA-60-1 and SA-240-1 were designed in accordance with ASTM E185-82, which was the version of ASTM E185 that was accepted by the NRC at that time.

Due to space limitations in the capsules and the need for a sufficient number of specimens to monitor irradiation effects, annealing recovery and re-embrittlement 18 mm x 10 mm x 10 mm Charpy inserts for each of the three weld metal heats in the beltline region (W5124, 34B009, and 27204) were inserted in the capsules, as follows:

Weld Metal Heat	Capsule SA-60-1	Capsule SA-240-1
W5124	39 Charpy inserts	42 Charpy inserts
34B009	39 Charpy inserts	36 Charpy inserts
27204	36 Charpy inserts	36 Charpy inserts

These inserts were to be reconstituted into full size Charpy specimens after irradiation following the guidance in ASTM E1253-88, "Standard Guide for Reconstitution of Irradiated Charpy Specimens." Both SA-60-1 and SA-240-1 capsules contained equivalent dosimetry and melt wires, like other surveillance capsules in the PNP surveillance program. Additionally, 12 correlation monitor material (heavy-section steel technology (HSST) Plate 02) Charpy specimens were included in each of these supplemental capsules as well as 12 full size Charpy specimens and three tensile specimens for weld metal heat 27204. Both supplemental surveillance capsules, SA-60-1 and SA-240-1, were installed into original surveillance capsule locations that were vacated during prior capsule removals.

Additional information on reconstitution of Charpy specimens is documented in BAW-2184, "Verification of Reconstituted Charpy V-Notch Test Values," dated May 1993. The dosimetry evaluations for capsule SA-60-1 were documented in WCAP-15353, Revision 0, "Palisades Reactor Pressure Vessel Neutron Fluence Evaluation," (ADAMS Accession No. ML003686582). The dosimetry analysis for capsule SA-240-1 was transmitted to Consumer Energy Company (former PNP license holder) via Westinghouse Project Letter CPAL-01-009, "Neutron Fluence Analysis for Palisades Surveillance Capsule SA-240-1," dated April 30, 2001. The irradiation assessments for SA-60-1 and SA-240-1 have been updated under WCAP-15353, Supplement 1. Note that all mechanical property testing was done in accordance with ASTM E185-82 requirements.

Test results for SA-60-1 are included in BAW-2341, Revision 2, (provided in Attachment 1 to this enclosure) and test results for SA-240-1 are included in BAW-2398 (provided in Attachment 2). The latest determinations of irradiation effects are summarized in SIA Report No. 1000915.401, "Revised Pressurized Thermal Shock Evaluation for the Palisades Reactor Pressure Vessel," and WCAP-17341-NP, "Palisades Nuclear Power Plant Heatup and Cooldown Limit Curves for Normal Operation and Upper-Shelf Energy Evaluation." WCAP-17341-NP was provided to the NRC in ENO submittal, "License Amendment Request for Primary Coolant System Pressure-Temperature Limits," dated March 7, 2011.

NRC Request

2. (continued)

- *Provide information about the reconstituted full size Charpy V-notch specimens using weld metal inserts. Cite studies and demonstrate that the Charpy data obtained this way is equivalent to those from conventional weld metal specimens.*

ENO Response

ASTM E1253 provides guidance on reconstitution of Charpy specimens, as mentioned in the previous response. This standard guidance was used in the preparation of all reconstituted Charpy specimens of the irradiated welds from the two supplemental capsules. Confirmation that equivalent results are obtained from reconstituted Charpy specimens as compared to full size Charpy specimens is documented in BAW-2184. Extensive studies also have been conducted, including an ASTM round robin in which many United States and international laboratories participated (including the laboratory that produced these reconstituted specimens), that further support the guidance in ASTM E1253. This ASTM round robin is documented in NUREG/CR-6777 (ORNL/TM-2001/34), "Results and Analysis of the ASTM Round Robin on Reconstitution," August 2002 [ML022540225].

NRC Request

2. (continued)

- *Discuss whether the Palisades surveillance program augmented with two supplemental capsules was reviewed by the NRC.*

ENO Response

The PNP surveillance program augmented with the two supplemental capsules, SA-60-1 and SA-240-1, has not been previously reviewed by the NRC.

The supplemental capsules are discussed in the PNP Final Safety Analysis Report (FSAR). FSAR Section 4.5.3, "Surveillance Program" describes the supplemental capsules, and references the aforementioned BAW-2341 and BAW-2398, which contain the test results for these capsules.

In addition, the dosimetry results from capsule SA-60-1 are included in WCAP-15353, Revision 0, which has been reviewed by the NRC.

ATTACHMENT 1

TEST RESULTS CAPSULE SA-60-1

BAW-2341

REVISION 2

MAY 2001

93 Pages Follow

BAW-2341, Revision 2
May 2001

Test Results of Capsule SA-60-1 Consumers Energy Palisades Nuclear Plant

-- Reactor Vessel Material Surveillance Program --

by

M. J. DeVan

FTI Document No. 77-2341-02
(See Section 7 for document signatures.)

Prepared for

Consumers Energy

Prepared by

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FRAMATOME ANP

Executive Summary

This report describes the results of the test specimens from the first supplemental capsule (Capsule SA-60-1) of the Consumers Energy Palisades Nuclear Plant as part of their reactor vessel surveillance program. The objective of the program is to monitor the effects of neutron irradiation on the mechanical properties of the reactor vessel materials by testing and evaluation of Charpy impact specimens.

Supplemental Capsule SA-60-1 was removed from the Palisades reactor vessel at the end-of-cycle 13 (EOC-13) for testing and evaluation. The capsule contents were removed from Capsule SA-60-1 for testing and examination. The test specimens included modified 18mm Charpy V-notch inserts for three weld metals fabricated with weld wire heats W5214, 34B009, and 27204 and standard Charpy V-notch specimens fabricated from the correlation monitor plate material, HSST Plate 02. The weld metal Charpy inserts were reconstituted to full size Charpy V-notch specimens. The reconstituted weld metals along with HSST Plate 02 material were Charpy impact tested.

Following the initial Charpy V-notch impact testing, the laboratory performed a calibration of the temperature indicator used in the Palisades Capsule SA-60-1 testing. The results of the laboratory calibration indicated the instrument was out-of-tolerance. Based on the results of this calibration test, the laboratory revised the Charpy impact test temperatures accordingly. Revision 1 corrects the test temperatures for the Supplemental Capsule SA-60-1 reconstituted weld metal Charpy V-notch impact specimens and the HSST Plate 02 Charpy V-notch impact specimens.

Revision 2 provides an update to the hyperbolic tangent curve fits of the Charpy impact curves by restraining the upper-shelf energy. For these curve fits, the lower-shelf energy was fixed at 2.2 ft-lbs for all cases, and for each materials the upper-shelf energy was fixed at the average of 2
all test energies exhibiting 100% shear, consistent with ASTM Standard E 185-82.

Acknowledgement

The author would like to thank Kevin Hour of the McDermott Technology, Inc. Lynchburg Technology Center for his efforts and expertise in specimen testing and Hongqing Xu of Framatome Technologies, Inc. for his work on the Charpy specimen reconstitution. The efforts by both these individuals contributed greatly to the success of this project.

Record of Revisions

Date	Revision No.	Description
March 1999	0	Original Issue
May 1999	1	Executive Summary – Revision statement added. Section 1 – Revision statement added. Section 4 – Added paragraph referencing laboratory test report. Table 4-2. – Corrected Specimen IDs. Table 4-3. – Revised test temperatures. Table 4-4. – Revised test temperatures. Table 4-5. – Revised test temperatures. Table 4-6. – Revised test temperatures. Table 4-7. – Revised test temperatures. Table 4-8. – Revised test temperatures. Table 4-9. – Revised test temperatures. Table 4-10. – Revised test temperatures. Table 4-11. – Revised coefficients based on revised test temperatures. Table 4-12. – Revised Figure 4-2. – Revised figure based on revised test temperatures. Figure 4-3. – Revised figure based on revised test temperatures. Figure 4-4. – Revised figure based on revised test temperatures. Figure 4-5. – Revised figure based on revised test temperatures. Figure 4-6. – Removed reported test temperature. Figure 4-7. – Removed reported test temperature. Figure 4-8. – Removed reported test temperature. Figure 4-9. – Removed reported test temperature. Section 6. – Revised transition temperatures in items 3 through 6 based on revised test temperatures. Section 7. – New signatures added. Section 8. – Revised reference.

Record of Revisions (continued)

Date	Revision No.	Description
May 2000	2	Executive Summary – Revision statement added. Section 1 – Revision statement added. Section 3 – Corrected typo. Section 4.1 – Corrected typo. Section 4.5 – Added paragraph describing the method used for the hyperbolic tangent curve fitting of the Charpy impact data. Table 4-2. – Changed "width" and "thickness" tolerance from ±0.001" to ±0.003". Table 4-11. – Revised coefficients for Absorbed Energy based on fixing the upper-shelf energy at the average of all test energies exhibiting 100% shear. Table 4-12. – Revised . Figure 4-2. – Revised figure. Figure 4-3. – Revised figure. Figure 4-4. – Revised figure. Figure 4-5. – Revised figure. Section 6. – Revised transition temperatures in items 3 through 6 based on revised hyperbolic tangent curve fit coefficients. Section 7. – New signatures added. Table A-1. – Revised table to be consistent with the NRC's RVID2 database.

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1.0 Introduction

Two supplemental surveillance capsules were fabricated containing the three weld metals found in the core region of the Palisades reactor vessel. The supplemental capsules were prepared to obtain information on the effects of irradiation on the mechanical properties of weld metals fabricated using the same weld wire heats and weld procedures as was used in the Palisades reactor vessel beltline region. Supplemental Capsules SA-60-1 and SA-240-1 were inserted in the Palisades reactor vessel at the end-of-cycle 11 (EOC-11) in locations near the outer wall of the core support barrel for accelerated exposure. Supplemental Capsule SA-60-1 was removed from the Palisades reactor vessel at the end-of-cycle 13 (EOC-13) for testing and evaluation.

This report describes the specimen testing and the post-irradiation results from the first supplemental surveillance capsule (Capsule SA-60-1) for the Consumers Energy's Palisades Nuclear Plant.

Following the initial Charpy V-notch impact testing, the laboratory performed a calibration of the temperature indicator used in the Palisades Capsule SA-60-1 testing. The results of the laboratory calibration indicated the instrument was out-of-tolerance. Based on the results of this calibration test, the laboratory revised the Charpy impact test temperatures accordingly. Revision 1 corrects the test temperatures for the Supplemental Capsule SA-60-1 reconstituted weld metal Charpy V-notch impact specimens and the HSST Plate 02 Charpy V-notch impact specimens.

Revision 2 provides an update to the hyperbolic tangent curve fits of the Charpy impact curves by restraining the upper-shelf energy. For these curve fits, the lower-shelf energy was fixed at 2.2 ft-lbs for all cases, and for each materials the upper-shelf energy was fixed at the average of all test energies exhibiting 100% shear, consistent with ASTM Standard E 185-82. 2

2.0 Background

The ability of the reactor vessel to resist fracture is a primary factor in ensuring the safety of the primary system in light water-cooled reactors. The reactor vessel beltline region is the most critical region of the vessel because it is exposed to the highest level of neutron irradiation. The general effects of fast neutron irradiation on the mechanical properties of low-alloy ferritic steels used in the fabrication of reactor vessels are well characterized and documented. The low-alloy ferritic steels used in the beltline region of reactor vessels exhibit an increase in ultimate and yield strength properties with a corresponding decrease in ductility after irradiation. The most significant mechanical property change in reactor vessel steels is the increase in the ductile-to-brittle transition temperature accompanied by a reduction in the Charpy upper-shelf energy (C_vUSE) value.

Code of Federal Regulations, Title 10, Part 50, (10 CFR 50) Appendix G,[1] "Fracture Toughness Requirements," specifies minimum fracture toughness requirements for the ferritic materials of the pressure-retaining components of the reactor coolant pressure boundary (RCPB) of light water-cooled power reactors and provides specific guidelines for determining the pressure-temperature limitations for operation of the RCPB. The fracture toughness and operational requirements are specified to provide adequate safety margins during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service lifetime. Although the requirements of 10 CFR 50, Appendix G, became effective on August 16, 1973, the requirements are applicable to all boiling and pressurized water-cooled nuclear power reactors, including those under construction or in operation on the effective date.

10 CFR 50, Appendix H,[2] "Reactor Vessel Materials Surveillance Program Requirements," defines the material surveillance program required to monitor changes in the fracture toughness properties of ferritic materials in the reactor vessel beltline region of water-cooled reactors resulting from exposure to neutron irradiation and the thermal environment. Fracture toughness test data are obtained from material specimens contained in capsules that are periodically withdrawn from the reactor vessel. These data permit determination of the conditions under which the vessel can be operated with adequate safety margins against non-ductile fracture throughout its service life.

A method for guarding against non-ductile fracture in reactor vessels is described in Appendix G to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III,[3] "Nuclear Power Plant Components" and Section XI,[4] "Rules for Inservice Inspection." This method uses fracture mechanics concepts and the reference nil-ductility temperature, RT_{NDT}, which is defined as the greater of the drop weight nil-ductility transition temperature (in accordance with ASTM Standard E 208-81[5]) or the temperature that is 60°F below that at which the material exhibits 50 ft-lbs and 35 mils lateral expansion. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{IR} curve), which appears in Appendix G of ASME B&PV Code Section III and Section XI. The K_{IR} curve is a lower bound of dynamic and crack arrest fracture toughness data obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{IR} curve, allowable stress intensity factors can be obtained for the material as a function of temperature. The operating limits can then be determined using these allowable stress intensity factors.

The RT_{NDT} and, in turn, the operating limits of a nuclear power plant, are adjusted to account for the effects of irradiation on the fracture toughness of the reactor vessel materials. The irradiation embrittlement and the resultant changes in mechanical properties of a given pressure vessel steel can be monitored by a surveillance program in which surveillance capsules containing prepared specimens of the reactor vessel materials are periodically removed from the operating nuclear reactor and the specimens are tested. The increase in the Charpy V-notch 30 ft-lb temperature is added to the original RT_{NDT} to adjust it for irradiation embrittlement. The adjusted RT_{NDT} is used to index the material to the K_{IR} curve which, in turn, is used to set operating limits for the nuclear power plant. These new limits take into account the effects of irradiation on the reactor vessel materials.

10 CFR 50, Appendix G, also requires a minimum initial Charpy V-notch upper-shelf energy (C_vUSE) of 75 ft-lbs for all beltline region materials unless it is demonstrated that lower values of upper-shelf fracture energy will provide an adequate margin of safety against fracture equivalent to those required by ASME Section XI, Appendix G. No action is required for a material that does not meet the initial 75 ft-lbs requirement provided that the irradiation embrittlement does not cause the C_vUSE to drop below 50 ft-lbs. The regulations specify that if the C_vUSE drops below 50 ft-lbs, it must be demonstrated, in a manner approved by the Office of Nuclear Reactor Regulation, that the lower values will provide adequate margins of safety.

3.0 Surveillance Program Description

The original reactor vessel surveillance program (RVSP) for the Palisades Nuclear Plant was designed and furnished by Combustion Engineering, Inc.[6] The program was designed to the requirements of ASTM Standard E 185-66,[7] "Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors." The Palisades RVSP includes ten capsules designed to monitor the effects of neutron and thermal environments on the materials of the reactor pressure vessel core region. These capsules were inserted into the reactor vessel before initial plant startup. Six capsules were positioned such that they were located near the inside surface of the reactor vessel wall adjacent to the core, and two capsules were positioned closer to the core located on the outer wall of the core support barrel for accelerated exposure. Two capsules, designed for monitoring the effects of operating temperature on the surveillance materials, were located above the core such that the exposure was in a low flux region of the reactor vessel. The locations of the Palisades surveillance capsules within the reactor vessel are shown in Figure 3-1.

In addition to the above ten surveillance capsules, two supplemental surveillance capsules were fabricated containing three weld metals representative of those found in the core region of the Palisades reactor vessel. These capsules were installed at the end-of-cycle 11 (EOC-11) in locations near the outer wall of the core support barrel for accelerated exposure. The locations of the two supplemental surveillance capsules within the Palisades reactor vessel are shown in Figure 3-2.

Supplemental surveillance Capsule SA-60-1 was removed from the Palisades reactor vessel at the end-of-cycle 13 (EOC-13). The capsule contained standard Charpy V-notch impact test specimens fabricated from a submerged-arc weld metal (weld wire heat number 27204) and a correlation monitor plate material (HSST Plate 02). In addition, the Capsule SA-60-1 contained modified 18mm Type A Charpy V-notch specimens fabricated from three submerged-arc weld metals (weld wire heat numbers W5214, 34B009, and 27204); the 18mm Type A Charpy V-notch specimens are available for reconstitution such that full size Charpy V-notch impact specimens can be fabricated. The tension test specimens included in Capsule SA-60-1 were fabricated from a submerged-arc weld metal (weld wire heat number 27204). The number of specimens of each material contained in supplemental surveillance Capsule SA-60-1 is described in Table 3-1, and the locations of the individual specimens within the capsule are shown in Figures 3-3 through 3-7. The chemical composition and heat treatment of the surveillance materials in Capsule SA-60-1 are described in Tables 3-2 and 3-3 respectively.

The weld metal Charpy V-notch and tensile specimens were machined throughout the thickness of the weldment and were oriented with the longitudinal axis of the specimen either parallel or perpendicular to the welding direction.

There are three sets of nine dosimeter monitors in Capsule SA-60-1; one each located in the top, middle, and bottom of the capsule. The dosimeter monitors included in each set consist of shielded copper, shielded nickel, unshielded iron, unshielded titanium, shielded and unshielded aluminum-cobalt, shielded and unshielded neptunium-237 (^{237}Np), and shielded and unshielded uranium-238 (^{238}U).

Thermal monitors fabricated from four low-melting alloys were included in Capsule SA-60-1, and were located in the middle of the capsule. The eutectic alloys and their melting points are listed below:

80% Au, 20% Sn	Melting Point 536°F
5% Ag, 5% Sn, 90% Pb	Melting Point 558°F
2.5% Ag, 97.5% Pb	Melting Point 580°F
1.75% Ag, 0.75% Sn, 97.5% Pb	Melting Point 590°F

Table 3-1. Test Specimens Contained in Palisades Capsule SA-60-1

Material Description	Number of Test Specimens		
	Tension	Standard Charpy V-Notch Impact	18mm Charpy V-Notch Inserts
Weld Metal W5214	---	---	39
Weld Metal 34B009	---	---	39
Weld Metal 27204	3	12	36
Correlation Monitor Material, HSST Plate 02 (Heat No. A1195-1)	---	12	---

Table 3-2. Chemical Composition of Palisades Capsule SA-60-1 Surveillance Materials

Element	Chemical Composition, wt%			
	Weld Metal W5214[a]	Weld Metal 34B009[a]	Weld Metal 27204[b]	Correlation Monitor Plate Heat No. A1195-1[c]
C	0.094	0.110	0.142	0.23
Mn	1.161	1.269	1.281	1.39
P	0.009	0.012	0.009	0.013
S	0.012	0.016	0.008	0.013
Si	0.252	0.181	0.217	0.21
Ni	1.045[b]	1.121[b]	1.067	0.64
Cr	0.040	0.040	0.071	---
Mo	0.510	0.543	0.525	0.50
Cu	0.307[b]	0.185[b]	0.194	0.17

(a) AEA Technology analysis.[8]
(b) Analysis provided by Consumers Energy.[9]
(c) ORNL analysis.[10]

Table 3-3. Heat Treatment of Palisades Capsule SA-60-1 Surveillance Materials

Material Description	Heat Treatment
Weld Metal W5214	Post weld heat treatment: >1100°F for 25 hrs, cooled at 8°F/hr for 24 hrs.[(a)] Re-post weld heat treatment: 1150°F for 2 hrs, with 100°F/hr heating/cooling rates (above 500°F)[(b)]
Weld Metal 34B009	Post weld heat treatment: >1100°F for 16 hrs, cooled at 7°F/hr for 27 hrs.[(a)] Re-post weld heat treatment: 1150°F for 2 hrs, with 100°F/hr heating/cooling rates (above 500°F)[(b)]
Weld Metal 27204	Post weld heat treatment: >1100°F for 40 hrs.[(c)]
Correlation Monitor Plate, HSST Plate 02 (Heat No. A1195-1)	1675 ± 25°F for 4 hrs., air cooled 1600 ± 25°F for 4 hrs., water quenched to 300°F 1225 ± 25°F for 4 hrs., furnace cooled to 500°F 1150 ± 25°F for 40 hrs., furnace cooled to 600°F

(a) Original post weld heat treatment.[11]

(b) Post weld heat treatment performed on retired steam generator material to ensure that the material would be as close as possible to the original start-of-life condition.[8] 2

(c) Post weld heat treatment provided by Consumers Energy.[9]

Figure 3-1. Reactor Vessel Cross Section Showing Location of Palisades Original RVSP Capsules

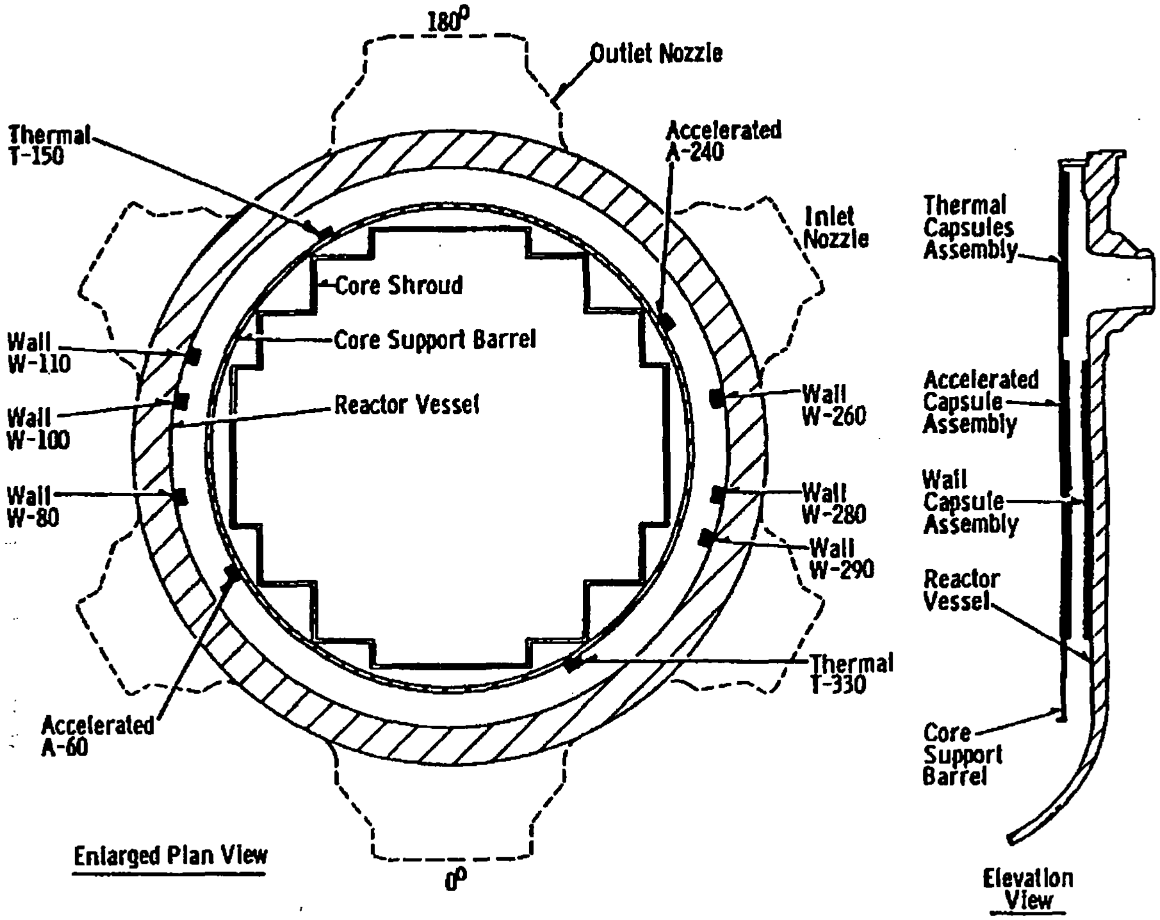


Figure 3-2. Reactor Vessel Cross Section Showing Location of Palisades Supplemental Surveillance Capsules

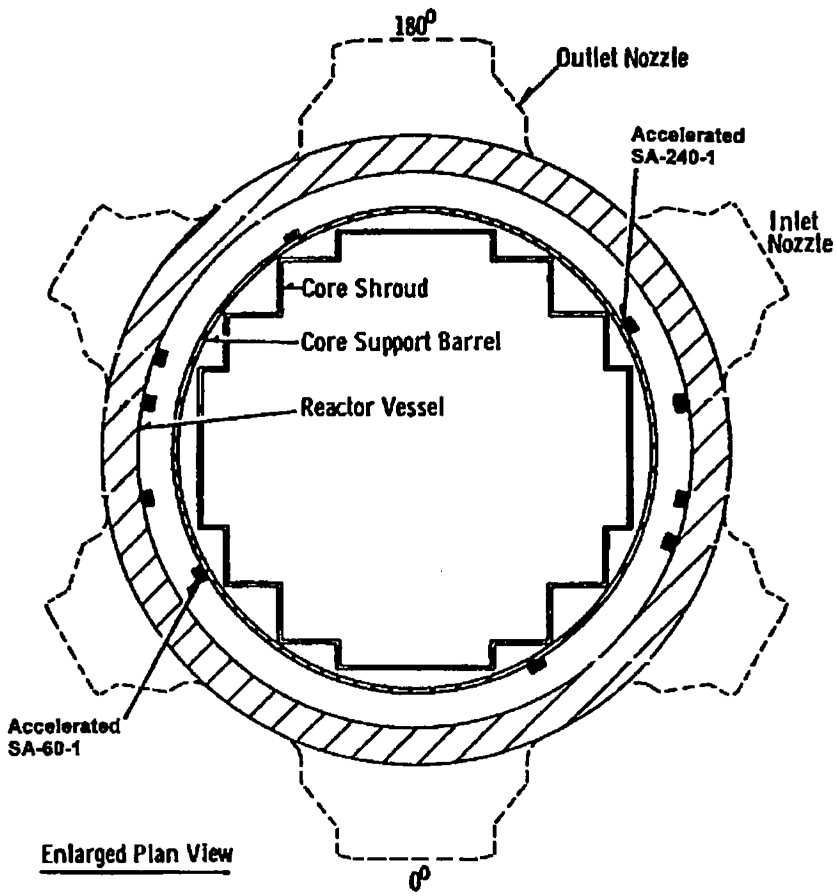
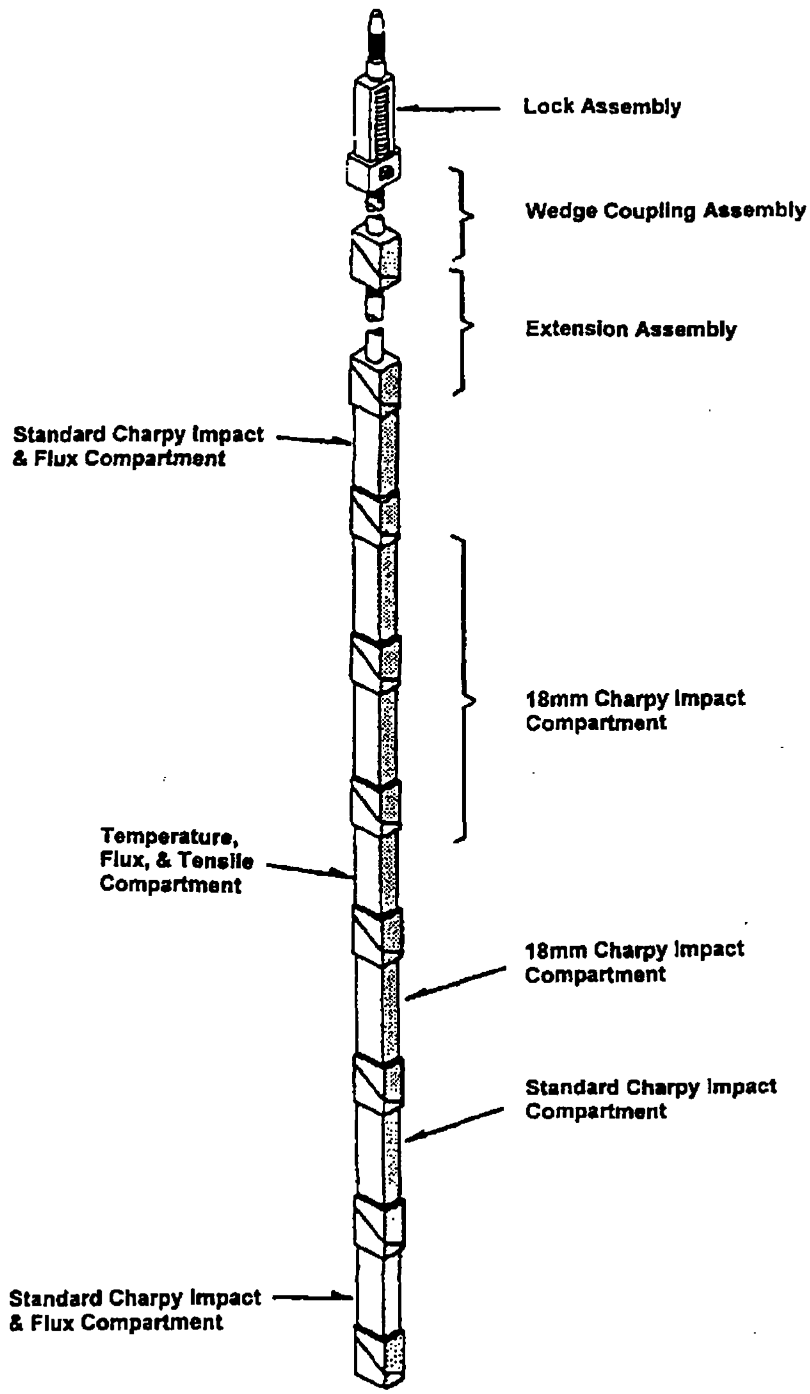
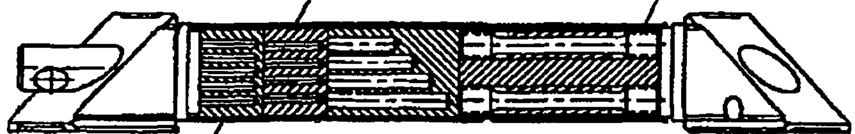


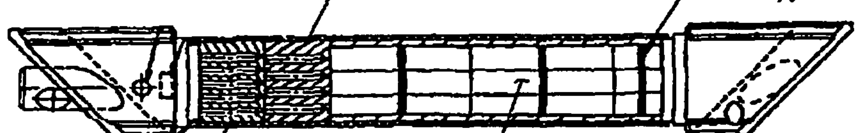
Figure 3-3. Supplemental Surveillance Capsule Assembly Showing Location of Specimens and Monitors



3-4. Temperature, Flux, and Tensile (TFT) Capsule Compartment Assembly



3-5. Standard Charpy Impact and Flux Capsule Compartment Assembly (Two Per Capsule)



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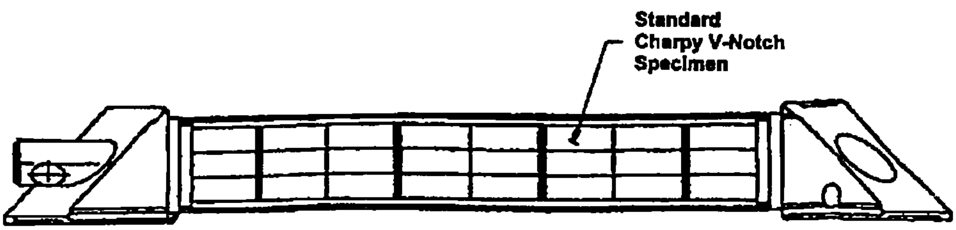
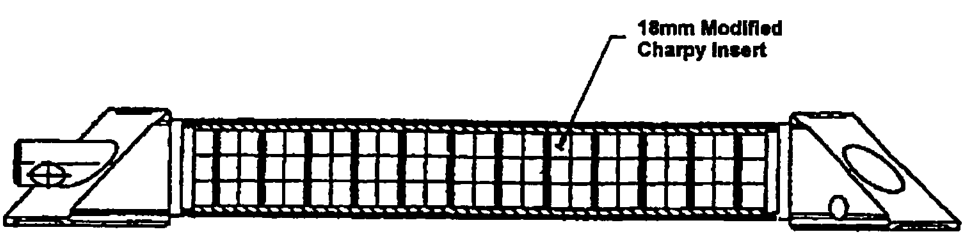
3-6. Standard Charpy Impact Capsule Compartment Assembly



3-7. Typical 18mm Charpy Impact Capsule Compartment Assembly (Three Per Capsule)



4.0 Post-Irradiation Testing

The post-irradiation testing of the Charpy V-notch impact specimens, thermal monitors, and dosimeters for the Palisades Capsule SA-60-1 was performed at the B&W Services Inc. (BWSI) Lynchburg Technology Center (LTC).[18]

4.1. Visual Examination and Inventory

After capsule disassembly, the contents of Capsule SA-60-1 were removed, inspected, and inventoried. The capsule contained a total of 24 standard Charpy V-notch specimens, 114 modified 18mm Charpy inserts, three tension test specimens, three dosimetry blocks, and four temperature monitors, which is consistent with the manufacturing report inventory. | 2

4.2. Thermal Monitors

The four low-melting point eutectic alloys contained in Capsule SA-60-1 were examined for evidence of melting. The results of the thermal monitor examination are tabulated in Table 4-1. Photographs of the monitors are shown in Figure 4-1.

Only the thermal monitor with complete melting was the monitor with the melting point at 536°F, and the remaining thermal monitors with melting points at 558°F, 580°F and 590°F had no evidence of melting. Based on these observations, it can be concluded that the capsule did not exceed a maximum irradiation temperature of 558°F.

4.3. Tension Test Specimens

The tension test specimens removed from Capsule SA-60-1 were not tested at the request of Consumers Power Company. The specimens are to be held for testing at a future date.

4.4. Reconstitution of Irradiated Charpy Inserts

Pre-machined 18mm Charpy inserts fabricated from three submerged-arc weld metals (weld wire heat numbers W5214, 34B009, and 27204) were included in Capsule SA-60-1 for reconstitution of full size Type A Charpy V-notch impact specimens. Each 18mm weld metal Charpy insert included a centrally located V-notch that was machined prior to capsule irradiation. The reconstitution technique was performed by stud welding steel end tabs onto the irradiated modified 18mm Charpy inserts and machining full size Type A Charpy V-notch impact specimens to the dimensional requirements of ASTM Standard E 23-91.[12] The proof-of-principal and validation test results for the FTI Charpy reconstitution process is documented in BAW-2184.[13] The reconstitution of the irradiated weld metal 18mm modified Charpy inserts was performed in accordance with ASTM Standard E 1253-88,[14] "Standard Guide for Reconstitution of Irradiated Charpy Specimens."

Sixteen (16) modified 18mm Charpy inserts were selected from weld metal 34B009, and fifteen (15) modified 18mm Charpy inserts were selected from each of the weld metals W5214 and 27204 for reconstitution to full size Charpy V-notch specimens. Prior to welding the irradiated 18mm Charpy inserts, the reconstitution process was performed on two mockup inserts to assure that the reconstitution welding process would produce quality welds. A steel end tab was stud welded to each end of the mockup insert, and each weldment was visually inspected for good fillet formation resulting from the stud welding process. In addition, each mockup specimen was subjected to a 45-degree bend test, to determine acceptance of the stud weld. An acceptable weld is one that did not fracture in the weld fusion zone resulting from the stud welding process. Once acceptable welds were established on the mockup inserts, reconstitution of the irradiated 18mm Charpy inserts could begin. Using the same welding parameters used to reconstitute the mockup inserts, a steel end tab was stud welded to each end of the selected weld metal 18mm Charpy inserts irradiated in Capsule SA-60-1.

The ASTM Standard E 1253-88 specifies that temperature records be made during the welding on the first and last specimens of each set of Charpy specimens or on dummy specimens proceeding and following welding of the set. Prior to performing the reconstitution of the Capsule SA-60-1 modified 18mm Charpy inserts, temperatures were recorded on dummy specimens in the central test section. The amperage setting used in the stud welding process for these dummy specimens was significantly greater than the setting used to reconstitute the Capsule SA-60-1 modified 18mm Charpy inserts. The greater amperage results in a greater heat input to the central portion of the reconstituted specimen, however the maximum recorded temperature using this greater amperage was approximately 500°F which is less than the Palisades reactor vessel cold-leg temperature and meets the temperature requirement of ASTM Standard E 1253-88. Following the reconstitution of the Capsule SA-60-1 18mm Charpy inserts, a dummy specimen was reconstituted using the similar welding parameters to determine the maximum temperature at the center position of the Charpy insert section. The maximum temperature observed on the dummy specimen was 423°F for the first weld and 414°F for the second weld which again meets the temperature requirement of ASTM Standard E 1253-88.

Fourteen (14) stud-welded inserts were then selected from weld metal 34B009, and thirteen (13) stud-welded inserts were selected from each of the weld metals W5214 and 27204 for machining of full size Type A Charpy V-notch specimens in accordance with ASTM Standard E 23-91. The reconstituted Charpy specimen dimensions for each specimen are shown in Table 4-2. Upon completion of the machining of the reconstituted Charpy specimens, twelve (12) specimens were selected from each weld metal for Charpy impact testing.

4.5. Charpy V-Notch Impact Test Results

The Charpy V-notch impact testing was performed in accordance with the applicable requirements of ASTM Standard E 23-91. Impact energy, lateral expansion, and percent shear fracture were measured at numerous test temperatures and recorded for each specimen. The impact energy was measured using a certified Satec S1-1K Impact tester (traceable to NIST Standard) with 240 ft-lb of available energy. The lateral expansion was measured using a certified dial indicator. The specimen percent shear was estimated by video examination and comparison with the visual standards presented in ASTM Standard E 23-91. In addition, all Charpy V-notch impact testing was performed using instrumentation to record a load-versus-time trace and energy-versus-time trace for each impact event. The load-versus-time traces were analyzed to determine time, load, and impact energy for general yielding, maximum load, fast fracture, and crack arrest properties during the test. The dynamic yield stress is calculated from the three-point bend formula:

$$\sigma_y = 33.33 * (\textit{general yielding load})$$

The dynamic flow stress is calculated from the average of the yield and maximum loads, also using the three-point bend formula:

$$\sigma_{flow} = 33.33 * \left(\frac{(\textit{general yielding load} + \textit{maximum load})}{2}\right)$$

The results of the Charpy V-notch impact testing are shown in Tables 4-3 through 4-10 and Figures 4-2 through 4-5, and the individual load-versus-time traces for the instrumented Charpy V-notch impact tests are presented in Appendix B. The curves were generated using a hyperbolic tangent curve-fitting program to produce the best-fit curve through the data. The hyperbolic tangent (TANH) function (test response, i.e., absorbed energy, lateral expansion, and percent shear fracture, "R," as a function of test temperature, "T") used to evaluate the surveillance data is as follows:

$$R = A + B * \tanh\left[\frac{(T - To)}{C}\right]$$

For the absorbed (impact) energy curves, the lower-shelf energy was fixed at 2.2 ft-lbs for all materials, and the upper-shelf energy was fixed at the average of all test energies exhibiting 100 percent shear for each material, consistent with the ASTM Standard E 185-82. The lateral expansion curves were generated with the lower-shelf mils lateral expansion fixed at 1 mil and the upper-shelf mils lateral expansion not constrained (i.e., not fixed). The percent shear fracture curves for each material were generated with the lower-shelves and upper-shelves fixed at 0 and 100 respectively. 2

The Charpy V-notch data was entered, and the coefficients *A, B, To,* and *C* are determined by the program minimizing the sum of the errors squared (least-squares fit) of the data points about the fitted curve. Using these coefficients and the above TANH function, a smooth curve is generated through the data for interpretation of the material transition region behavior. The coefficients determined for irradiated materials in Capsule SA-60-1 are shown in Table 4-11.

The transition temperature shifts and upper-shelf energy decreases for the Capsule SA-60-1 materials with respect to the unirradiated material properties are summarized in Table 4-12.

Photographs of the Charpy V-notch specimen fracture surfaces are presented in Figures 4-6 through 4-9.

Table 4-1. Conditions of Palisades Capsule SA-60-1 Thermal Monitors

Capsule Segment	Melt Temperature	Post-Irradiation Condition
Middle	536°F	Melted
Middle	558°F	Unmelted
Middle	580°F	Unmelted
Middle	590°F	Unmelted

Table 4-2. Dimensions of Reconstituted Charpy Specimens for Palisades Capsule SA-60-1

Weld Metal	Specimen ID	Width 0.394 ±0.003"	Thickness 0.394 ±0.003"	Length 2.165 +0, -0.100"	Notch Depth[a] 0.079 ±0.001"	Comments
W5214	AA4	0.394	0.395	2.160	---	Acceptable
	2AH1	0.394	0.395	2.160	---	Acceptable
	2AE2	0.394	0.394	2.155	---	Acceptable
	2AH6	0.394	0.394	2.157	---	Acceptable
	AA2	0.393	0.393	2.156	---	Acceptable
	AV4	0.394	0.394	2.159	---	Acceptable
	AT2	0.393	0.394	2.158	---	Acceptable
	AR94	0.394	0.394	2.159	---	Acceptable
	AW2	0.393	0.395	2.160	---	Acceptable
	AW1	0.394	0.393	2.157	---	Acceptable
	2AF5	0.393	0.394	2.160	---	Acceptable
	AL3	0.392	0.392	2.149	0.078	Acceptable
	2AL6	0.396	0.395	2.158	---	Acceptable
34B009	BR91	0.395	0.395	2.160	---	Acceptable
	BW5	0.393	0.394	2.160	---	Acceptable
	BW1	0.394	0.394	2.160	---	Acceptable
	2BK1	0.394	0.395	2.157	---	Acceptable
	BU2	0.394	0.394	2.160	---	Acceptable
	BL2	0.394	0.393	2.155	---	Acceptable
	2BF5	0.392	0.394	2.160	0.079	Acceptable
	2BK5	0.393	0.394	2.160	---	Acceptable
	BD2	0.393	0.394	2.157	---	Acceptable
	2BJ2	0.393	0.394	2.160	---	Acceptable
	BV5	0.394	0.394	2.157	---	Acceptable
	BO2	0.393	0.393	2.159	---	Acceptable
	2BH2	0.393	0.393	2.158	---	Note b
	2BH5	0.391	0.391	2.160	---	Note b
27204	PB15	0.394	0.393	2.160	---	Acceptable
	PB42	0.394	0.393	2.155	---	Acceptable
	PB91	0.394	0.394	2.160	---	Acceptable
	PB96	0.393	0.393	2.155	---	Acceptable
	PB94	0.394	0.393	2.158	---	Acceptable
	PB78	0.393	0.392	2.155	---	Acceptable
	PB95	0.393	0.394	2.155	---	Acceptable
	PB28	0.394	0.393	2.154	---	Acceptable
	PB93	0.393	0.394	2.158	---	Acceptable
	PB68	0.393	0.393	2.160	---	Acceptable
	PB92	0.392	0.392	2.158	0.08	Note b
	PB81	0.392	0.392	2.155	0.08	Acceptable
	PB56	0.393	0.393	2.158	---	Acceptable

| 2

Notes:

a. Notch depth only checked when depth of the notch was suspected to be changed by the machining process.
b. Specimen squareness unacceptable.

Table 4-3. Charpy Impact Results for Palisades Capsule SA-60-1 Irradiated Weld Metal W5214

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
AA2	74	10	4	0
AW1	129	24	15	5
AW2	154	23.5	15	15
2AF5	204	30	16	50
AL3	229	33.5	23	65
AA4	254	28	19	60
2AL6	279	43.5	35	80
2AE2	279	48.5	38	90
2AH6	329	47.5	35	90
AR94	404	51.5*	43	100
2AH1	454	55*	47	100
AV4	479	57*	46	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[15]

Table 4-4. Charpy Impact Results for Palisades Capsule SA-60-1 Irradiated Weld Metal 34B009

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
BD2	74	18	8	5
BW5	129	21.5	13	30
BO2	154	23.5	13	40
2BK5	179	32	18	50
2BJ2	204	36.5	25	50
2BF5	229	40	32	75
2BK1	254	46.5	41	90
BW1	279	51	42	95
BR91	329	57*	50	100
BU2	404	53*	44	100
BV5	454	58*	50	100
BL2	479	53*	49	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[15]

Table 4-5. Charpy Impact Results for Palisades Capsule SA-60-1 Irradiated Weld Metal 27204

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
PB68	74	12.5	7	0
PB56	129	16.5	13	40
PB81	154	17	10	30
PB78	204	25	19	45
PB93	229	28	27	70
PB91	254	39.5	35	85
PB28	279	44.5	39	95
PB96	329	52.5*	48	100
PB94	329	52*	50	100
PB15	404	57*	53	100
PB42	454	55*	49	100
PB95	479	48.5*	43	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[15]

Table 4-6. Charpy Impact Results for Palisades Capsule SA-60-1 Irradiated Correlation Monitor Plate Material (HSST Plate 02) Heat No. A1195-1

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
O2D2-9	74	8	3	5
O2D2-3	104	20.5	16	10
O2D2-1	129	24.5	18	20
O2D2-7	154	26.5	23	40
O2D2-18	179	35.5	28	45
OCD2-21	204	48.5	40	70
O2D2-14	229	53.5	43	65
O2D2-16	229	51.5	43	70
O2D2-4	254	73.5	65	80
O2D2-6	279	85*	70	100
O2D2-12	329	87.5*	74	100
O2D2-20	404	86.5*	77	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[15]

Table 4-7. Instrumented Charpy Impact Properties for Palisades Capsule SA-60-1 Irradiated Weld Metal W5214

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties Time (µsec)	Yield Properties Load (lbf)	Yield Properties Energy (ft-lbf)	Maximum Load Properties Time (µsec)	Maximum Load Properties Load (lbf)	Maximum Load Properties Energy (ft-lbf)	Fast Fracture Properties Time (µsec)	Fast Fracture Properties Load (lbf)	Fast Fracture Properties Energy (ft-lbf)	Crack Arrest Properties Time (µsec)	Crack Arrest Properties Load (lbf)	Crack Arrest Properties Energy (ft-lbf)	Propagation Load Properties Load (lbf)	Propagation Load Properties Energy (ft-lbf)	Total Load Properties Time (µsec)	Total Load Properties Energy (ft-lbf)	Yield Stress (ksi)	Flow Stress (ksi)
AA2	74	10	166	4043	5.8	188	4050	7.3	188	4050	7.3	243	5	9.5	4046	2.2	243	9.5	134.8	134.9
AW1	129	24	168	3820	6.1	376	4409	20.5	376	4409	20.5	440	0	23.3	4430	2.8	440	23.3	127.3	137.1
AW2	154	23.5	176	3820	5.8	378	4382	19.7	389	4375	20.4	452	12	23	4363	3.3	452	23.0	127.3	136.7
2AF5	204	30	169	3726	5.8	418	4421	22.8	418	4421	22.8	541	1012	26.6	3409	6.3	1217	29.1	124.2	135.8
AL3	229	33.5	168	3485	5.5	439	4368	23.8	439	4368	23.8	553	1605	28.4	2762	9.6	1555	33.4	116.2	130.9
AA4	254	28	178	3643	5.8	344	4195	16.7	344	4195	16.7	460	1727	21.4	2468	11.1	1556	27.8	121.4	130.6
2AL6	279	43.5	178	3600	5.8	440	4262	23.2	528	4119	29.1	666	1999	35.5	2120	19.3	1766	42.5	120.0	131.0
2AE2	279	48.5	180	3558	5.8	440	4267	22.9	N/A	N/A	N/A	N/A	N/A	N/A	0	25.3	1848	48.2	118.6	130.4
2AH6	329	47.5	172	3531	5.7	430	4168	22.4	N/A	N/A	N/A	N/A	N/A	N/A	0	25.2	1778	47.6	117.7	128.3
AR94	404	51.5	168	3374	5.4	425	3997	21.4	N/A	N/A	N/A	N/A	N/A	N/A	0	29.4	2056	50.8	112.5	122.8
2AH1	454	55	182	3328	5.8	444	3958	21.9	N/A	N/A	N/A	N/A	N/A	N/A	0	32.8	2060	54.7	110.9	121.4
AV4	479	57	170	3188	5.2	530	3889	26.7	N/A	N/A	N/A	N/A	N/A	N/A	0	28.9	2148	55.6	106.3	117.9

Table 4-8. Instrumented Charpy Impact Properties for Palisades Capsule SA-60-1 Irradiated Weld Metal 34B009

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties Time (μsec)	Yield Properties Load (lbf)	Yield Properties Energy (ft-lbf)	Maximum Load Properties Time (μsec)	Maximum Load Properties Load (lbf)	Maximum Load Properties Energy (ft-lbf)	Fast Fracture Properties Time (μsec)	Fast Fracture Properties Load (lbf)	Fast Fracture Properties Energy (ft-lbf)	Crack Arrest Properties Time (μsec)	Crack Arrest Properties Load (lbf)	Crack Arrest Properties Energy (ft-lbf)	Propagation Load Properties Load (lbf)	Propagation Load Properties Energy (ft-lbf)	Total Load Properties Time (μsec)	Total Load Properties Energy (ft-lbf)	Yield Stress (ksi)	Flow Stress (ksi)
BD2	74	18	161	4016	5.6	303	4391	15.5	303	4391	15.5	357	0	17.8	4411	2.2	357	17.8	133.9	140.1
BW5	129	21.5	166	3710	5.4	336	4287	16.7	336	4287	16.7	448	653	19.9	3634	4.1	719	20.9	123.7	133.3
BO2	154	23.5	163	3758	5.1	348	4349	17.5	348	4349	17.5	472	736	21.4	3613	5.1	738	22.6	125.3	135.1
2BK5	179	32	170	3705	5.2	442	4398	23.6	448	4388	24	567	1208	28	3181	7.7	1566	31.2	123.5	135.0
2BJ2	204	36.5	167	3678	5.2	444	4409	23.9	469	4375	25.7	592	1789	30.6	2585	12.4	1673	36.4	122.6	134.8
2BF5	229	40	178	3604	5.4	456	4338	23.9	517	4260	28.1	634	2088	33	2171	15.9	1570	39.8	120.1	132.4
2BK1	254	46.5	170	3577	5.5	438	4239	23.2	524	4101	28.9	N/A	N/A	N/A	4101	23.3	1854	46.4	119.2	130.3
BW1	279	51	170	3432	5.5	432	4112	22.2	N/A	N/A	N/A	N/A	N/A	N/A	0	28.8	2024	51.0	114.4	125.7
BR91	329	57	180	3404	5.2	454	4080	22.4	N/A	N/A	N/A	N/A	N/A	N/A	0	34.4	2248	56.8	113.5	124.7
BU2	404	53	164	3275	5.0	434	3931	21.4	N/A	N/A	N/A	N/A	N/A	N/A	0	31.7	2018	53.1	109.2	120.1
BV5	454	58	168	3202	5.3	526	3882	26.8	N/A	N/A	N/A	N/A	N/A	N/A	0	30.1	2242	56.8	106.7	118.1
BL2	479	53	170	3213	5.1	438	3293	21.0	N/A	N/A	N/A	N/A	N/A	N/A	0	31.5	2210	52.4	107.1	108.4

Table 4-9. Instrumented Charpy Impact Properties for Palisades Capsule SA-60-1 Irradiated Weld Metal 27204

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties			Maximum Load Properties			Fast Fracture Properties			Crack Arrest Properties			Propagation Load Properties		Total Load Properties		Yield Stress (ksi)	Flow Stress (ksi)
			Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Energy (ft-lbf)		
PB68	74	12.5	158	3922	4.9	229	4080	9.6	229	4080	9.6	279	20.7	11.5	4060	1.9	279	11.5	130.7	133.4
PB56	129	16.5	173	3629	5.4	230	3813	8.9	230	3813	8.9	343	1242	12.2	2571	6.6	1005	15.5	121.0	124.0
PB81	154	17	167	3696	5.3	248	4016	10.5	248	4016	10.5	366	1099	14.1	2916	5.9	915	16.4	123.2	128.5
PB78	204	25	167	3498	4.9	264	3841	10.8	264	3841	10.8	389	2095	16.1	1746	13.4	1480	24.2	116.6	122.3
PB93	229	28	164	3466	5.3	292	3807	13.1	292	3807	13.1	409	2040	17.8	1766	14.6	1843	27.7	115.5	121.2
PB91	254	39.5	172	3367	5.1	356	3853	16.2	404	3827	19.2	690	1746	31.9	2082	22.9	1932	39.1	112.2	120.3
PB28	279	44.5	170	3399	4.9	442	3968	21.6	N/A	N/A	N/A	N/A	N/A	N/A	0	22.6	2062	44.2	113.3	122.8
PB96	329	52.5	160	3268	4.6	430	3774	20.5	N/A	N/A	N/A	N/A	N/A	N/A	0	32.1	2068	52.6	108.9	117.4
PB94	329	52	168	3280	5.0	432	3809	20.7	N/A	N/A	N/A	N/A	N/A	N/A	0	30.8	2086	51.5	109.3	118.1
PB15	404	57	170	3158	4.9	532	3765	26.1	N/A	N/A	N/A	N/A	N/A	N/A	0	29.8	2324	55.9	105.3	115.4
PB42	454	55	156	3225	4.3	440	3795	20.8	N/A	N/A	N/A	N/A	N/A	N/A	0	33.9	2120	54.6	107.5	117.0
PB95	479	48.5	168	3036	4.9	428	3514	19.2	N/A	N/A	N/A	N/A	N/A	N/A	0	29.0	2022	48.3	101.2	109.2

Table 4-10. Instrumented Charpy Impact Properties for Palisades Capsule SA-60-1 Irradiated Correlation Monitor Plate Material (HSST Plate 02) Heat No. A1195-1

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties			Maximum Load Properties			Fast Fracture Properties			Crack Arrest Properties			Propagation Load Properties		Total Load Properties		Yield Stress (ksi)	Flow Stress (ksi)
			Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Energy (ft-lbf)		
O2D2-9	74	8	129	3588	3.9	129	3588	3.9	129	3588	3.9	182	14	5.7	3574	1.9	182	5.7	119.6	119.6
O2D2-3	104	20.5	169	3558	5.5	345	4262	17.0	345	4262	17	409	2	19.4	4260	2.4	409	19.4	118.6	130.3
O2D2-1	129	24.5	159	3528	4.9	385	4292	19.6	385	4292	19.6	459	5	22.2	4287	2.6	459	22.2	117.6	130.3
O2D2-7	154	26.5	173	3413	5.5	375	4186	18.4	375	4186	18.4	498	1210	22	2976	6.8	1167	25.1	113.8	126.6
O2D2-18	179	35.5	160	3427	5.1	520	4428	28.7	520	4428	28.7	629	1157	32.2	3271	6.1	1310	34.8	114.2	130.9
O2D2-21	204	48.5	172	3312	5.4	538	4352	29.1	614	4333	34.2	728	2116	39.1	2217	19.0	2630	48.0	110.4	127.7
O2D2-14	229	53.5	184	3303	5.5	548	4313	29.0	628	4262	34.4	812	2445	43.9	1817	23.0	1916	51.9	110.1	126.9
O2D2-16	229	51.5	174	3275	5.6	538	4313	28.9	592	4276	32.6	706	2519	37.9	1757	21.2	2724	50.1	109.2	126.5
O2D2-4	254	73.5	168	3241	5.0	620	4349	34.1	712	4296	40.3	1176	1753	59.6	2544	37.6	3204	71.7	108.0	126.5
O2D2-6	279	85	172	3192	4.7	626	4329	33.5	N/A	N/A	N/A	N/A	N/A	N/A	0	49.0	3174	82.5	106.4	125.3
O2D2-12	329	87.5	168	3123	4.7	538	4207	27.3	N/A	N/A	N/A	N/A	N/A	N/A	0	57.5	3252	84.8	104.1	122.2
O2D2-20	404	86.5	140	2916	3.6	614	4080	32.1	N/A	N/A	N/A	N/A	N/A	N/A	0	51.6	3704	83.7	97.2	116.6

Table 4-11. Hyperbolic Tangent Curve Fit Coefficients for the Palisades Capsule SA-60-1 Surveillance Materials

Material Description	Hyperbolic Tangent Curve Fit Coefficients		
	Absorbed Energy	Lateral Expansion	Percent Shear Fracture
Weld Metal W5214	A: 28.4 B: 26.2 C: 158.1 T0: 188.8	A: 25.0 B: 24.0 C: 160.0 T0: 239.6	A: 50.0 B: 50.0 C: 80.5 T0: 214.9
Weld Metal 34B009	A: 28.7 B: 26.5 C: 123.8 T0: 161.8	A: 25.3 B: 24.3 C: 97.6 T0: 196.4	A: 50.0 B: 50.0 C: 89.6 T0: 179.6
Weld Metal 27204	A: 27.6 B: 25.4 C: 111.4 T0: 201.4	A: 25.9 B: 24.9 C: 101.8 T0: 214.4	A: 50.0 B: 50.0 C: 92.1 T0: 187.1
Correlation Monitor Plate, HSST Plate 02 (Heat No. A1195-1)	A: 44.3 B: 42.1 C: 95.1 T0: 193.0	A: 41.3 B: 40.3 C: 104.9 T0: 208.6	A: 50.0 B: 50.0 C: 85.2 T0: 183.7

2

Table 4-12. Summary of Charpy Impact Test Results for the Palisades Capsule SA-60-1 Surveillance Materials

Material Description	30 ft-lb Transition Temperature, °F			50 ft-lb Transition Temperature, °F			35 mil Lateral Expansion Transition Temperature, °F			Upper-Shelf Energy, ft-lb		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	Decrease
Weld Metal W5214	-60.2[a]	198.8	259.0	-17.4[a]	375.6	393.0	-29.6[a]	310.1	339.7	102.7[a]	54.5	48.2
Weld Metal 34B009	-82.0[a]	167.8	249.8	-45.0[a]	298.6	343.6	-51.6[a]	237.5	289.1	113.9[a]	55.25	58.65
Weld Metal 27204	-41.2[b]	211.9	253.1	-6.1[b]	355.6	361.7	Not available.	249.4	---	108.4[b]	53.0	55.4
HSST Plate 02 Heat No A1195-1	45.7[c]	159.4	113.7	78.3[c]	206.0	127.7	Not available.	187.9	---	120.3[c]	86.3	34.0

2

(a) Data reported in AEA Technology Report AEA-TSD-0774.[8]

(b) Data reported in CE Report No. TR-MCC-189.[16]

(c) Data reported in NUREG/CR-6413.[10]

Figure 4-1. Photographs of Thermal Monitors Removed from Palisades Capsule SA-60-1

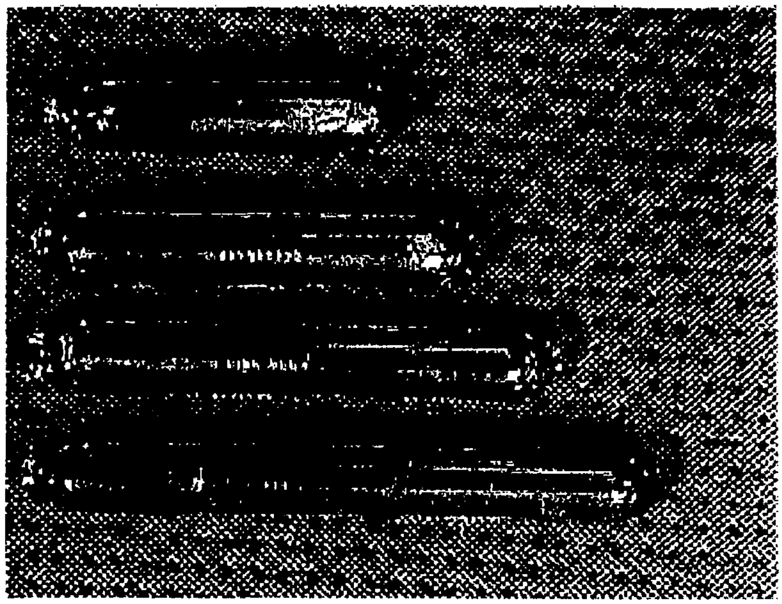
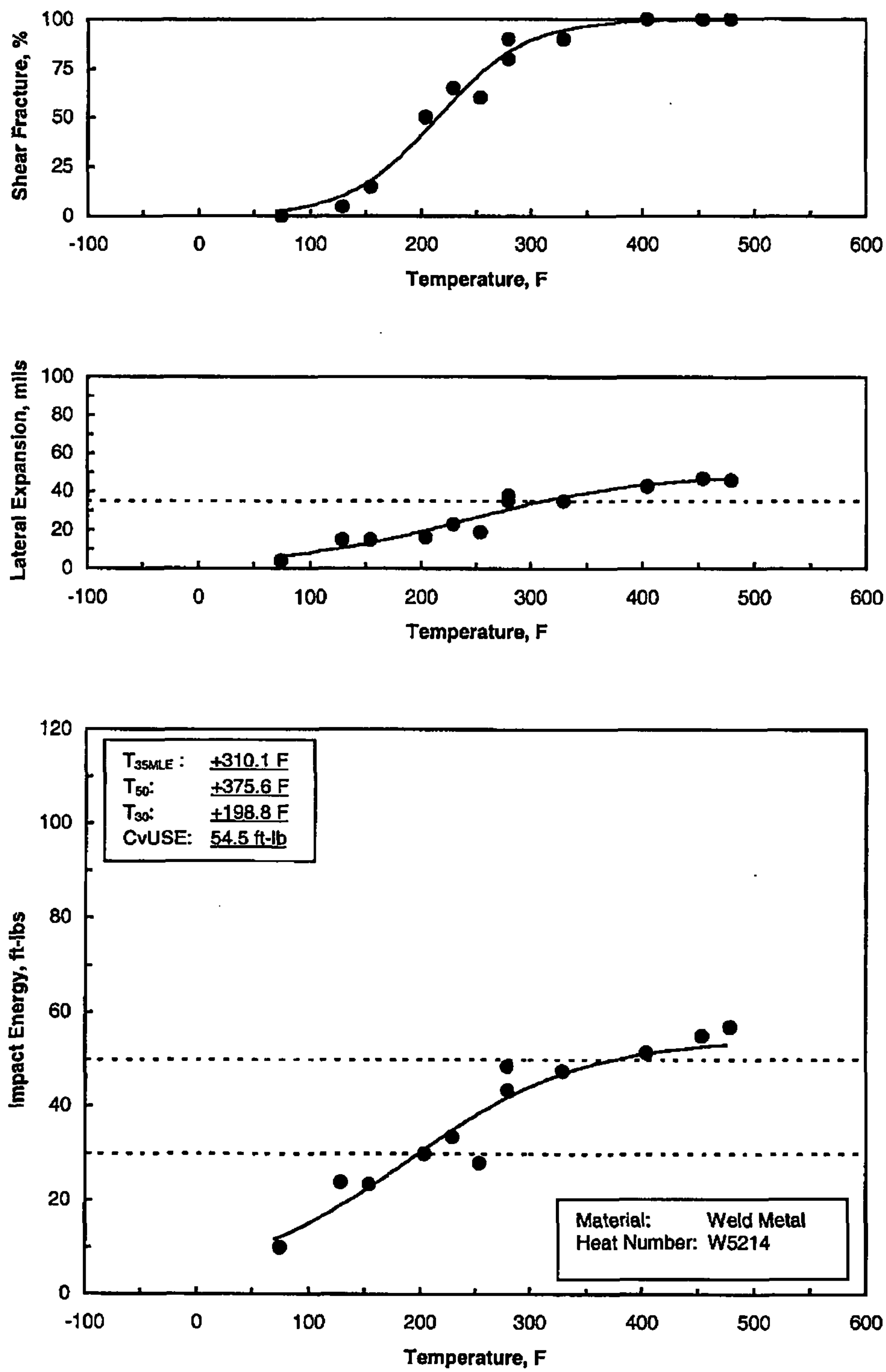


Figure 4-2. Charpy Impact Data for Irradiated Weld Metal W5214



2

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Figure 4-3. Charpy Impact Data for Irradiated Weld Metal 34B009

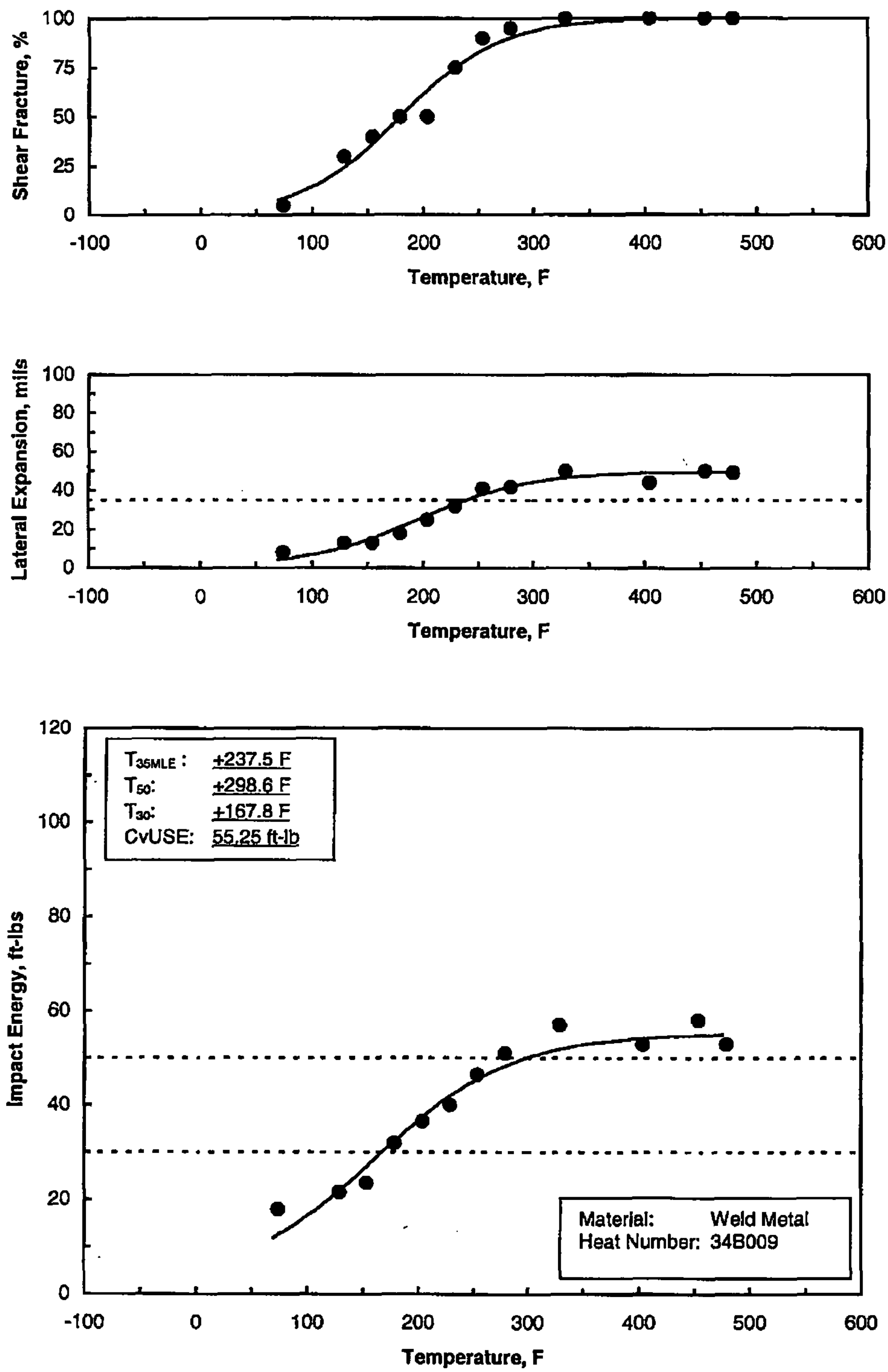

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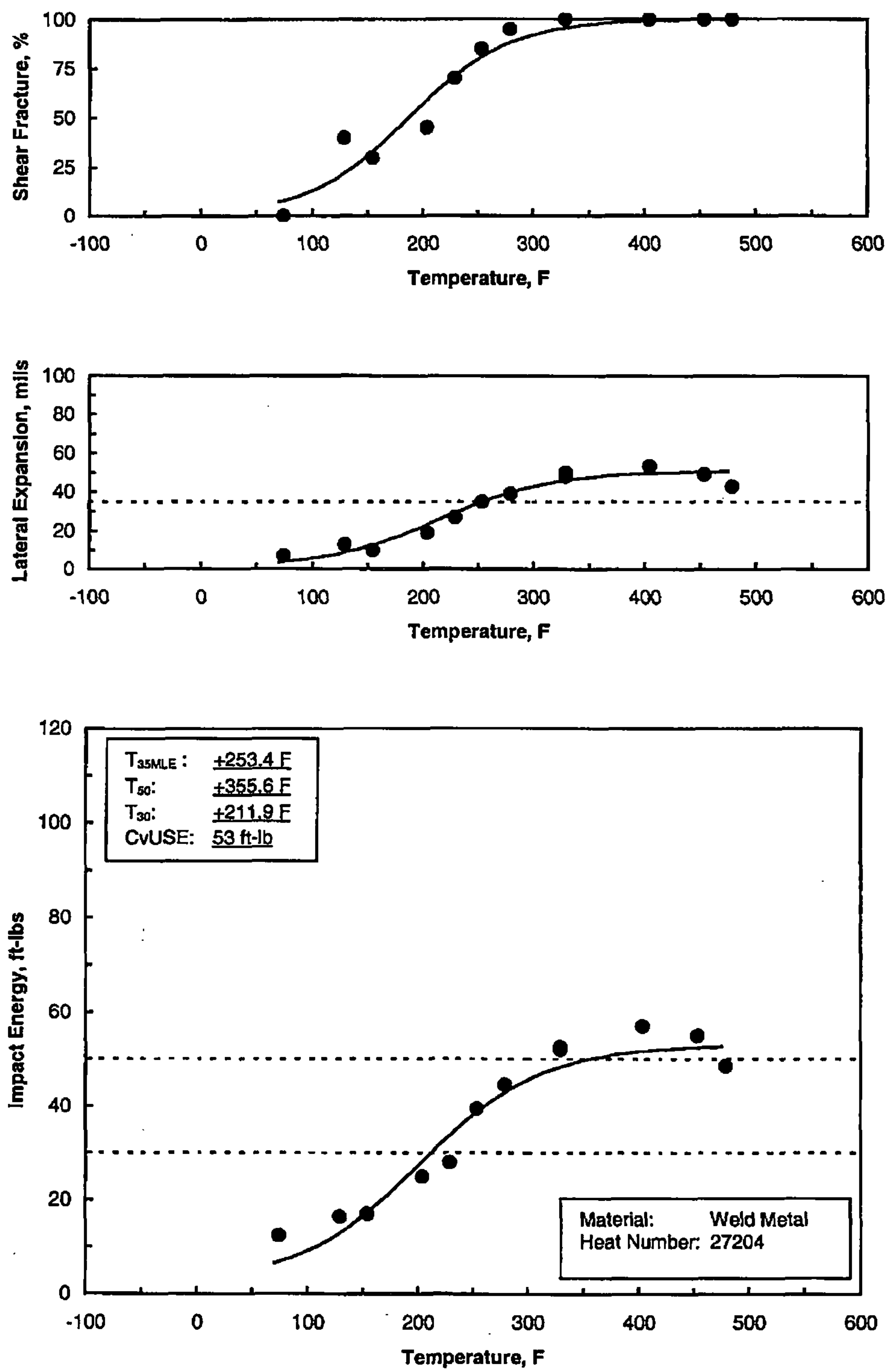
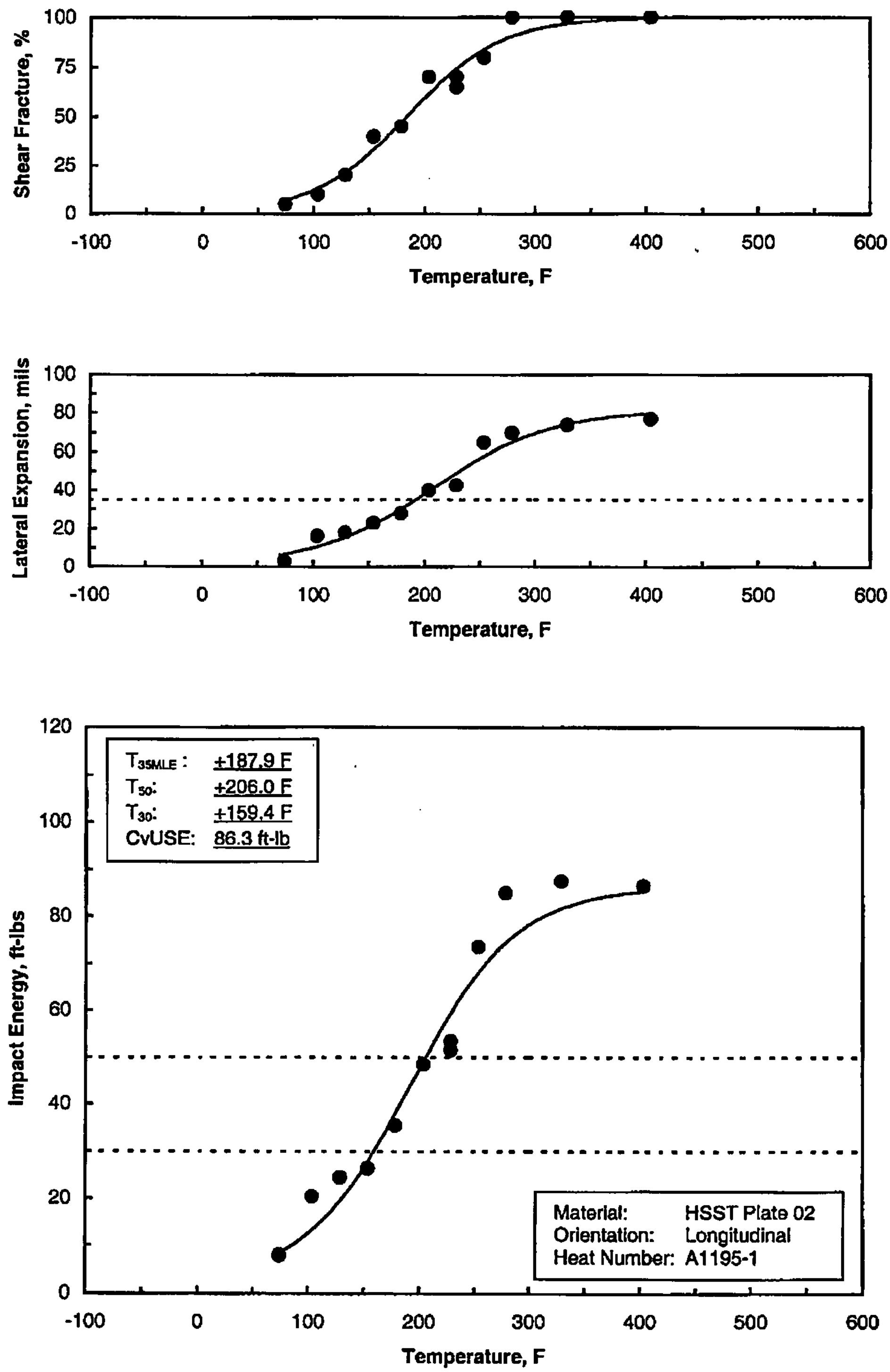
Figure 4-4. Charpy Impact Data for Irradiated Weld Metal 27204



2

Figure 4-5. Charpy Impact Data for Irradiated Correlation Monitor Plate Material (HSST Plate 02), Heat No. A1195-1

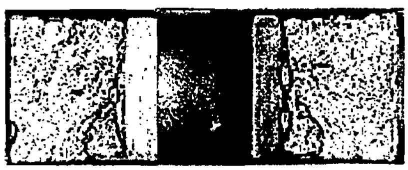


2

Figure 4-6. Photographs of Charpy Impact Specimen Fracture Surfaces, Weld Metal W5214


Specimen No. AA2,


Specimen No. 2AL6,

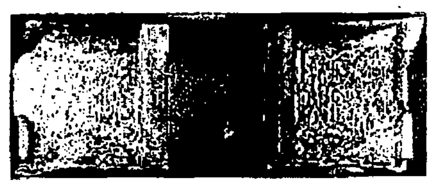

Specimen No. AW1,


Specimen No. 2AE2,


Specimen No. AW2,


Specimen No. 2AH6,


Specimen No. 2AF5,


Specimen No. AR94,

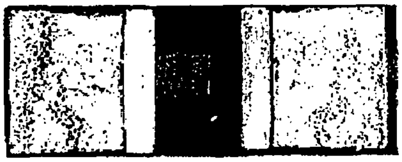

Specimen No. AL3,


Specimen No. 2AH1,


Specimen No. AA4,


Specimen No. AV4,

Figure 4-7. Photographs of Charpy Impact Specimen Fracture Surfaces, Weld Metal 34B009

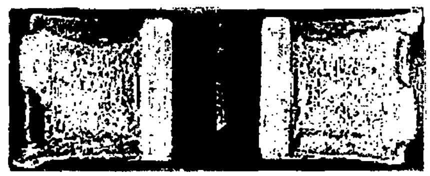

Specimen No. BD2,


Specimen No. 2BK1,


Specimen No. BW5,


Specimen No. BW1,


Specimen No. BO2,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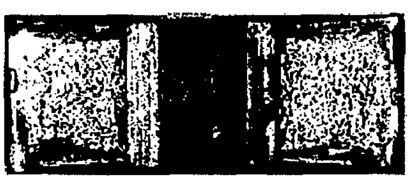
Specimen No. 2BK5,


Specimen No. BU2,


Specimen No. 2BJ2,


Specimen No. BV5,


Specimen No. 2BF5,

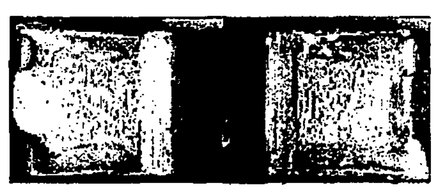

Specimen No. BL2,

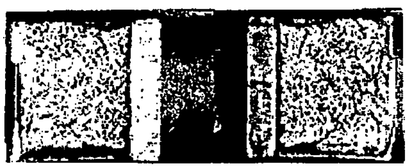
Figure 4-8. Photographs of Charpy Impact Specimen Fracture Surfaces, Weld Metal 27204


Specimen No. PB68,

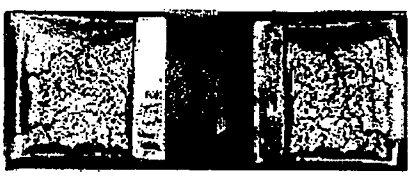

Specimen No. PB28,


Specimen No. PB56,

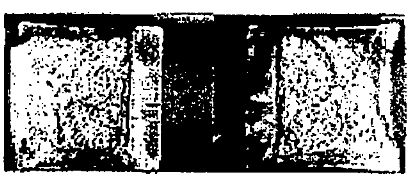

Specimen No. PB96,


Specimen No. PB81,


Specimen No. PB94,


Specimen No. PB78,


Specimen No. PB15,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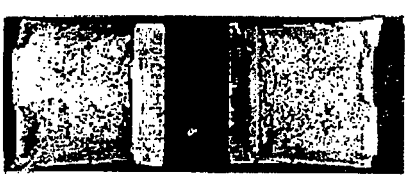
Specimen No. PB42,


Specimen No. PB91,

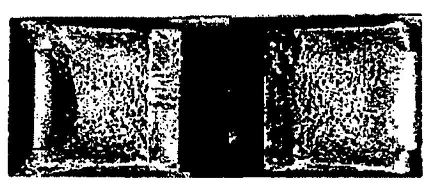
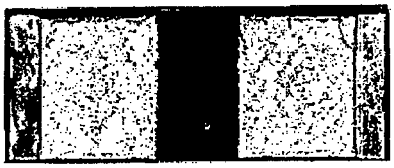

Specimen No. PB95,

Figure 4-9. Photographs of Charpy Impact Specimen Fracture Surfaces, Correlation Monitor Plate Material (HSST Plate 02)



Specimen No. O2D2-9,

Specimen No. O2D2-14,

Specimen No. O2D2-3,

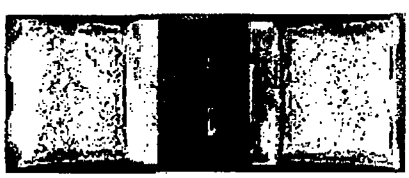
Specimen No. O2D2-16,

Specimen No. O2D2-1,

Specimen No. O2D2-4,

Specimen No. O2D2-7,

Specimen No. O2D2-06,



Specimen No. O2D2-18,

Specimen No. O2D2-12,

Specimen No. O2D2-21,

Specimen No. O2D2-20,

5.0 Dosimeter Measurements

5.1. Introduction

Three dosimeter sets were located in blocks that were installed in top, middle, and bottom positions of the Capsule SA-60-1 assembly. Each dosimeter set consisted of dosimeters made up of shielded and unshielded cobalt/aluminum and uranium dosimeters, shielded copper, nickel, and neptunium dosimeters, and unshielded iron and titanium dosimeters. The dosimeters were stored in vials identified by labels consisting of the position of the dosimeter holder block within the capsule assembly and the location from where the dosimeters where recovered.

5.2. Dosimeter Preparation

Vials were prepared for the dosimeters by labeling them with identifications that indicated their types and positions in the holder blocks. For example, the one top block shielded cobalt/aluminum dosimeter was labeled Palisades T (or TOP) Sh Co/Al. The analyte nuclides were verified during gamma scanning.

The dosimeter wires were washed in reagent grade acetone and blotted dry with a laboratory towel. Each dosimeter wire was then measured with a certified micrometer caliper and weighed on a certified analytical balance. Each wire was then mounted in the center of a PetriSlide™ with double-sided tape.

5.3. Quantitative Gamma Spectrometry

Several of the dosimeters, placed in the PetriSlide™, were given a 300 second preliminary count on the 31% PGT gamma spectrometer. This provided information to best judge the distance at which to count the dosimeter to obtain a minimum of 10,000 counts in the photopeak of interest while keeping the counter dead time below 15%. It also provided qualitative identification of the dosimeters. This identification was made from the presence of the gamma rays in Table 5-1. The spectra were used to confirm the identities of the dosimeters.

The spectra were then measured quantitatively at the appropriate counting positions and for the appropriate count times determined from the preliminary counts.

5.4. Dosimeter Specific Activities

The associated elemental weight fractions of the dosimeters and the isotopic fractions of the target nuclides are listed in Table 5-2. The isotopic fractions of the target nuclides were obtained from the CRC Handbook of Chemistry and Physics, 63rd Edition.[17]

The dosimeter specific activities were calculated by dividing the corrected activity of the analyte nuclide by the target nuclide mass, and the results are shown in Table 5-3.

The shielded uranium dosimeter identified as "Palisades, SA-60-1 161T Sh U" is considered to be invalid since this dosimeter has a bright shiny color and a non-wire shape. This non-wire shape was different from the other shielded uranium dosimeters removed from the other capsule locations (i.e., compartments 164T and 167T). Photographs of the shielded uranium dosimeters removed from compartments 161T and 164T are shown in Figure 5-1.

Table 5-1. Quantifying Gamma Rays

Dosimeter	Analyte
Iron	^{54}Mn @ 834 keV from ^{54}Fe
Co/Al	^{60}Co @ 1332 keV from ^{59}Co
Nickel	^{58}Co @ 811 keV from ^{58}Ni
Titanium	^{46}Sc@ 1121 keV from ^{46}Ti
Copper	^{60}Co @ 1332 keV from ^{63}Cu, very low activity compared to Co wires, wire has coppery color
^{237}Np	^{137}Cs @ 662 keV
^{238}U	^{137}Cs @ 662 keV

Table 5-2. Isotopic Fractions and Weight Fractions of Target Nuclides

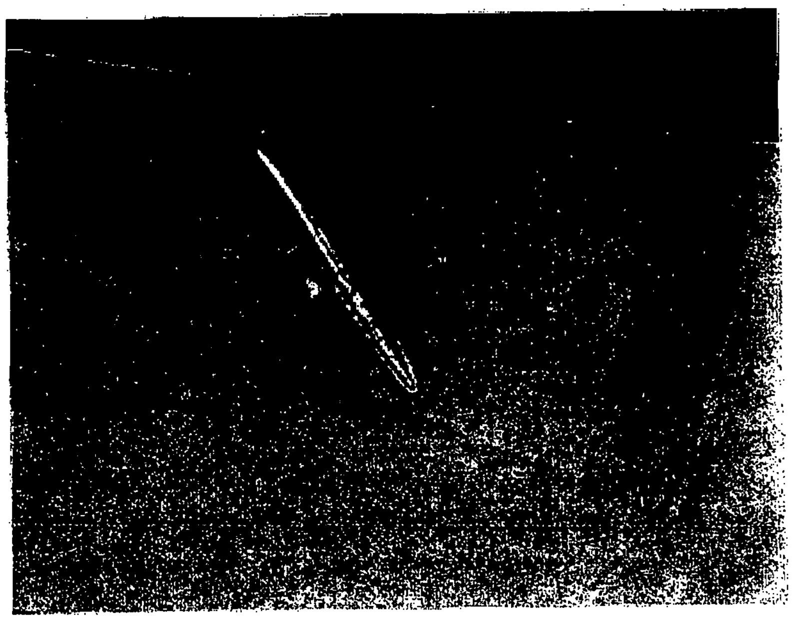
Dosimeter	Target Nuclide	Isotopic Fraction of Target	Weight Fraction of Target Element
Iron	^{54}Fe	0.0570	0.999704
Cobalt	^{59}Co	1.0	0.0102
Nickel	^{58}Ni	0.6739	0.99997
Titanium	^{46}Ti	0.0793	0.99793
Copper	^{63}Cu	0.6850	0.99998
Neptunium-237	^{237}Np	1.0	Determined from ^{233}Pa
Uranium-238	^{238}U	1.0	1

Table 5-3. Specific Activities for Palisades Capsule SA-60-1 Dosimetry

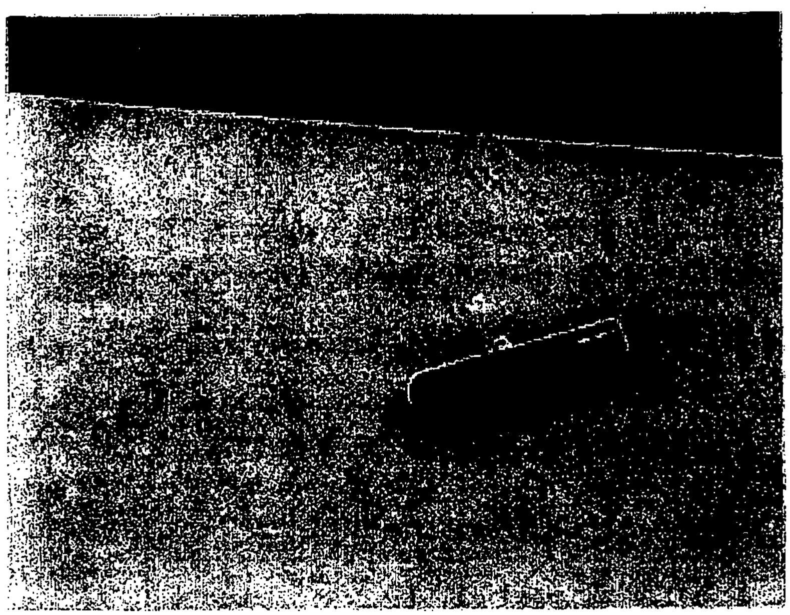
Dosimeter Identification	Shielded (Yes/No)	Target Nuclide	Analyte Nuclide	Specific Activity (µCi/gm Target)	% Error (%)
Palisades, SA-60-1 161T Sh Co	Yes	Co-59	Co-60	3.638E+04	7.51
Palisades, SA-60-1 161T Co	No	Co-59	Co-60	1.065E+05	6.93
Palisades, SA-60-1 164T Sh Co	Yes	Co-59	Co-60	3.760E+04	6.58
Palisades, SA-60-1 164T Co	No	Co-59	Co-60	9.600E+04	6.70
Palisades, SA-60-1 167T Sh Co	Yes	Co-59	Co-60	3.489E+04	6.64
Palisades, SA-60-1 167T Co	No	Co-59	Co-60	9.682E+04	6.75
Palisades, SA-60-1 161T Sh Cu	Yes	Cu-63	Co-60	14.07	5.24
Palisades, SA-60-1 164T Sh Cu	Yes	Cu-63	Co-60	13.87	5.25
Palisades, SA-60-1 167T Sh Cu	Yes	Cu-63	Co-60	13.79	5.24
Palisades, SA-60-1 161T Sh Ni	Yes	Ni-58	Co-58	7458	5.24
Palisades, SA-60-1 164T Sh Ni	Yes	Ni-58	Co-58	7184	5.24
Palisades, SA-60-1 167T Sh Ni	Yes	Ni-58	Co-58	7238	5.24
Palisades, SA-60-1 161T Fe	No	Fe-54	Mn-54	4921	5.68
Palisades, SA-60-1 164T Fe	No	Fe-54	Mn-54	4886	5.77
Palisades, SA-60-1 167T Fe	No	Fe-54	Mn-54	4970	5.68
Palisades, SA-60-1 161T Ti	No	Ti-46	Sc-46	1165	5.89
Palisades, SA-60-1 164T Ti	No	Ti-46	Sc-46	1173	6.33
Palisades, SA-60-1 167T Ti	No	Ti-46	Sc-46	1168	6.12
Palisades, SA-60-1 161T Sh U	Yes	U-238	Cs-137	NA	—
Palisades, SA-60-1 161T U	No	U-238	Cs-137	27.81	8.11
Palisades, SA-60-1 164T Sh U	Yes	U-238	Cs-137	22.71	8.13
Palisades, SA-60-1 164T U	No	U-238	Cs-137	NA*	NA*
Palisades, SA-60-1 167T Sh U	Yes	U-238	Cs-137	22.41	8.11
Palisades, SA-60-1 167T U	No	U-238	Cs-137	27.97	8.07
Palisades, SA-60-1 161T Sh Np	Yes	Np-237	Cs-137	145.7	8.08
Palisades, SA-60-1 164T Sh Np	Yes	Np-237	Cs-137	2263*	8.16*
Palisades, SA-60-1 167T Sh Np	Yes	Np-237	Cs-137	765.3*	8.16*

* Data were not available due to the fact that only a small amount of the dosimeter was recovered and the uncertainty of the dosimeter weight measurement was high (see Reference 18).

Figure 5-1. Photographs of Shielded Uranium Dosimeters Removed from Capsule SA-60-1



Shielded Uranium Dosimeter Removed from Compartment 161T



Shielded Uranium Dosimeter Removed from Compartment 164T

6.0 Summary of Results

The investigation of the post-irradiation test results of the materials contained in the first supplemental surveillance capsule, Capsule SA-60-1, removed from the Consumers Power Company Palisades reactor vessel, led to the following conclusions:

1. Observation of the Capsule SA-60-1 thermal monitors indicated that the irradiated test specimens were exposed to a maximum irradiation temperature no greater than 558°F.

2. Thirty-six pre-machined irradiated 18mm Charpy inserts were successfully reconstituted and machined to Type A Charpy impact specimens. Upon completion of the machining of the reconstituted Charpy specimens, the specimens were impact tested.

3. The 30 ft-lb transition temperature for the weld metal W5214 increased 259.0°F, and the 50 ft-lb transition temperature increased 393.0°F. In addition, the C_vUSE for this material decrease 46.9%.

4. The 30 ft-lb transition temperature for the weld metal 34B009 increased 249.8°F, and the 50 ft-lb transition temperature increased 343.6°F. In addition, the C_vUSE for this material decrease 51.5%.

5. The 30 ft-lb transition temperature for the weld metal 27204 increased 253.1°F, and the 50 ft-lb transition temperature increased 361.7°F. In addition, the C_vUSE for this material decrease 51.1%. 2

6. The correlation monitor plate demonstrated similar behavior with an increase in the 30 ft-lb transition temperature of 113.7°F, and an increase in the 50 ft-lb transition temperature of 127.7°F. The percent decrease in the C_vUSE for this material is 28.3%.

7.0 Certification

The specimens obtained from the Consumers Energy's Palisades first supplemental surveillance capsule (Capsule SA-60-1) were tested and evaluated using accepted techniques and established standard methods and procedures in accordance with the requirements of 10 CFR 50, Appendices G and H.

3/16/99

M. J. DeVan, Engineer IV — Date

Materials & Structural Analysis Unit

This report has been reviewed for technical content and accuracy.

3/16/99

H. Xu, Engineer II — Date

Materials & Structural Analysis Unit

Verification of independent review.

3-16-99

K. E. Moore, Manager — Date

Materials & Structural Analysis Unit

This report is approved for release.

3/16/99

D. L. Howell — Date

Program Manager

Revision 1

The revisions to this report were made as stated in accordance with the standard methods and procedures for the original report.

M J DeVan 5/28/99

M. J. DeVan, Engineer IV Date
Materials & Structural Analysis Unit

This report has been reviewed for technical content and accuracy.

Hongqing Xu 5/28/99

H. Xu, Engineer II Date
Materials & Structural Analysis Unit

Verification of independent review.

JF Shepard for KEMoore 5/28/99

K. E. Moore, Manager Date
Materials & Structural Analysis Unit

This report is approved for release.

DL Howell 6/1/99

D. L. Howell Date
Program Manager

FRAMATOME TECHNOLOGIES

Revision 2

The revisions to this report were made as stated in accordance with the standard methods and procedures for the original report.

5/22/01

M. J. DeVan, Supervisory Engineer — Date
Materials & Structural Analysis Unit

This report has been reviewed for technical content and accuracy.

5-22-01

K. E. Moore, Advisory Engineer — Date
Materials & Structural Analysis Unit

Verification of independent review.

David R Cofflin for ADM 5/22/01

A. D. McKim, Unit Manager — Date
Materials & Structural Analysis Unit

This report is approved for release.

5/22/01

D. L. Howell — Date
Program Manager

8.0 References

1. Code of Federal Regulation, Title 10, Part 50, *"Domestic Licensing of Production and Utilization Facilities,"* Appendix G, Fracture Toughness Requirements.

2. Code of Federal Regulation, Title 10, Part 50, *"Domestic Licensing of Production and Utilization Facilities,"* Appendix H, Reactor Vessel Material Surveillance Program Requirements.

3. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *"Nuclear Power Plant Components,"* Appendix G, Protection Against Nonductile Failure, 1989 Edition.

4. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, *"Rules for Inservice Inspection of Nuclear Power Plant Components,"* Appendix G, Fracture Toughness Criteria for Protection Against Failure, 1989 Edition.

5. ASTM Standard E 208-81, *"Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels,"* American Society for Testing and Materials, Philadelphia, Pennsylvania.

6. R. C. Groeschel, *"Summary Report on Manufacture of Test Specimens and Assembly of Capsules for Irradiation Surveillance of Palisades Reactor Vessel Materials,"* CE Report No. P-NLM-019, Combustion Engineering, Inc., Windsor, Connecticut, April 1, 1971.

7. ASTM Standard E 185-66, *"Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors,"* American Society for Testing and Materials, Philadelphia, Pennsylvania.

8. G. Gage, R. J. McElroy, and C. A. English, *"Evaluation of Weldmetals from Retired Palisades Steam Generators,"* AEA-TSD-0774, AEA Technology, November 23, 1995.

9. Letter from J. R. Kneeland to D. L. Howell (FTI), FTG Document No. 38-1247683-00, released March 9, 1999.

10. J. A. Wang, *"Analysis of the Irradiation Data for A302B and A533B Correlation Monitor Materials,"* NUREG/CR-6413 (ORNL/TM-13133), Prepared for U.S. Nuclear Regulatory Commission by Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 1996.

11. Letter from R. A. Fenech (CPCo) to NRC, *"Docket 50-255 – License DPR-20 – Palisades Plant Response to Request for Additional Information, Revision 1 – 10 CFR 50.61 Screening Crtierion (RE: TAC No. M83227),"* dated December 28, 1994.

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APPENDIX A

Reactor Vessel Surveillance Program
Background Data and Information

A.1. Palisades Reactor Pressure Vessel

The Palisades reactor pressure vessel was fabricated by Combustion Engineering, Inc. (CE). The Palisades reactor vessel beltline region consists of two shells, containing six heats of base metal plate, six longitudinal weld seams, and two circumferential weld seams. Table A-1 presents a description of the Palisades reactor vessel beltline materials including their copper and nickel chemical contents and their unirradiated mechanical properties. The locations of the materials within the reactor vessel beltline region are shown in Figure A-1.

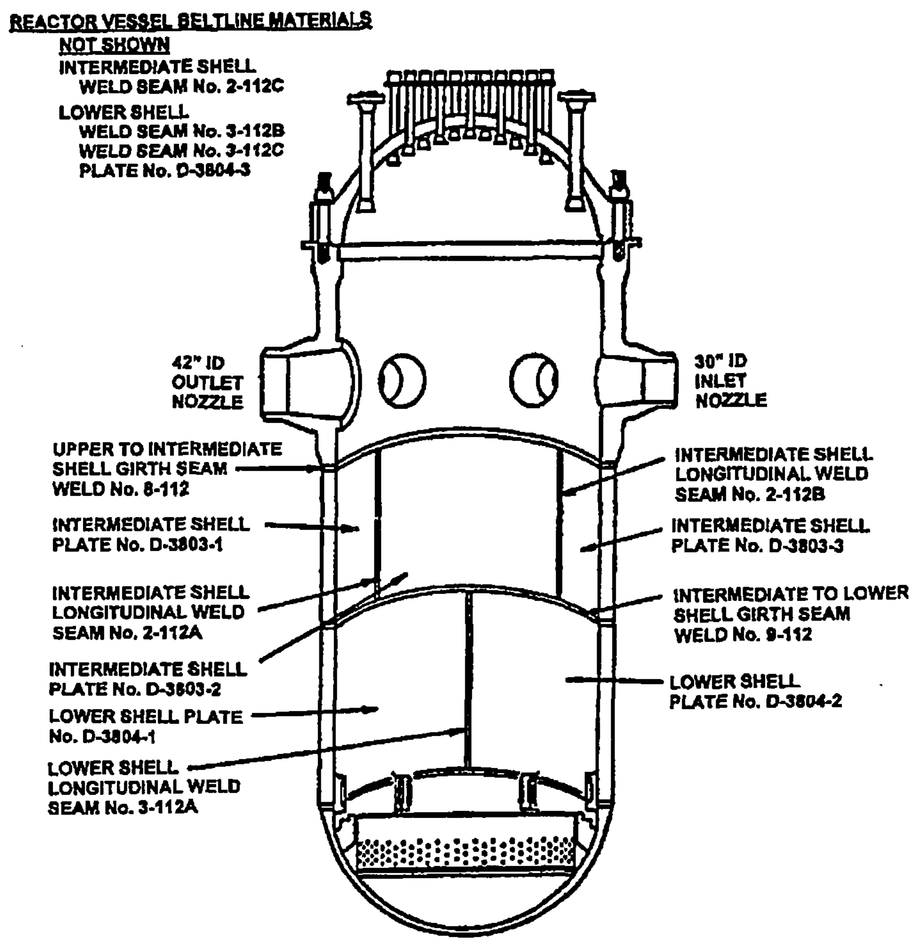
Table A-1. Description of the Palisades Reactor Vessel Beltline Region Materials

Fabricator Material Code	Material Heat No.	Material Type	Beltline Region Location	Chemical Composition		Toughness Properties					
				Cu, wt%	Ni, wt%	30 ft-lb, F	50 ft-lb, F	35 MLE, F	C_VUSE, ft-lbs	T_{NDT}, F	RT_{NDT}, F
D-3803-1	C1279-3	A 302 Gr. B Mod.	Intermediate Shell	0.24	0.51	---	---	---	102	-30	-5
D-3803-2	A0313-2	A 302 Gr. B Mod.	Intermediate Shell	0.24	0.52	---	---	---	87	-30	-30
D-3803-3	C1279-1	A 302 Gr. B Mod.	Intermediate Shell	0.24	0.50	---	---	---	102	-30	-5
D-3804-1	C1308-1	A 302 Gr. B Mod.	Lower Shell	0.19	0.48	---	---	---	72	-30	0
D-3804-2	C1308-3	A 302 Gr. B Mod.	Lower Shell	0.19	0.50	---	---	---	76	-40	-30
D-3804-3	B5294-2	A 302 Gr. B Mod.	Lower Shell	0.12	0.55	---	---	---	73	-30	-25
2-112A, B, C	W5214/ 3617*	ASA Weld/ Linde 1092	Intermediate Shell Longitudinal Welds	0.213	1.01	---	---	---	118	---	--56
9-112	27204/ 3687*	ASA Weld/ Linde 124	Intermediate to Lower Shell Circ. Weld	0.203	1.018	---	---	---	98	---	-56
3-112A, B, C	34B009, W5214/ 3692*	ASA Weld/ Linde 1092	Lower Shell Longitudinal Welds	0.192/ 0.213	0.98/ 1.01	---	---	---	111/ 118	---	-56

2

* Weld wire heat number and flux lot identifiers.

Figure A-1. Location and Identification of Materials Used in the Fabrication of Palisades Reactor Pressure Vessel



REACTOR VESSEL

APPENDIX B

Instrumented Charpy V-Notch Specimen Test Results
Load-Time Traces

Figure B-1. Load-Time Trace for Charpy V-Notch Impact Specimen AA2

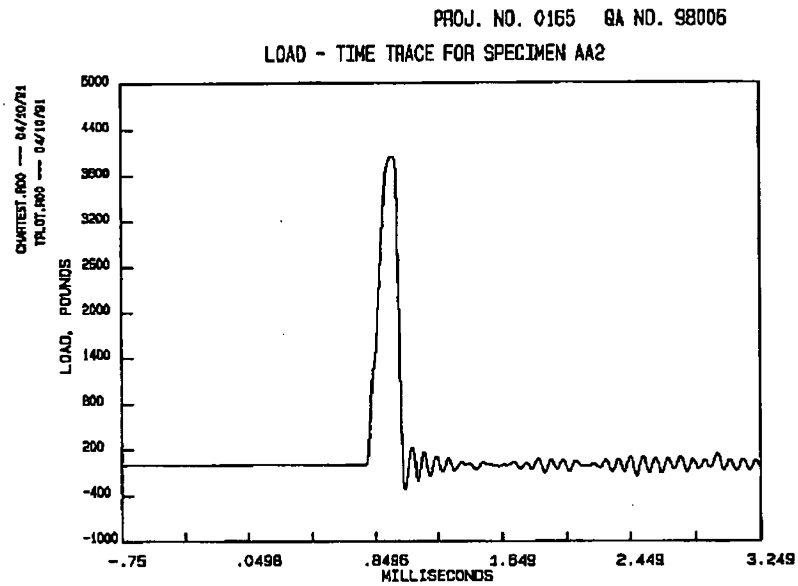


Figure B-2. Load-Time Trace for Charpy V-Notch Impact Specimen AW1

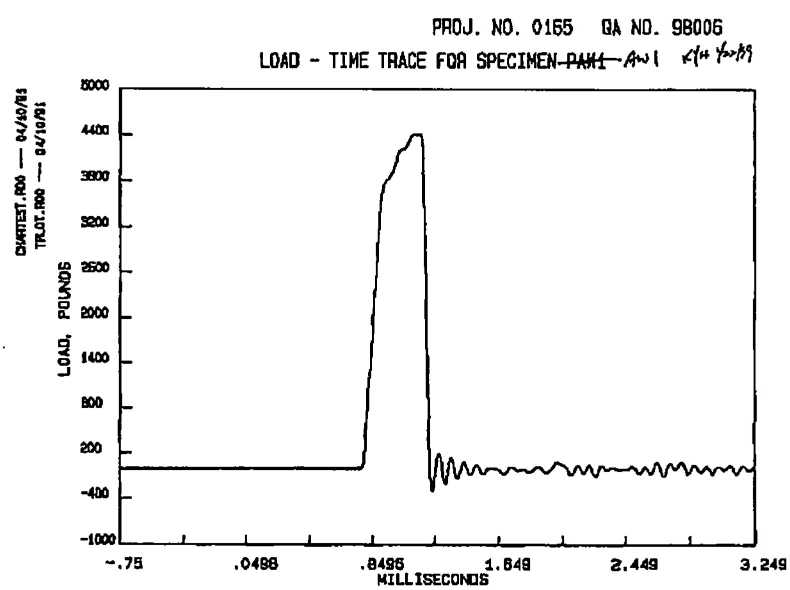


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Figure B-3. Load-Time Trace for Charpy V-Notch Impact Specimen AW2

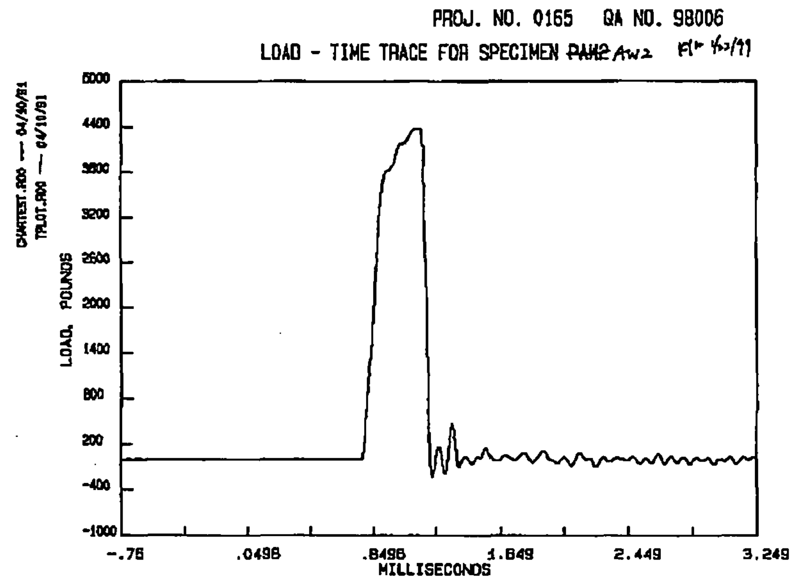

Figure B-4. Load-Time Trace for Charpy V-Notch Impact Specimen 2AF5

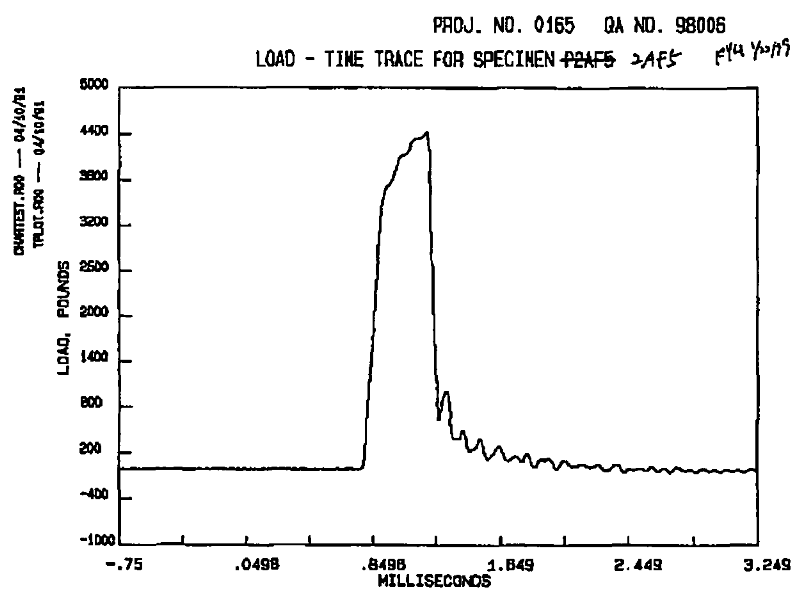

Figure B-5. Load-Time Trace for Charpy V-Notch Impact Specimen AL3

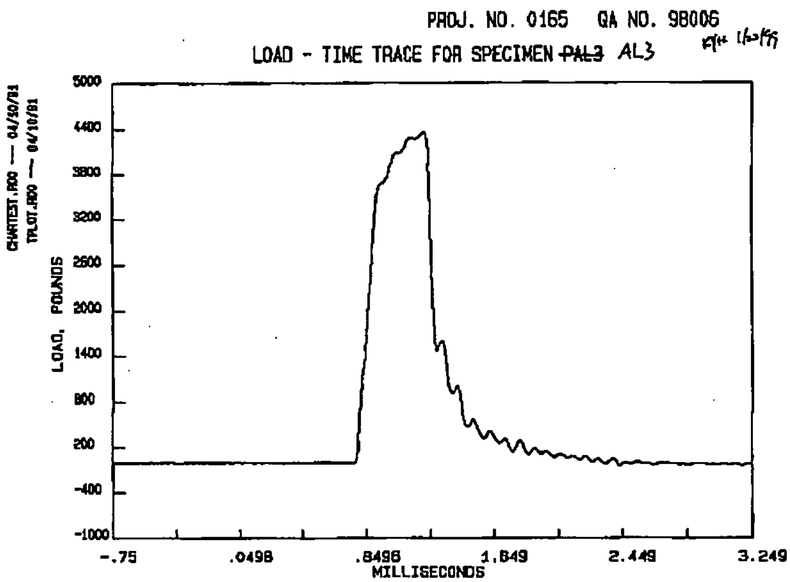

Figure B-6. Load-Time Trace for Charpy V-Notch Impact Specimen AA4

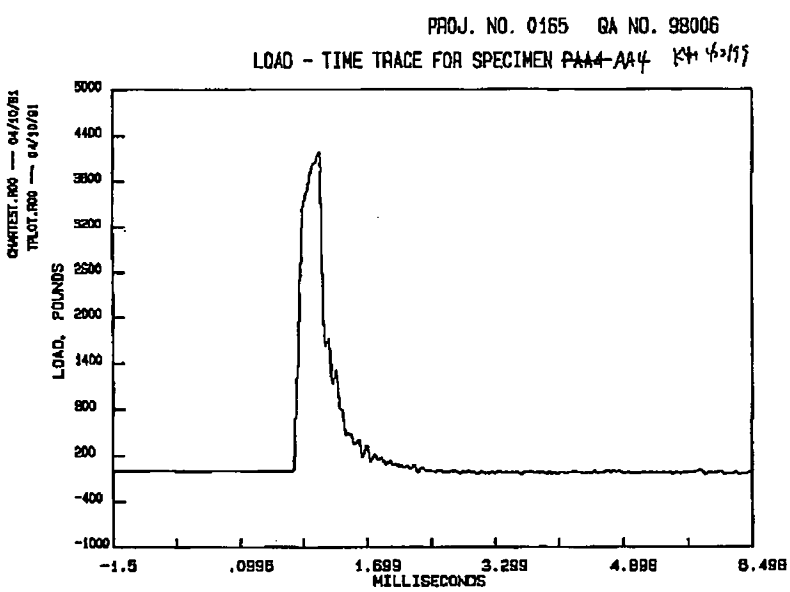

Figure B-7. Load-Time Trace for Charpy V-Notch Impact Specimen 2AL6

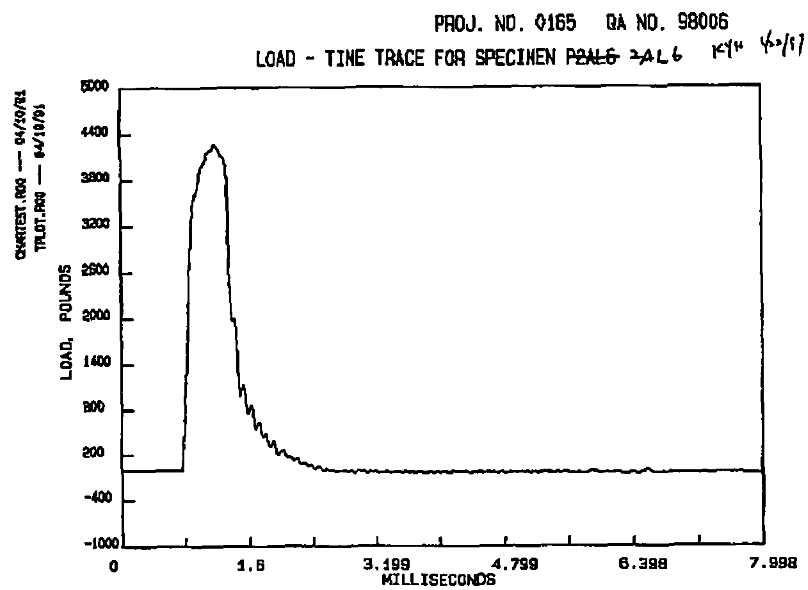

Figure B-8. Load-Time Trace for Charpy V-Notch Impact Specimen 2AE2

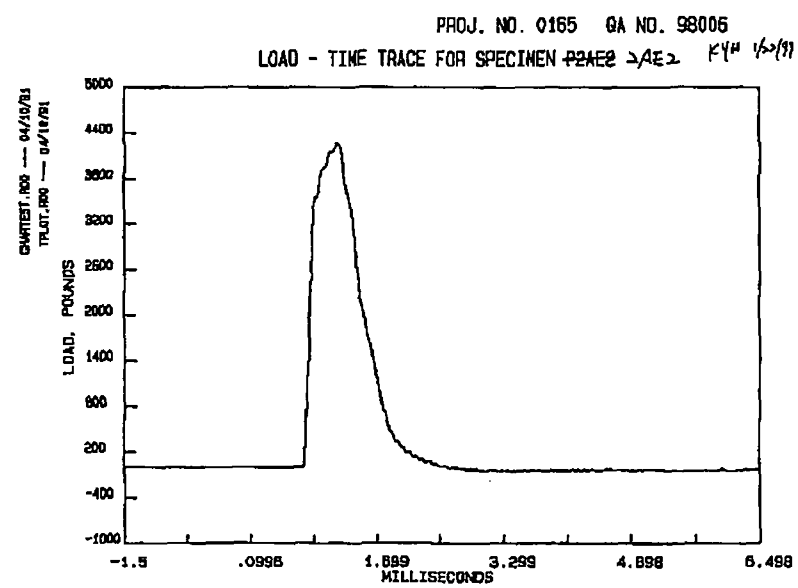

Figure B-9. Load-Time Trace for Charpy V-Notch Impact Specimen 2AH6

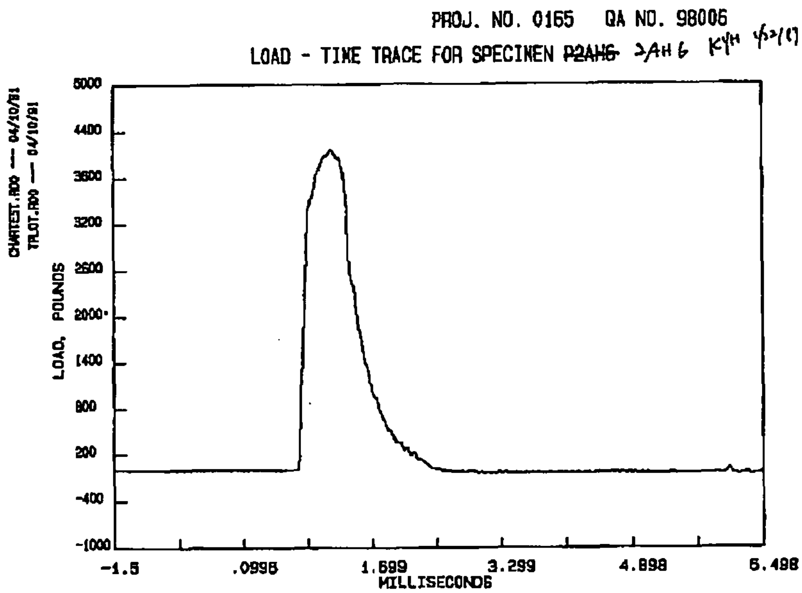

Figure B-10. Load-Time Trace for Charpy V-Notch Impact Specimen AR94

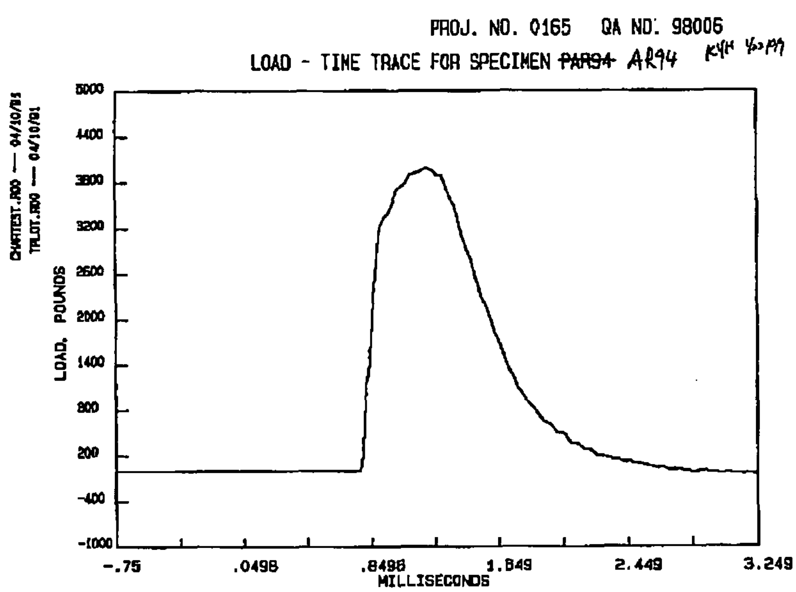

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Figure B-11. Load-Time Trace for Charpy V-Notch Impact Specimen 2AH1

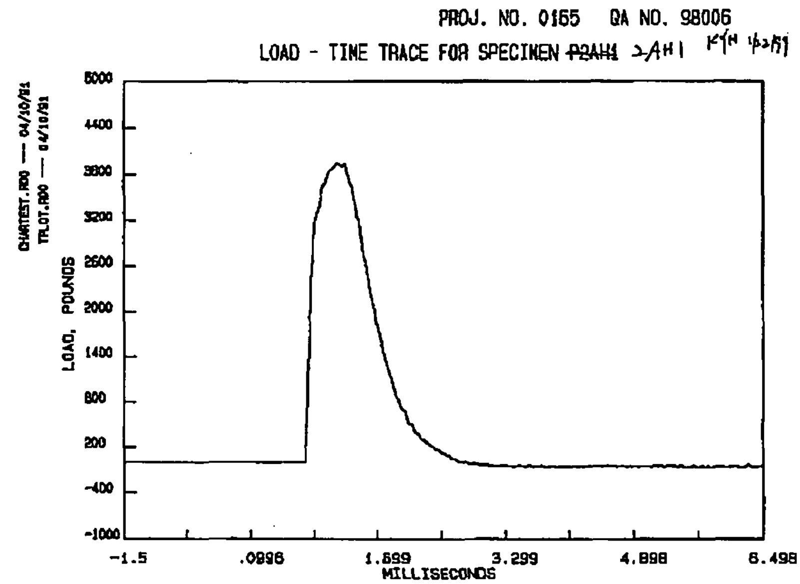

Figure B-12. Load-Time Trace for Charpy V-Notch Impact Specimen AV4

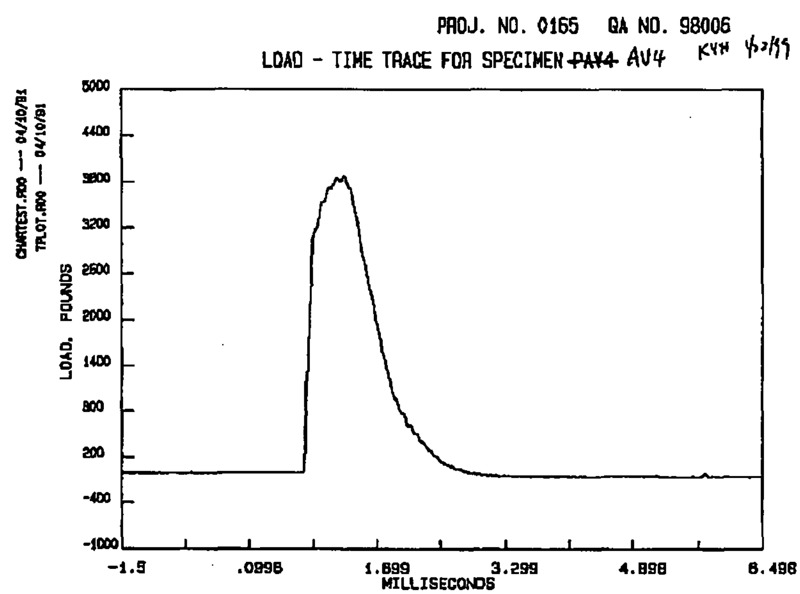

Figure B-13. Load-Time Trace for Charpy V-Notch Impact Specimen BD2

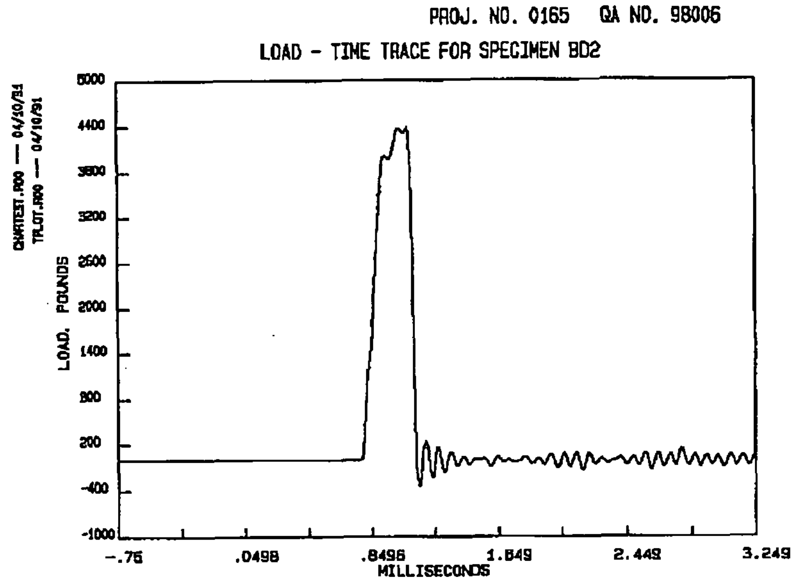

Figure B-14. Load-Time Trace for Charpy V-Notch Impact Specimen BW5

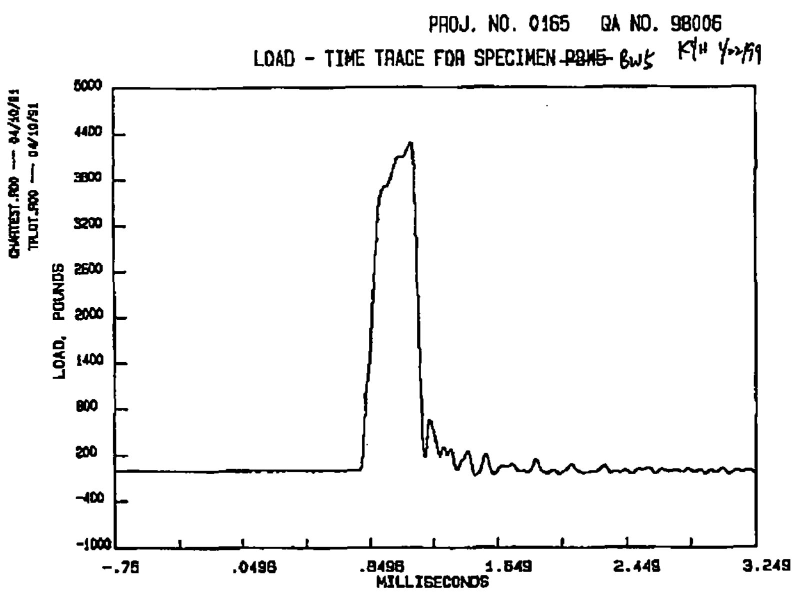

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Figure B-15. Load-Time Trace for Charpy V-Notch Impact Specimen BO2

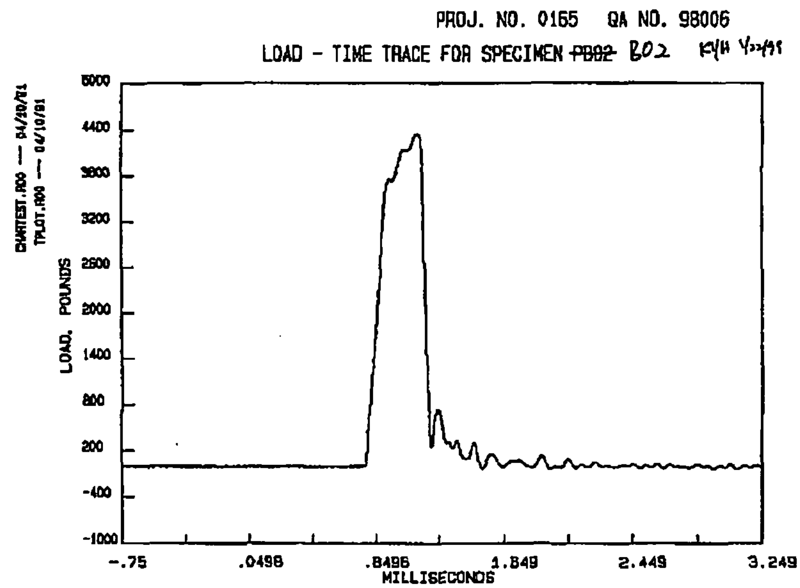

Figure B-16. Load-Time Trace for Charpy V-Notch Impact Specimen 2BK5

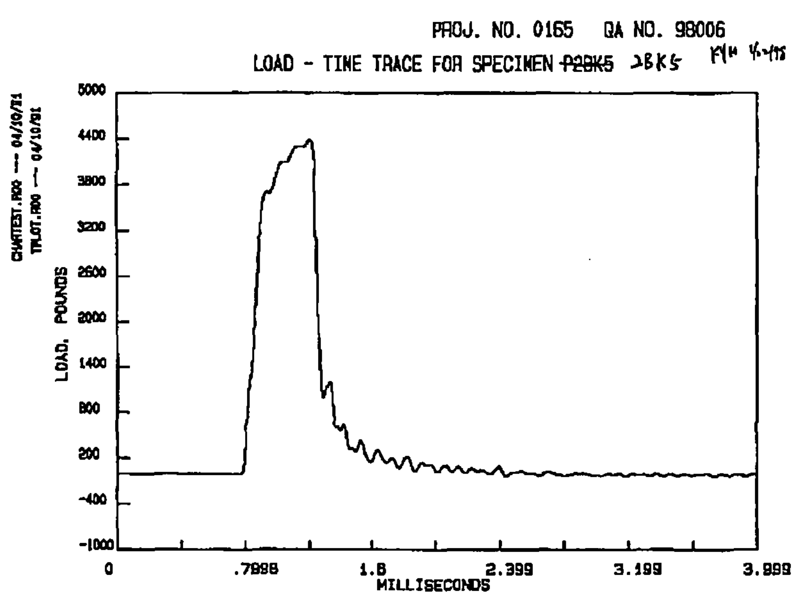

Figure B-17. Load-Time Trace for Charpy V-Notch Impact Specimen 2BJ2

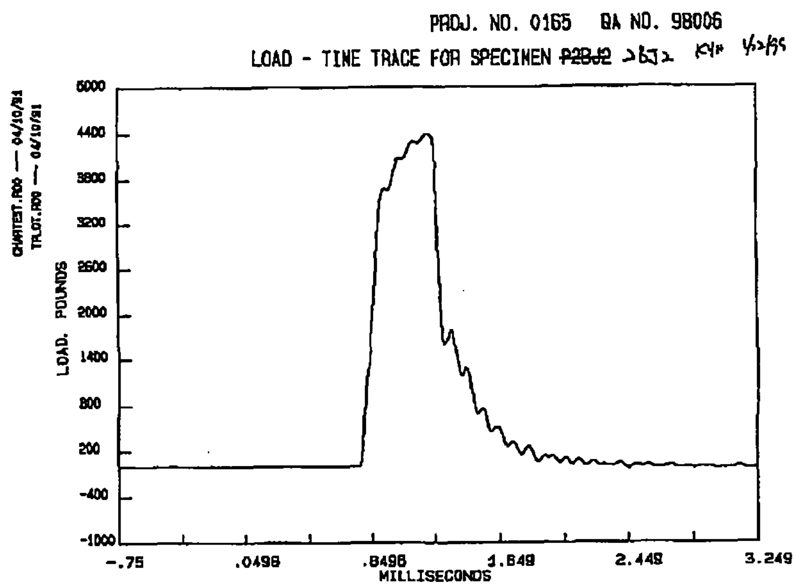

Figure B-18. Load-Time Trace for Charpy V-Notch Impact Specimen 2BF5

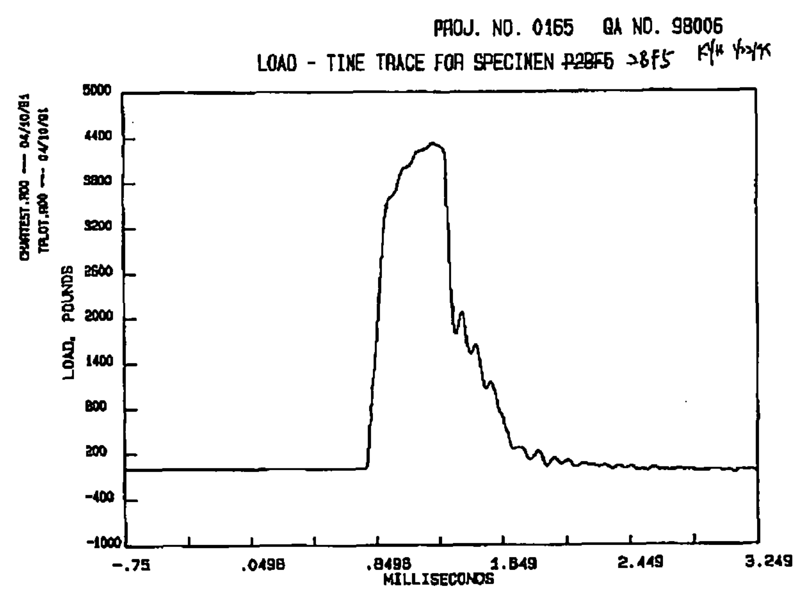

Figure B-19. Load-Time Trace for Charpy V-Notch Impact Specimen 2BK1

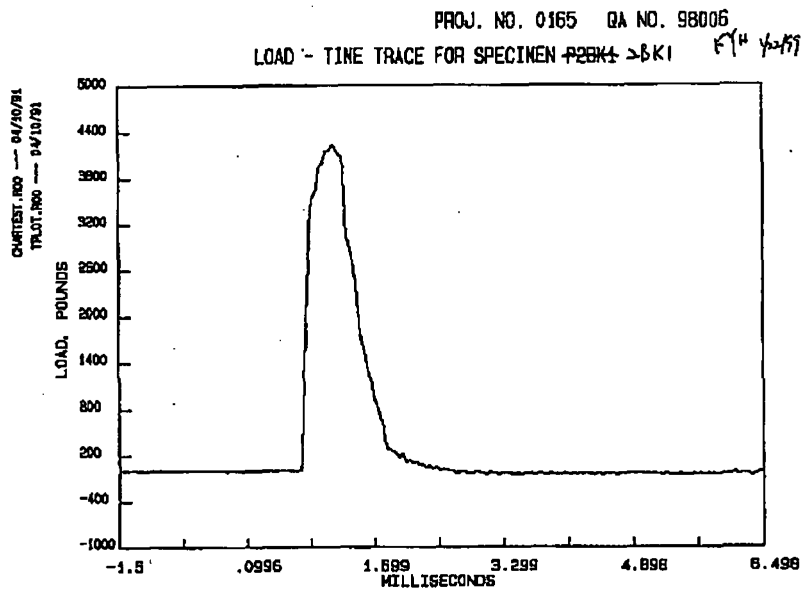

Figure B-20. Load-Time Trace for Charpy V-Notch Impact Specimen BW1

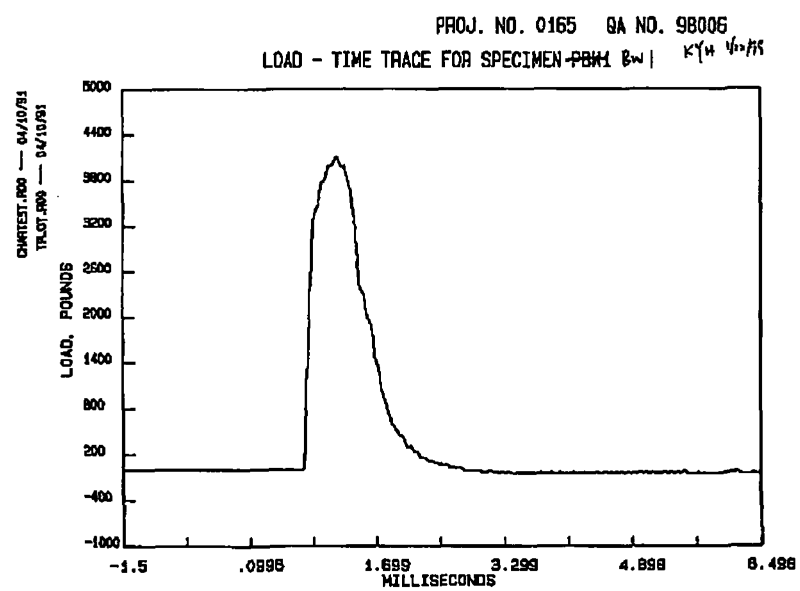

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Figure B-21. Load-Time Trace for Charpy V-Notch Impact Specimen BR91

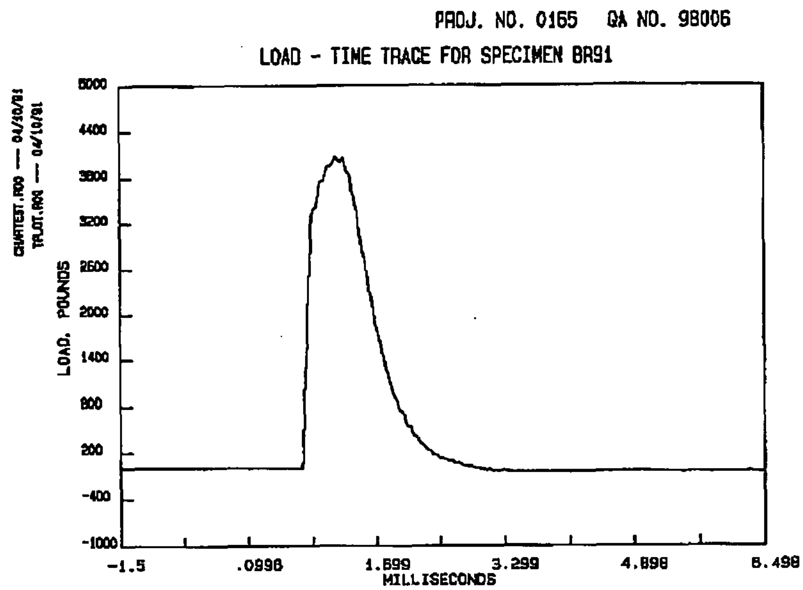

Figure B-22. Load-Time Trace for Charpy V-Notch Impact Specimen BU2

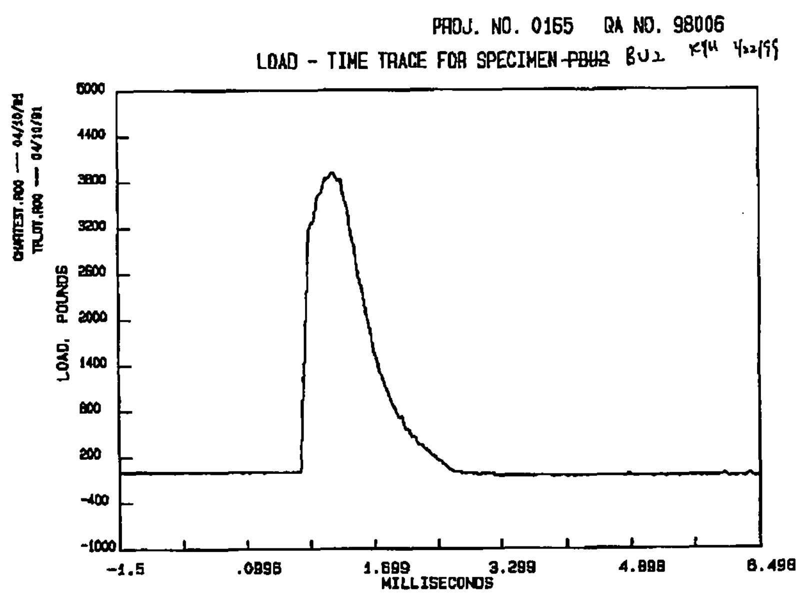

Figure B-23. Load-Time Trace for Charpy V-Notch Impact Specimen BV5

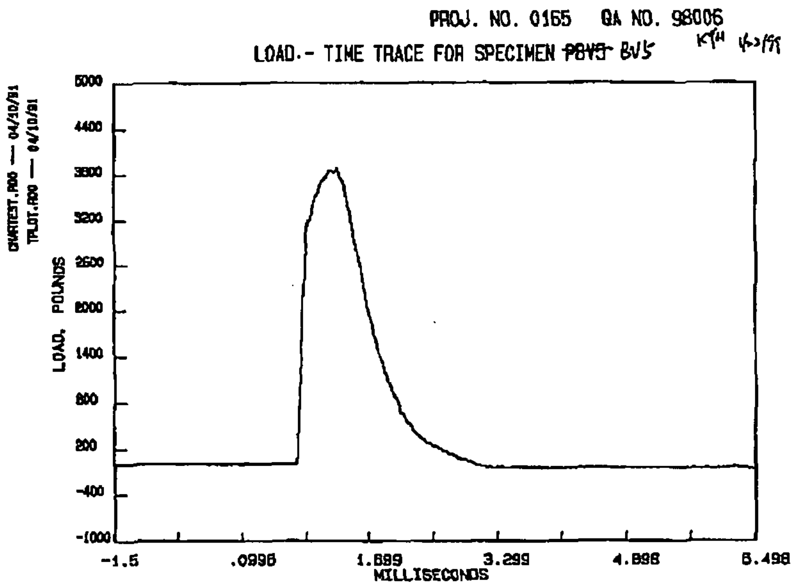

Figure B-24. Load-Time Trace for Charpy V-Notch Impact Specimen BL2

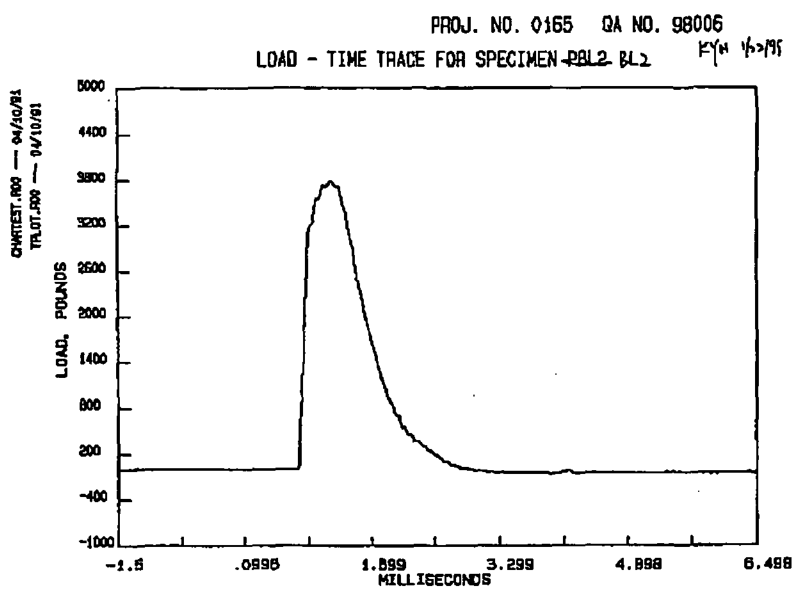

Figure B-25. Load-Time Trace for Charpy V-Notch Impact Specimen PB68

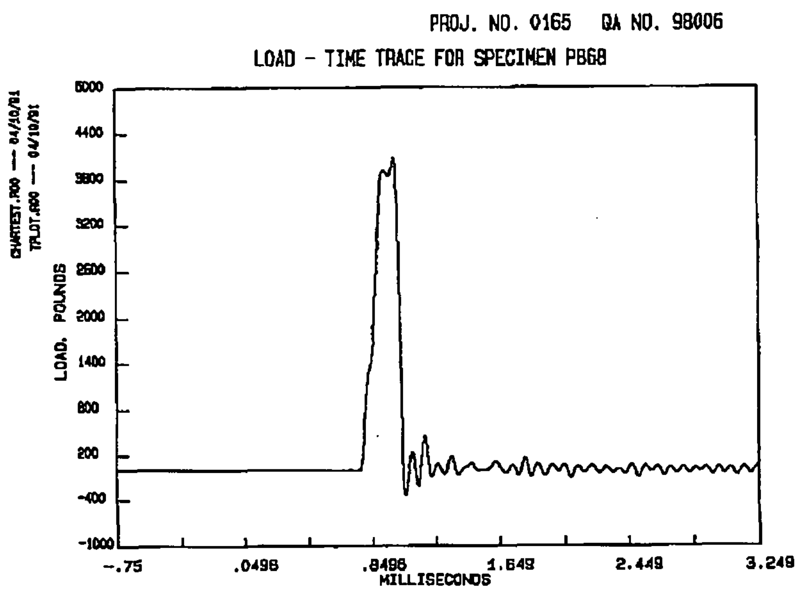

Figure B-26. Load-Time Trace for Charpy V-Notch Impact Specimen PB56

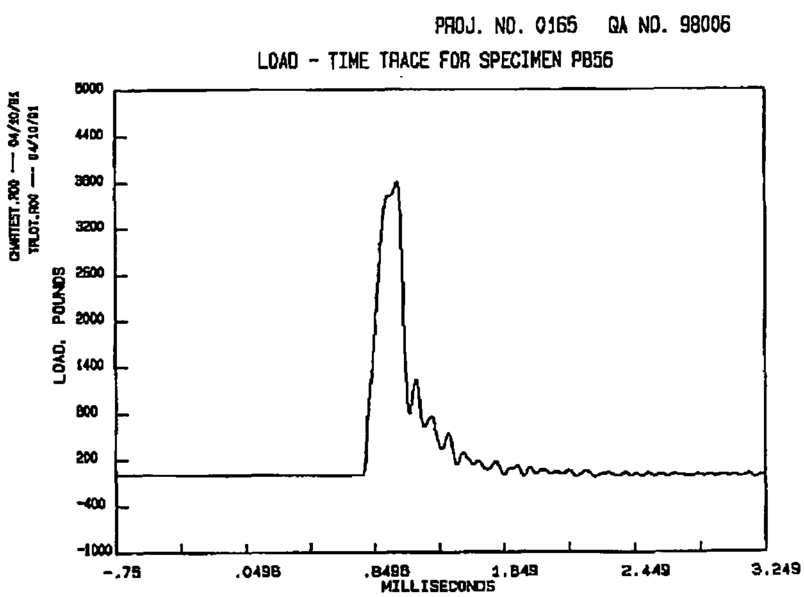

Figure B-27. Load-Time Trace for Charpy V-Notch Impact Specimen PB81

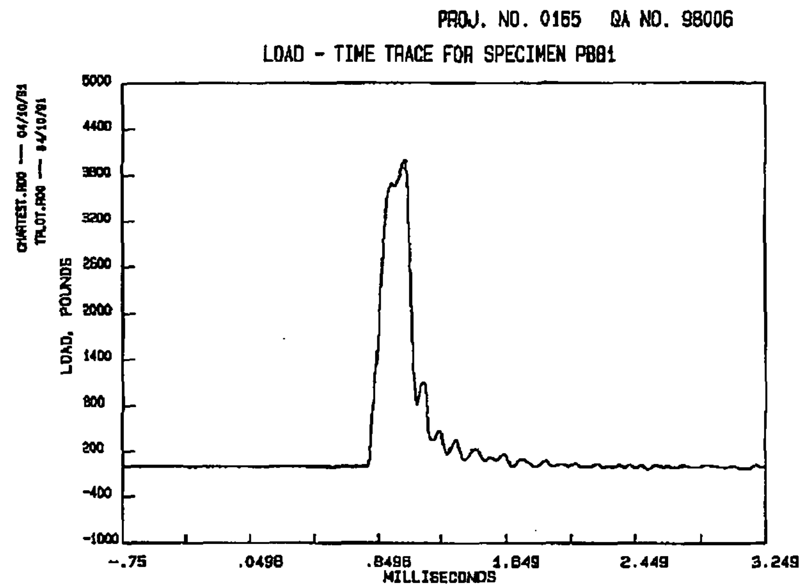

Figure B-28. Load-Time Trace for Charpy V-Notch Impact Specimen PB78

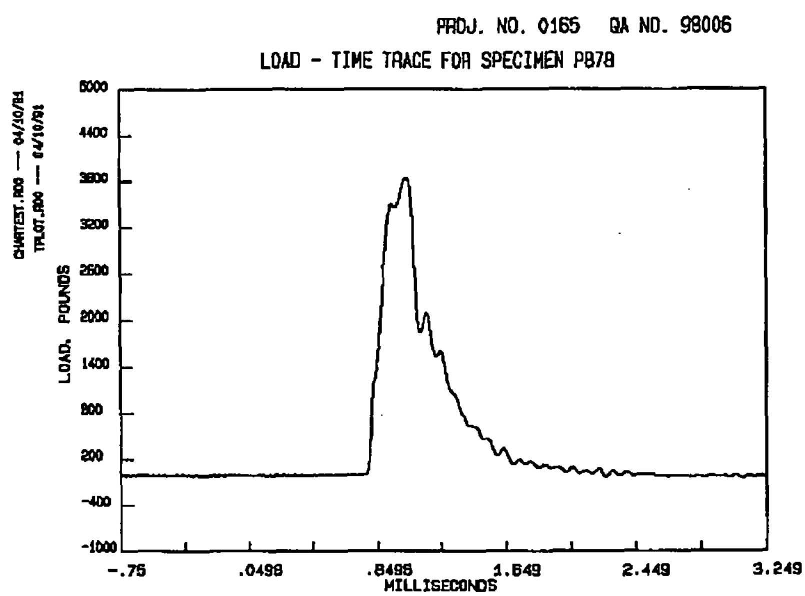

Figure B-29. Load-Time Trace for Charpy V-Notch Impact Specimen PB93

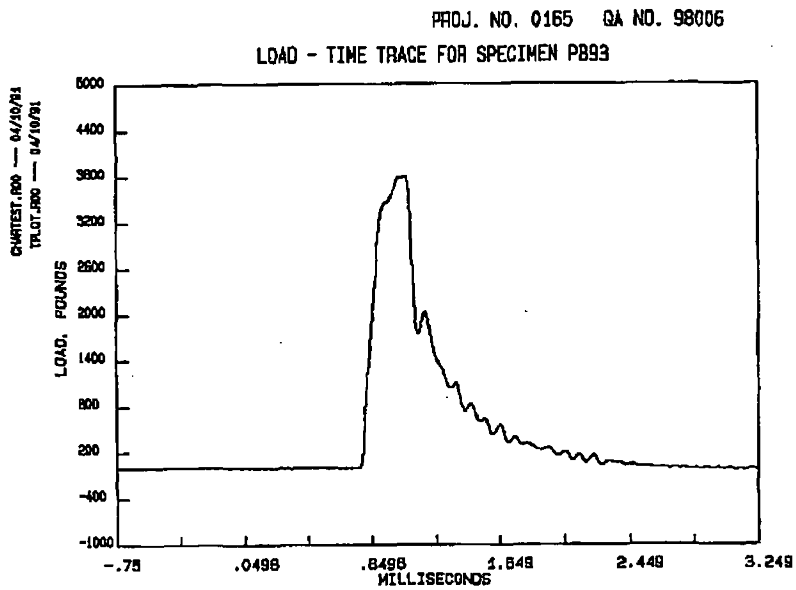

Figure B-30. Load-Time Trace for Charpy V-Notch Impact Specimen PB91

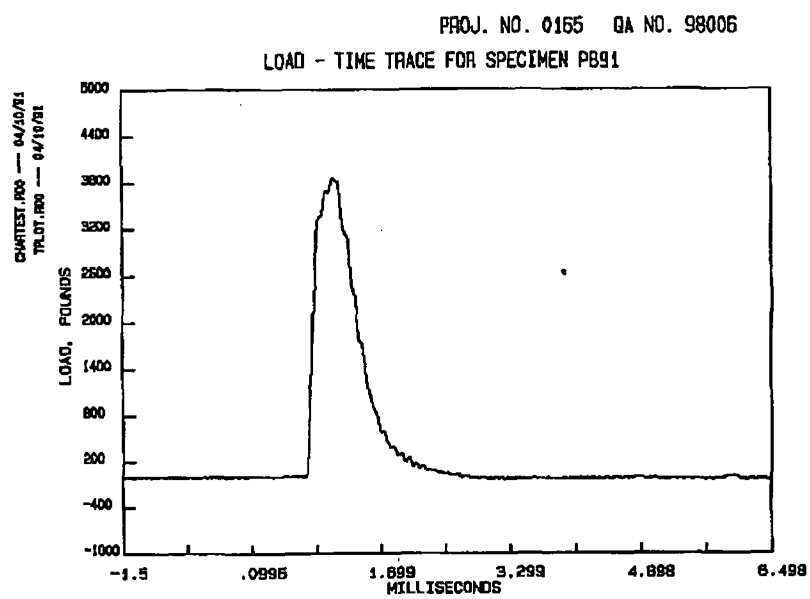

Figure B-31. Load-Time Trace for Charpy V-Notch Impact Specimen PB28

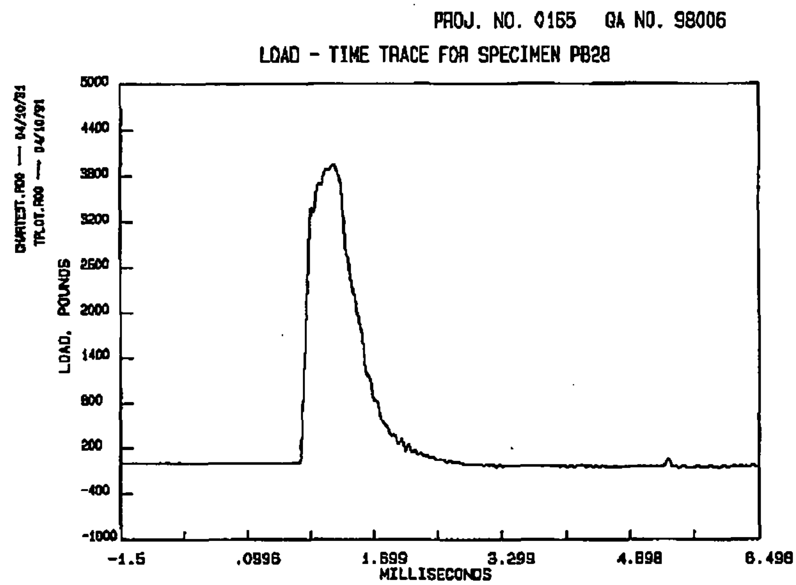

Figure B-32. Load-Time Trace for Charpy V-Notch Impact Specimen PB96

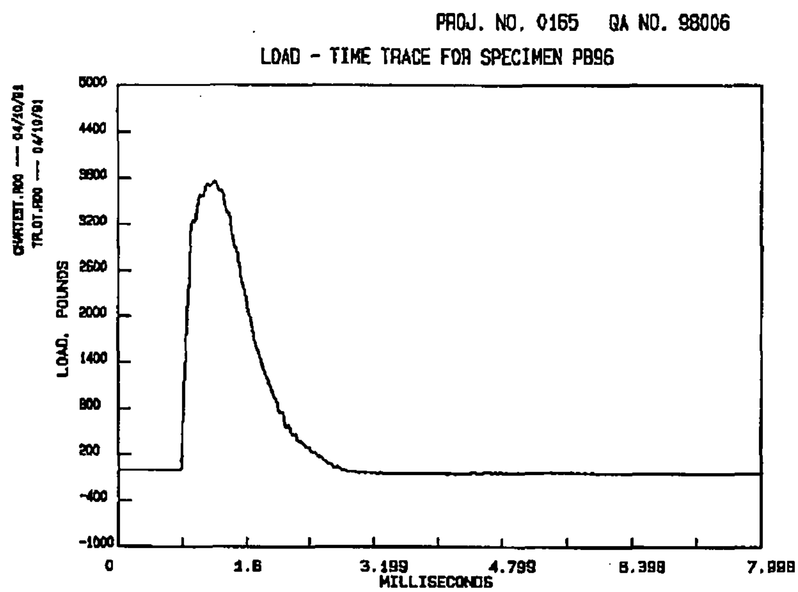

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Figure B-33. Load-Time Trace for Charpy V-Notch Impact Specimen PB94

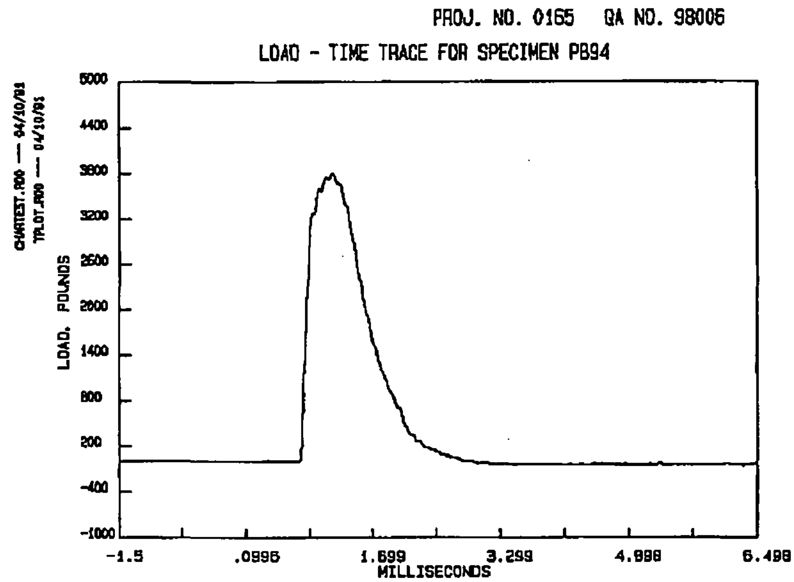

Figure B-34. Load-Time Trace for Charpy V-Notch Impact Specimen PB15

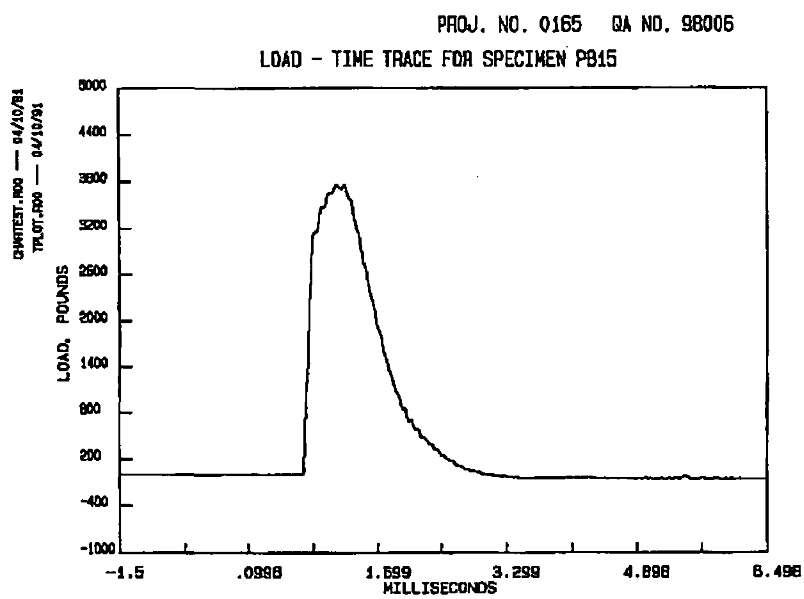

Figure B-35. Load-Time Trace for Charpy V-Notch Impact Specimen PB42

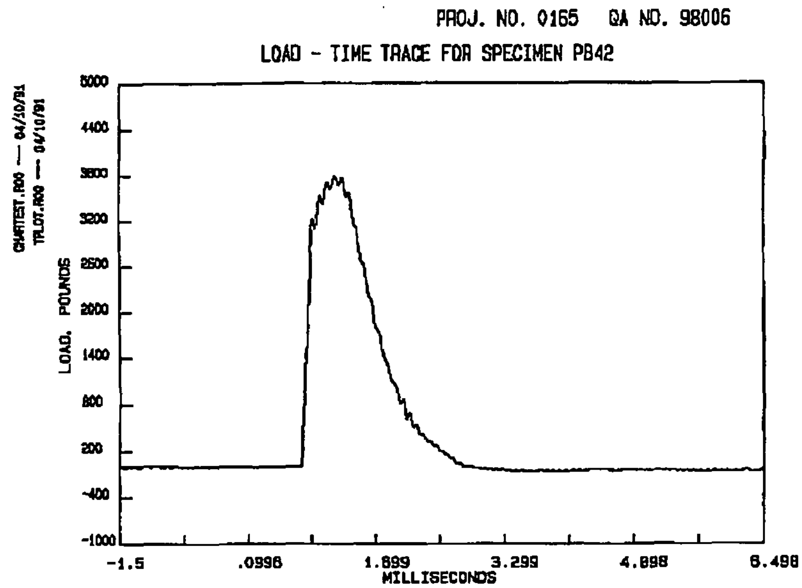

Figure B-36. Load-Time Trace for Charpy V-Notch Impact Specimen PB95

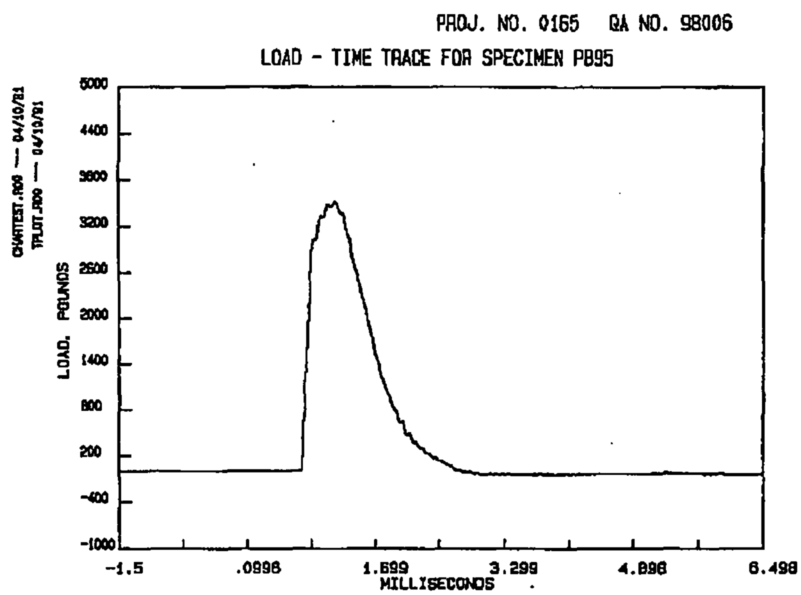

Figure B-37. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-9

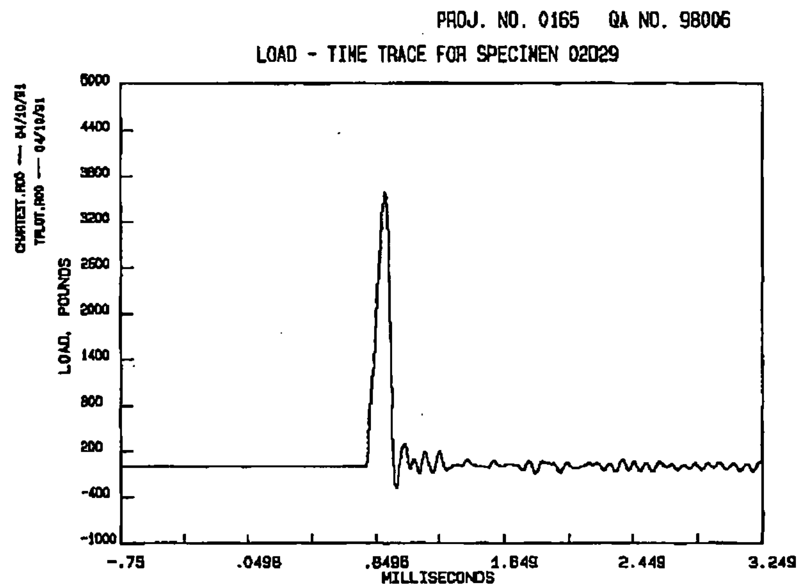

Figure B-38. Load-Time Trace for Charpy V-Notch Impact Specimen 02D2-3

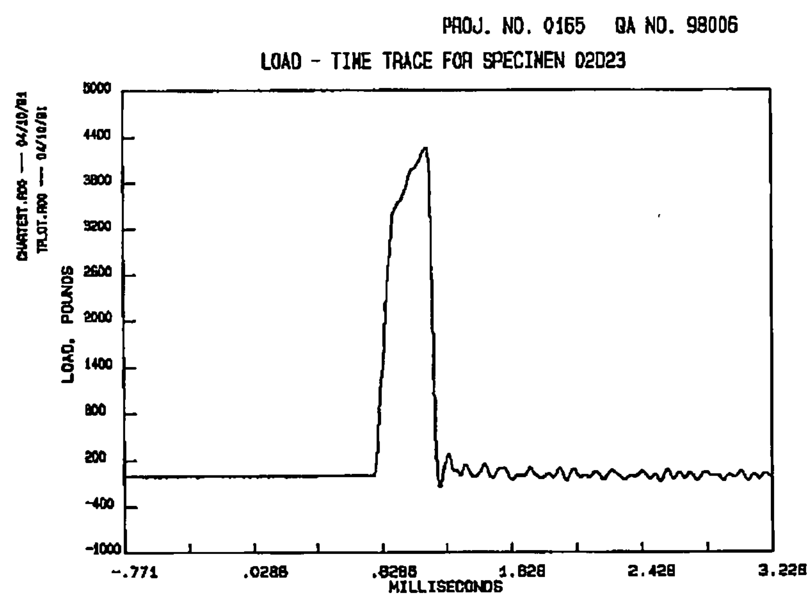

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Figure B-39. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-1

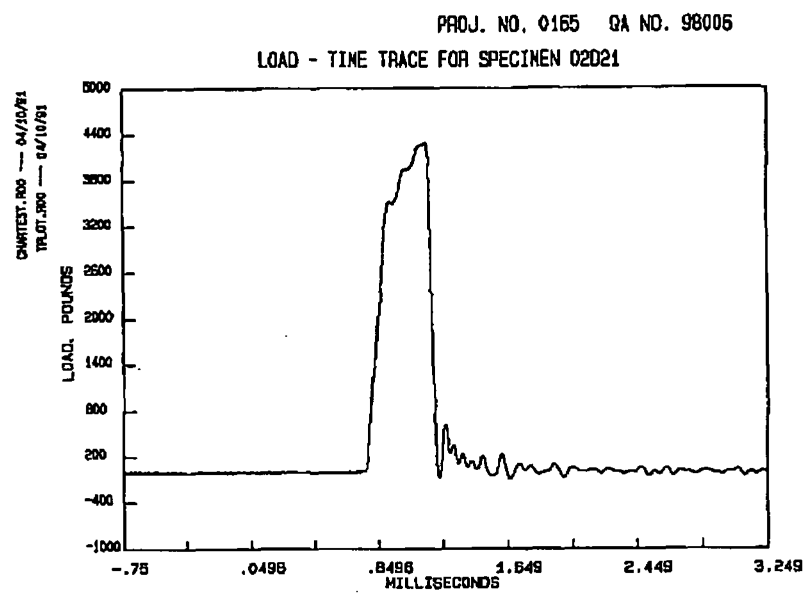


Figure B-40. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-7

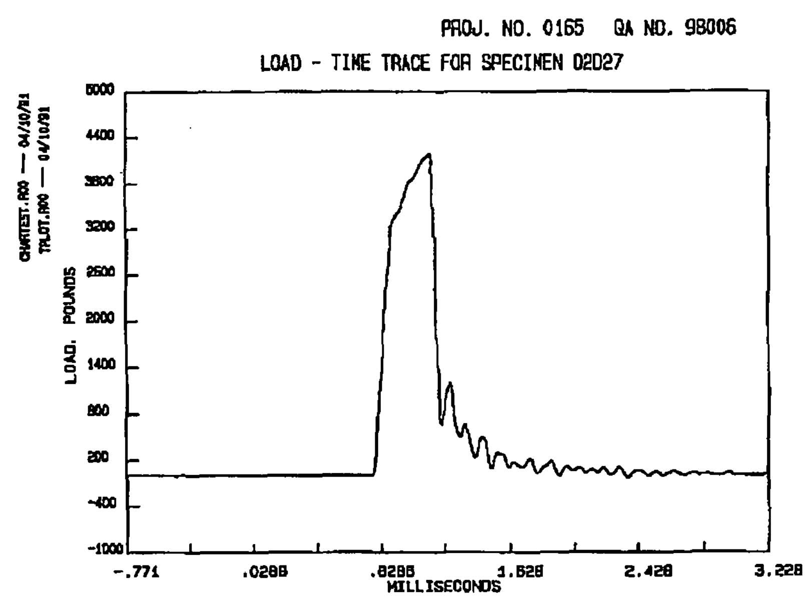


Figure B-41. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-18

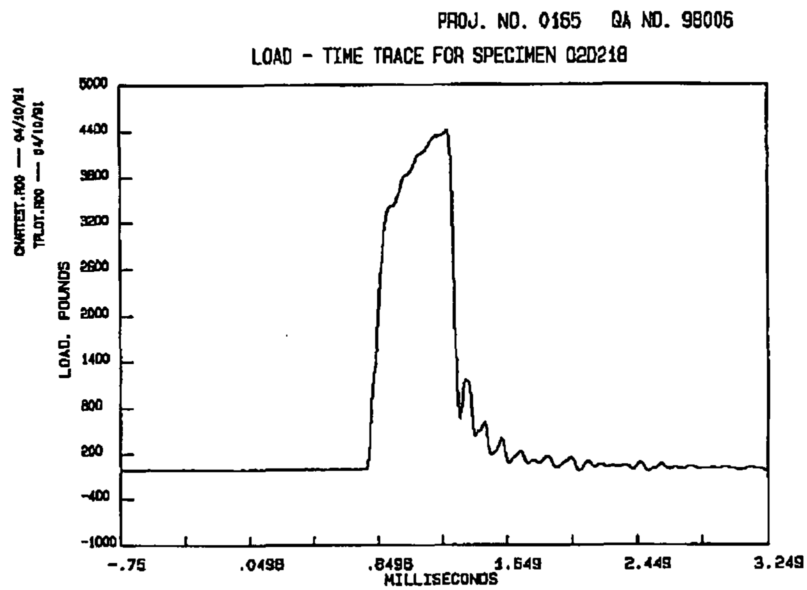


Figure B-42. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-21

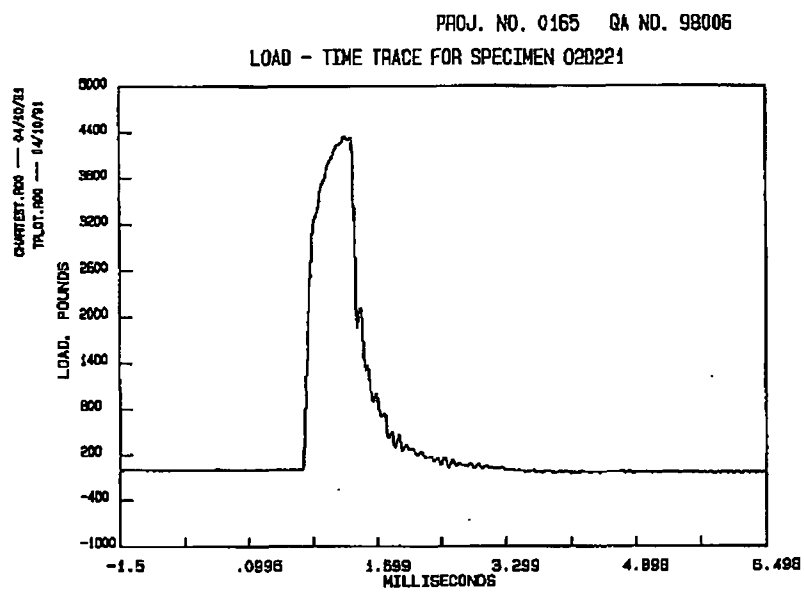


Figure B-43. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-14

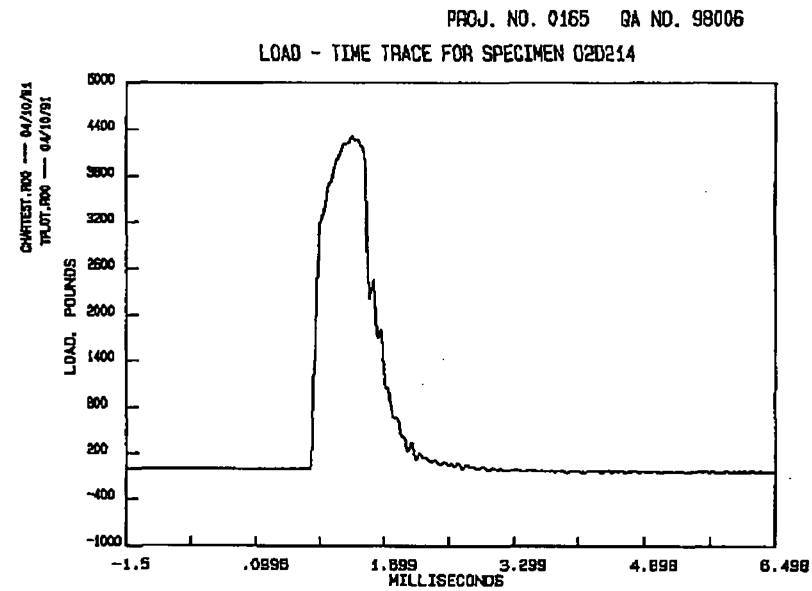


Figure B-44. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-16

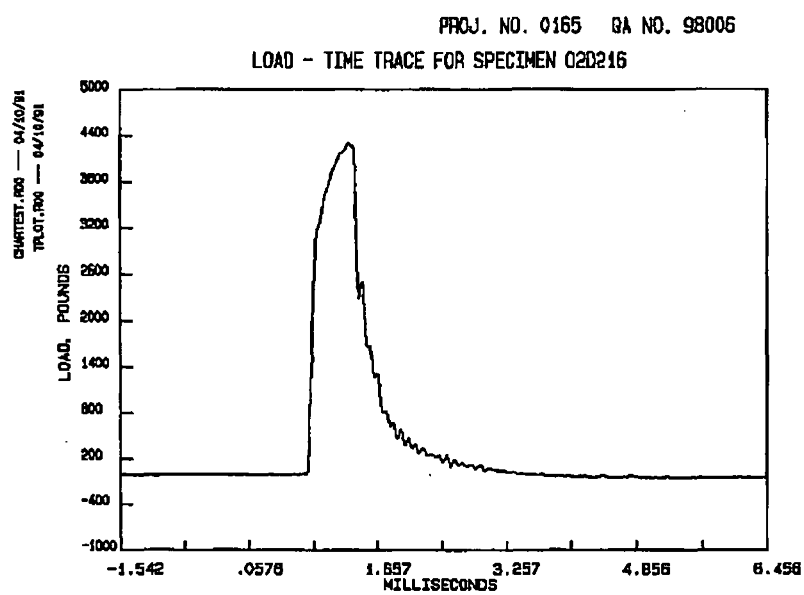


Figure B-45. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-4

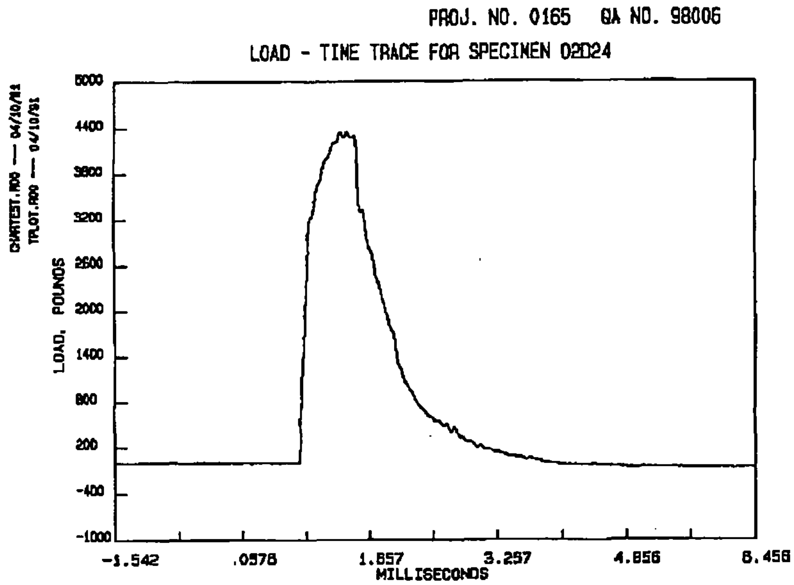


Figure B-46. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-6

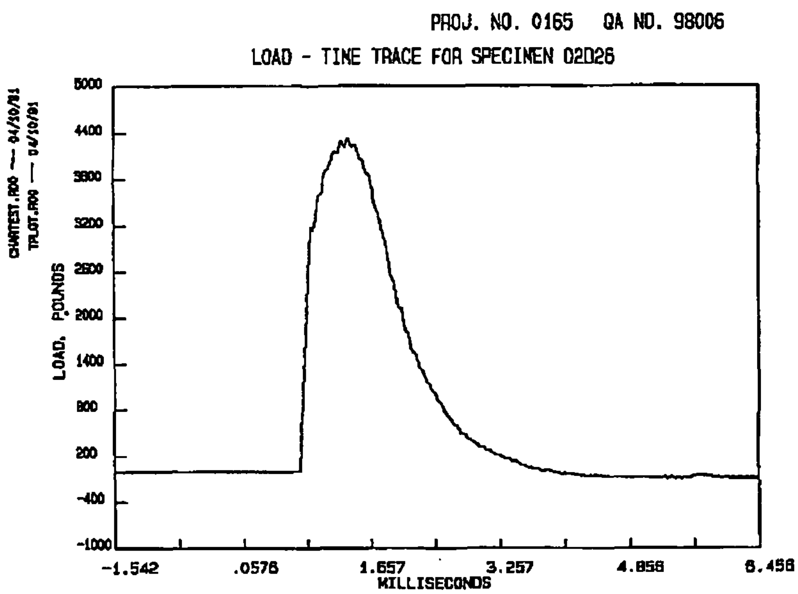


Figure B-47. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-12

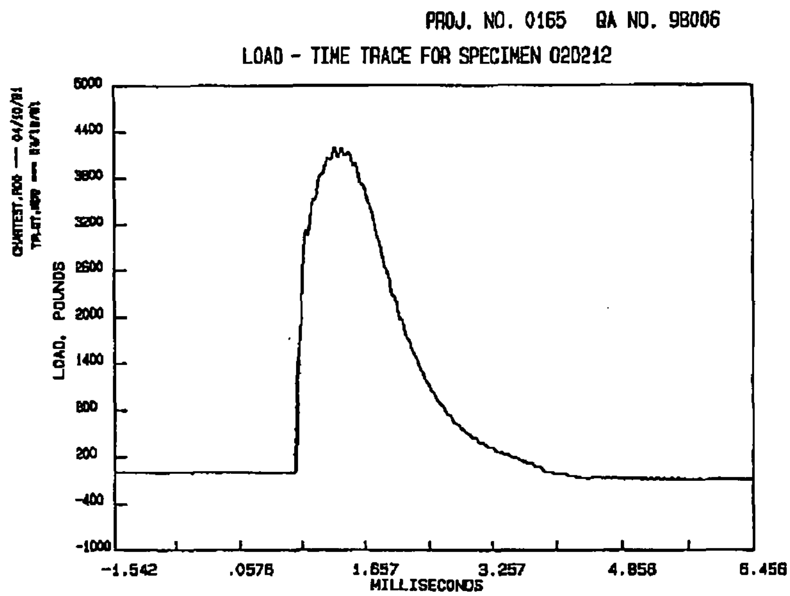
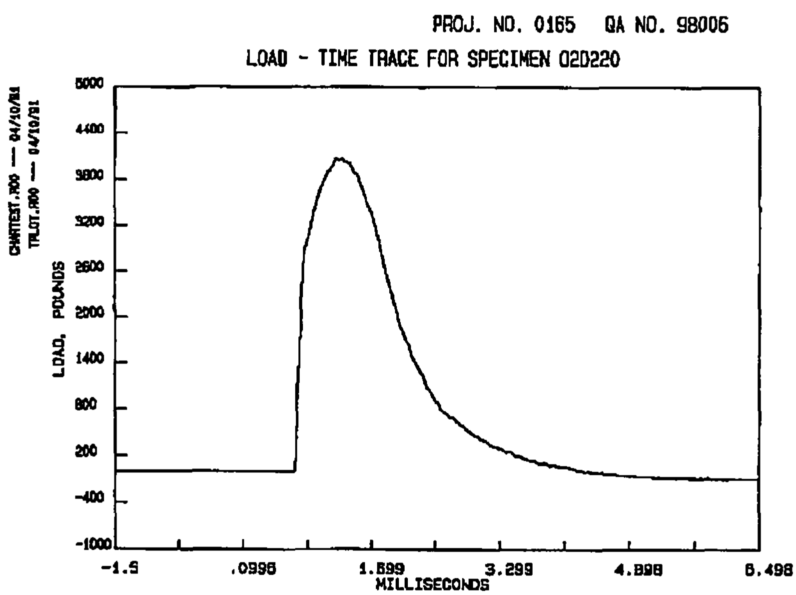


Figure B-48. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-20



ATTACHMENT 2

TEST RESULTS CAPSULE SA-240-1

BAW-2398

MAY 2001

84 Pages Follow

BAW-2398
May 2001

Test Results of Capsule SA-240-1
Consumers Energy
Palisades Nuclear Plant

-- Reactor Vessel Material Surveillance Program --

by

M. J. DeVan

FTI Document No. 77-2398-00
(See Section 7 for document signatures.)

Prepared for

Consumers Energy

Prepared by

Framatome ANP, Inc.
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Lynchburg, Virginia 24506-0935

FRAMATOME ANP

Executive Summary

This report describes the results of the tests performed on the specimens contained in the second supplemental reactor vessel surveillance capsule (Capsule SA-240-1) from the Consumers Energy Palisades Nuclear Plant. The objective of the program is to monitor the effects of neutron irradiation on the mechanical properties of the reactor vessel materials by testing and evaluation of Charpy impact specimens.

Supplemental Capsule SA-240-1 was removed from the Palisades reactor vessel at the end-of-cycle 14 (EOC-14) for testing and evaluation. The test specimens included modified 18mm Charpy V-notch inserts for three weld metals fabricated with weld wire heats W5214, 34B009, and 27204 and standard Charpy V-notch specimens fabricated from the correlation monitor plate material, HSST Plate 02. The weld metal Charpy inserts were reconstituted to full size Charpy V-notch specimens. The reconstituted weld metals along with HSST Plate 02 material were Charpy impact tested. The results of these tests are presented in this document.

Acknowledgement

The author would like to thank Kevin Hour of the BWXT Services, Inc. Lynchburg Technology Center for his efforts and expertise in specimen testing and Hongqing Xu of Framatome ANP, Inc. for his work on the Charpy specimen reconstitution. The efforts by both these individuals contributed greatly to the success of this project.

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1.0 Introduction

Two supplemental surveillance capsules were fabricated containing the three weld metals found in the core region of the Palisades reactor vessel. The supplemental capsules were prepared to obtain information on the effects of irradiation on the mechanical properties of weld metals fabricated using the same weld wire heats and weld procedures as was used in the Palisades reactor vessel beltline region. These supplemental Capsules, SA-60-1 and SA-240-1, were inserted in the Palisades reactor vessel at the end-of-cycle 11 (EOC-11) in locations near the outer wall of the core support barrel for accelerated exposure. At the end-of-cycle 13 (EOC-13), supplemental Capsule SA-60-1 was removed from the Palisades reactor vessel, tested, and evaluated.[1] The supplemental Capsule SA-240-1 was removed from the Palisades reactor vessel for testing at the end-of-cycle 14 (EOC-14).

This report describes the results of the testing performed on the specimens from the Palisades second supplemental surveillance capsule (Capsule SA-240-1).

2.0 Background

The ability of the reactor vessel to resist fracture is a primary factor in ensuring the safety of the primary system in light water-cooled reactors. The reactor vessel beltline region is the most critical region of the vessel because it is exposed to the highest level of neutron irradiation. The general effects of fast neutron irradiation on the mechanical properties of low-alloy ferritic steels used in the fabrication of reactor vessels are well characterized and documented. The low-alloy ferritic steels used in the beltline region of reactor vessels exhibit an increase in ultimate and yield strength properties with a corresponding decrease in ductility after irradiation. The most significant mechanical property change in reactor vessel steels is the increase in the ductile-to-brittle transition temperature accompanied by a reduction in the Charpy upper-shelf energy (C_VUSE) value.

Code of Federal Regulations, Title 10, Part 50, (10 CFR 50) Appendix G,[2] "Fracture Toughness Requirements," specifies minimum fracture toughness requirements for the ferritic materials of the pressure-retaining components of the reactor coolant pressure boundary (RCPB) of light water-cooled power reactors and provides specific guidelines for determining the pressure-temperature limitations for operation of the RCPB. The fracture toughness and operational requirements are specified to provide adequate safety margins during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service lifetime. Although the requirements of 10 CFR 50, Appendix G, became effective on August 16, 1973, the requirements are applicable to all boiling and pressurized water-cooled nuclear power reactors, including those under construction or in operation on the effective date.

10 CFR 50, Appendix H,[3] "Reactor Vessel Materials Surveillance Program Requirements," defines the material surveillance program required to monitor changes in the fracture toughness properties of ferritic materials in the reactor vessel beltline region of water-cooled reactors resulting from exposure to neutron irradiation and the thermal environment. Fracture toughness test data are obtained from material specimens contained in capsules that are periodically withdrawn from the reactor vessel. These data permit determination of the conditions under which the vessel can be operated with adequate safety margins against non-ductile fracture throughout its service life.

A method for guarding against non-ductile fracture in reactor vessels is described in Appendix G to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III,[4] "Nuclear Power Plant Components" and Section XI,[5] "Rules for Inservice Inspection." This method uses fracture mechanics concepts and the reference nil-ductility temperature, RT_{NDT}, which is defined as the greater of the drop-weight nil-ductility transition temperature (in accordance with ASTM Standard E 208-81[6]) or the temperature that is 60°F below that at which the material exhibits 50 ft-lbs and 35 mils lateral expansion. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{IR} curve), which appears in Appendix G of ASME B&PV Code Section III and Section XI. The K_{IR} curve is a lower bound of dynamic and crack arrest fracture toughness data obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{IR} curve, allowable stress intensity factors can be obtained for the material as a function of temperature. The operating limits can then be determined using these allowable stress intensity factors.

The RT_{NDT} and, in turn, the operating limits of a nuclear power plant, are adjusted to account for the effects of irradiation on the fracture toughness of the reactor vessel materials. The irradiation embrittlement and the resultant changes in mechanical properties of a given pressure vessel steel can be monitored by a surveillance program in which surveillance capsules containing prepared specimens of the reactor vessel materials are periodically removed from the operating nuclear reactor and the specimens are tested. The increase in the Charpy V-notch 30 ft-lb temperature is added to the original RT_{NDT} to adjust it for irradiation embrittlement. The adjusted RT_{NDT} is used to index the material to the K_{IR} curve which, in turn, is used to set operating limits for the nuclear power plant. These new limits take into account the effects of irradiation on the reactor vessel materials.

10 CFR 50, Appendix G, also requires a minimum initial Charpy V-notch upper-shelf energy (C_VUSE) of 75 ft-lbs for all beltline region materials unless it is demonstrated that lower values of upper-shelf fracture energy will provide an adequate margin of safety against fracture equivalent to those required by ASME Section XI, Appendix G. No action is required for a material that does not meet the initial 75 ft-lbs requirement provided that the irradiation embrittlement does not cause the C_vUSE to drop below 50 ft-lbs. The regulations specify that if the C_vUSE drops below 50 ft-lbs, it must be demonstrated, in a manner approved by the Office of Nuclear Reactor Regulation, that the lower values will provide adequate margins of safety.

3.0 Surveillance Program Description

The original reactor vessel surveillance program (RVSP) for the Palisades Nuclear Plant was designed and furnished by Combustion Engineering, Inc.[7] The program was designed to the requirements of ASTM Standard E 185-66,[8] "Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors." The Palisades RVSP includes ten capsules designed to monitor the effects of neutron and thermal environments on the materials of the reactor pressure vessel core region. These capsules were inserted into the reactor vessel before initial plant startup. Six capsules were positioned such that they were located near the inside surface of the reactor vessel wall adjacent to the core, and two capsules were positioned closer to the core located on the outer wall of the core support barrel for accelerated exposure. Two capsules, designed for monitoring the effects of operating temperature on the surveillance materials, were located above the core such that the exposure was in a low flux region of the reactor vessel. The locations of the Palisades surveillance capsules within the reactor vessel are shown in Figure 3-1.

In addition to the above ten surveillance capsules, two supplemental surveillance capsules were fabricated containing three weld metals representative of those found in the core region of the Palisades reactor vessel. These capsules were installed at the end-of-cycle 11 (EOC-11) in locations near the outer wall of the core support barrel for accelerated exposure. The locations of the two supplemental surveillance capsules within the Palisades reactor vessel are shown in Figure 3-2.

Supplemental surveillance Capsule SA-240-1 was removed from the Palisades reactor vessel at the end-of-cycle 14 (EOC-14). The capsule contained standard Charpy V-notch impact test specimens fabricated from a submerged-arc weld metal (weld wire heat number 27204) and a correlation monitor plate material (HSST Plate 02). In addition, the Capsule SA-240-1 contained modified 18mm Type A Charpy V-notch specimens fabricated from three submerged-arc weld metals (weld wire heat numbers W5214, 34B009, and 27204); the 18mm Type A Charpy V-notch specimens are available for reconstitution such that full size Charpy V-notch impact specimens can be fabricated. The tension test specimens included in Capsule SA-240-1 were fabricated from a submerged-arc weld metal (weld wire heat number 27204). The number of specimens of each material contained in supplemental surveillance Capsule SA-240-1 is described in Table 3-1, and the locations of the individual specimens within the capsule are shown in Figures 3-3 through 3-7. The chemical composition and heat treatment of the surveillance materials in Capsule SA-240-1 are described in Tables 3-2 and 3-3 respectively.

The weld metal Charpy V-notch and tensile specimens were oriented with the longitudinal axis of the specimen either parallel or perpendicular to the welding direction.

There are three sets of nine dosimeter monitors in Capsule SA-240-1; one set each located in the top, middle, and bottom of the capsule. The dosimeter monitors included in each set consist of shielded copper, shielded nickel, unshielded iron, unshielded titanium, shielded and unshielded aluminum-cobalt, shielded and unshielded neptunium-237 (^{237}Np), and shielded and unshielded uranium-238 (^{238}U).

Thermal monitors fabricated from four low-melting alloys were included in Capsule SA-240-1, and were located in the middle of the capsule. The eutectic alloys and their melting points are listed below:

80% Au, 20% Sn	Melting Point 536°F
5% Ag, 5% Sn, 90% Pb	Melting Point 558°F
2.5% Ag, 97.5% Pb	Melting Point 580°F
1.75% Ag, 0.75% Sn, 97.5% Pb	Melting Point 590°F

Table 3-1. Test Specimens Contained in Palisades Capsule SA-240-1

Material Description	Number of Test Specimens		
	Tension	Standard Charpy V-Notch Impact	18mm Charpy V-Notch Inserts
Weld Metal W5214	---	---	42
Weld Metal 34B009	---	---	36
Weld Metal 27204	3	12	36
Correlation Monitor Material, HSST Plate 02 (Heat No. A1195-1)	---	12	---

Table 3-2. Chemical Composition of Palisades Capsule SA-240-1 Surveillance Materials

Element	Chemical Composition, wt%			
	Weld Metal W5214[a]	Weld Metal 34B009[a]	Weld Metal 27204[b]	Correlation Monitor Plate Heat No. A1195-1[c]
C	0.094	0.110	0.142	0.23
Mn	1.161	1.269	1.281	1.39
P	0.009	0.012	0.009	0.013
S	0.012	0.016	0.008	0.013
Si	0.252	0.181	0.217	0.21
Ni	1.045[b]	1.121[b]	1.067	0.64
Cr	0.040	0.040	0.071	---
Mo	0.510	0.543	0.525	0.50
Cu	0.307[b]	0.185[b]	0.194	0.17

(a) AEA Technology analysis.[9]
(b) Analysis provided by Consumers Energy.[10]
(c) ORNL analysis.[11]

Table 3-3. Heat Treatment of Palisades Capsule SA-240-1 Surveillance Materials

Material Description	Heat Treatment
Weld Metal W5214	Post weld heat treatment: >1100°F for 25 hrs, cooled at 8°F/hr for 24 hrs.[a] Re-post weld heat treatment: 1150°F for 2 hrs, with 100°F/hr heating/cooling rates (above 500°F)[b]
Weld Metal 34B009	Post weld heat treatment: >1100°F for 16 hrs, cooled at 7°F/hr for 27 hrs.[a] Re-post weld heat treatment: 1150°F for 2 hrs, with 100°F/hr heating/cooling rates (above 500°F)[b]
Weld Metal 27204	Post weld heat treatment: >1100°F for 40 hrs.[c]
Correlation Monitor Plate, HSST Plate 02 (Heat No. A1195-1)	1675 ± 25°F for 4 hrs., air cooled 1600 ± 25°F for 4 hrs., water quenched to 300°F 1225 ± 25°F for 4 hrs., furnace cooled to 500°F 1150 ± 25°F for 40 hrs., furnace cooled to 600°F

(a) Original post weld heat treatment.[12]

(b) Post weld heat treatment performed on retired steam generator material to ensure that the material would be representative of the reactor vessel beltline materials.[9]

(c) Post weld heat treatment provided by Consumers Energy.[10]

Figure 3-1. Reactor Vessel Cross Section Showing Location of Palisades Original RVSP Capsules

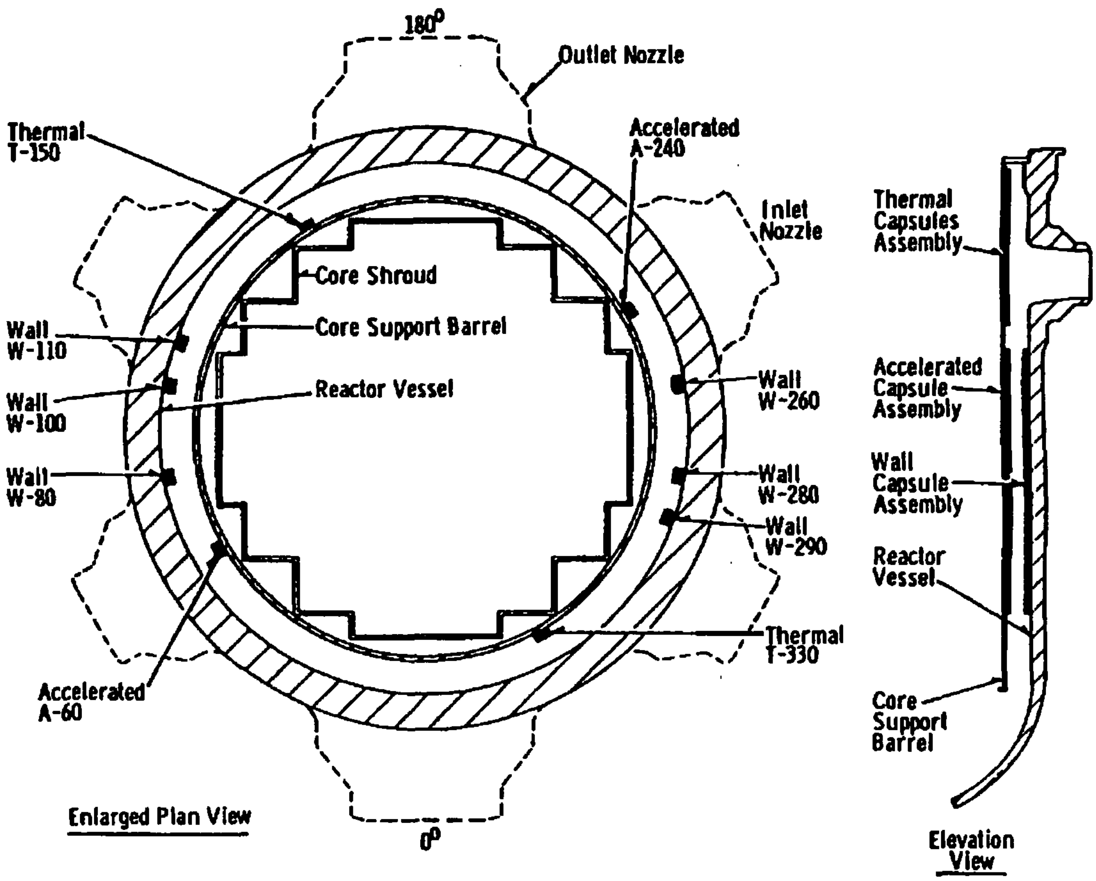


Figure 3-2. Reactor Vessel Cross Section Showing Location of Palisades Supplemental Surveillance Capsules

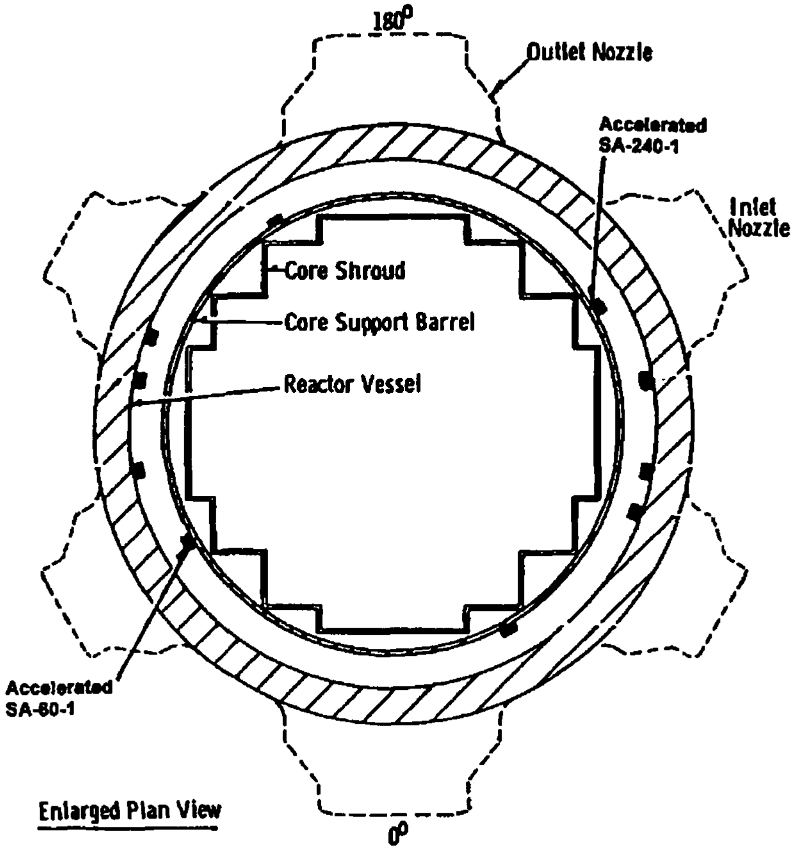
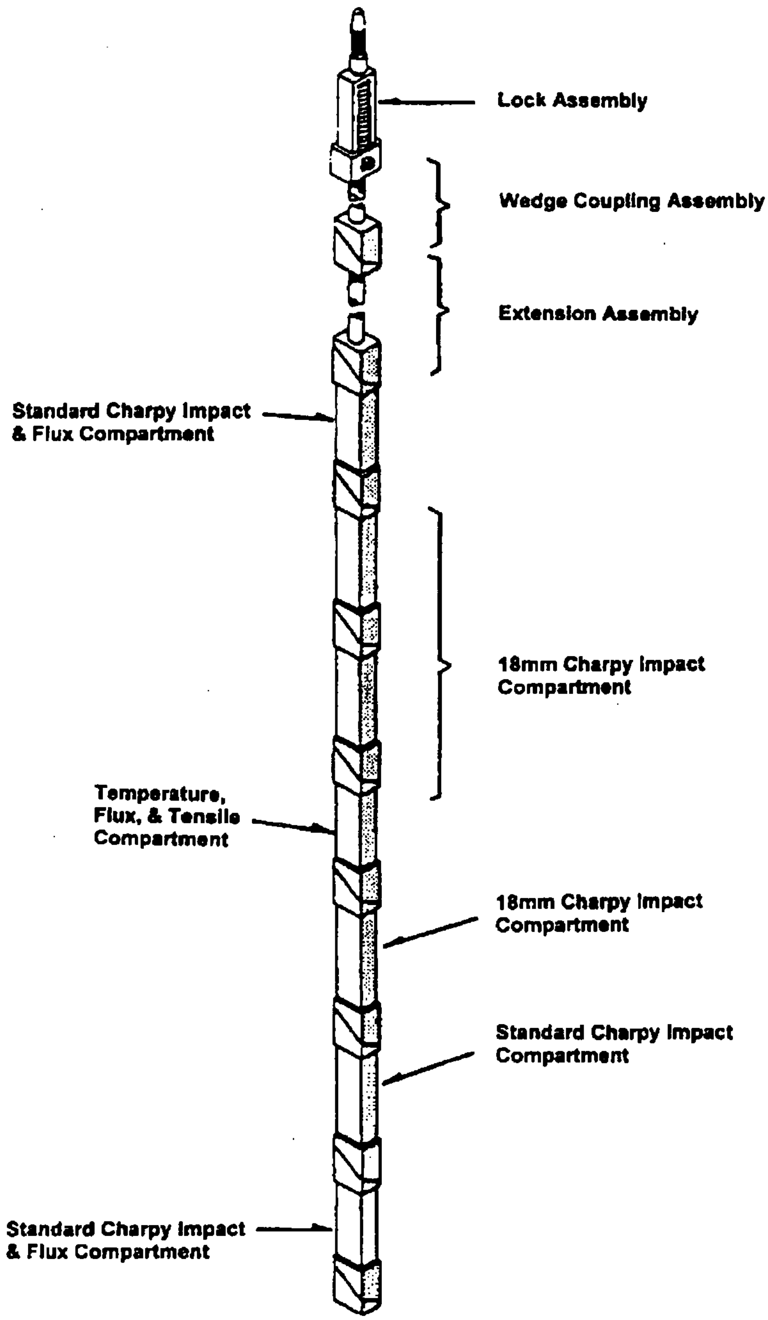
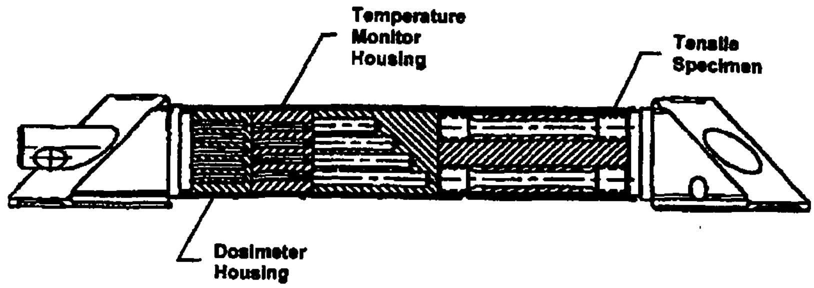


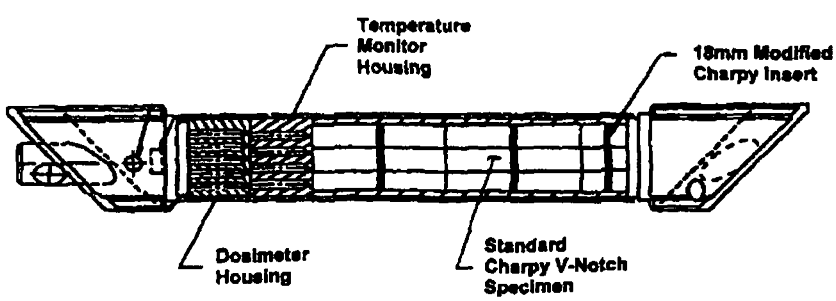
Figure 3-3. Supplemental Surveillance Capsule Assembly Showing Location of Specimens and Monitors



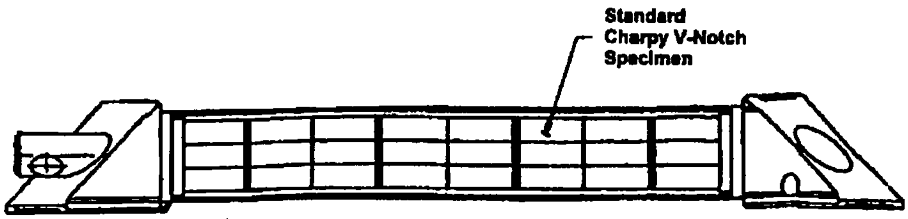
3-4. Temperature, Flux, and Tensile (TFT) Capsule Compartment Assembly



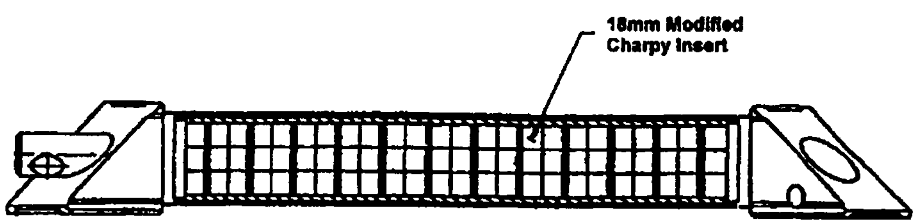
3-5. Standard Charpy Impact and Flux Capsule Compartment Assembly (Two Per Capsule)



3-6. Standard Charpy Impact Capsule Compartment Assembly



3-7. Typical 18mm Charpy Impact Capsule Compartment Assembly
(Three Per Capsule)



4.0 Post-Irradiation Testing

The post-irradiation testing of the Charpy V-notch impact specimens, thermal monitors, and dosimeters for the Palisades Capsule SA-240-1 was performed at the BWXT Services Inc. (BWXT) Lynchburg Technology Center (LTC).[13] All equipment and instruments used in conducting the post-irradiation testing and measurements are calibrated annually using standards traceable to the National Institute for Standards and Technology (NIST).

4.1. Visual Examination and Inventory

After capsule disassembly, the contents of Capsule SA-240-1 were removed, inspected, and inventoried. The capsule contained a total of 24 standard Charpy V-notch specimens, 114 modified 18mm Charpy inserts, three tension test specimens, three dosimetry blocks, and four temperature monitors, which is consistent with the manufacturing report inventory.

4.2. Thermal Monitors

The four low-melting point eutectic alloys contained in Capsule SA-240-1 were examined for evidence of melting. The results of the thermal monitor examination are tabulated in Table 4-1. Photographs of the monitors are shown in Figure 4-1.

Only the 536°F thermal monitor exhibited complete melting. The remaining thermal monitors with melting points at 558°F, 580°F and 590°F had no evidence of melting. Based on these observations, it can be concluded that the capsule did not exceed a maximum irradiation temperature of 558°F.

4.3. Tension Test Specimens

The tension test specimens removed from Capsule SA-240-1 were not tested as part of this capsule work effort at the request of Consumers Energy Company. However, these specimens were inadvertently tested under a separate work effort sponsored by the Electric Power Research Institute (EPRI) Reactor Vessel Issue Task Group (RV-ITG) and are no longer available for future testing.

4.4. Reconstitution of Irradiated Charpy Inserts

Pre-machined 18mm Charpy inserts fabricated from three submerged-arc weld metals (weld wire heat numbers W5214, 34B009, and 27204) were included in Capsule SA-240-1 for reconstitution of full size Type A Charpy V-notch impact specimens. Each 18mm weld metal Charpy insert included a centrally located V-notch that was machined prior to capsule irradiation. Reconstitution was performed by stud welding steel end tabs onto the irradiated modified 18mm Charpy inserts and machining full size Type A Charpy V-notch impact specimens to the dimensional requirements of ASTM Standard E 23-91.[14] The proof-of-principal and validation test results for the Framatome ANP Charpy reconstitution process is documented in BAW-2184.[15] The reconstitution of the irradiated weld metal 18mm modified Charpy inserts was performed in accordance with ASTM Standard E 1253-88,[16] "Standard Guide for Reconstitution of Irradiated Charpy Specimens."

Fifteen (15) modified 18mm Charpy inserts were selected from each of the weld metals W5214 and 34B009, and fourteen (14) modified 18mm Charpy inserts were selected from the weld metal 27204 for reconstitution to full size Charpy V-notch specimens. Prior to the welding of the irradiated 18mm Charpy inserts, the reconstitution process was performed on mockup inserts to assure that the reconstitution welding process would produce quality welds. A steel end tab was stud welded to each end of the mockup insert, and each weldment was visually inspected for good fillet formation resulting from the stud welding process. In addition, two mockup specimens (minimum) were subjected to a 45-degree (minimum) bend test, to determine acceptance of the stud weld. An acceptable weld is one that did not fracture in the weld fusion zone resulting from the stud welding process. Once acceptable stud welds were established, reconstitution of the irradiated capsule 18mm Charpy inserts could begin. Using the same welding parameters used to reconstitute the mockup inserts, a steel end tab was stud welded to each end of the selected weld metal 18mm Charpy inserts irradiated in Capsule SA-240-1.

The ASTM Standard E 1253-88 specifies that temperature records be made during the welding on the first and last specimens of each set of Charpy specimens or on dummy specimens proceeding and following welding of the set. The welding temperature verification is performed using identical welding parameters as those in the actual reconstitution process except the mockup insert was not clamped by the movable jaw due to the obstruction by the thermocouple. Since the movable jaw acts as a heat sink during the welding process, the measured temperatures are expected to be higher than the irradiated inserts. A certified thermocouple was connected to the midsection of the mockup insert and connected to a certified measuring temperature device. Temperature measurements are recorded after stud welding a steel end tab to each end of the mockup insert. A total of four welding temperature verifications were performed, one preceding and following the reconstitution stud welding of each weld series. The recorded temperatures at the center position of the temperature verification mockup insert ranged from 347°F to 511°F, which is less than the Palisades reactor vessel cold-leg temperature and meets the temperature requirement of ASTM Standard E 1253-88.

Twelve (12) stud-welded inserts were then selected from each of the weld metals W5214, 34B009, and 27204 for machining of full size Type A Charpy V-notch specimens in accordance with ASTM Standard E 23-91. The reconstituted Charpy specimen dimensions for each specimen are shown in Table 4-2.

4.5. Charpy V-Notch Impact Test Results

The Charpy V-notch impact testing was performed in accordance with the applicable requirements of ASTM Standard E 23-91. Prior to testing, the specimens were temperature-controlled in liquid immersion baths, capable of covering the temperature range -100°F to +550°F. Specimens remain immersed in the liquid medium at the test temperature ±2°F for at least 10 minutes before testing to assure achievement of thermal equilibrium. A certified Omega Model 462 device was used to measure the temperature. Impact energy, lateral expansion, and percent shear fracture were measured at numerous test temperatures and recorded for each specimen. The impact energy was measured using a certified Satec S1-1K Impact tester (traceable to NIST Standard[a]) with a striker velocity of 16.90 ft/sec and 240 ft-lb of available energy. The lateral expansion was measured using a certified dial indicator. The specimen percent shear was estimated by video examination and comparison with the visual standards presented in ASTM Standard E 23-91. In addition, all Charpy V-notch impact testing was performed using instrumentation to record a load-versus-time trace and energy-versus-time trace for each impact event. The load-versus-time traces were analyzed to determine time, load, and impact energy for general yielding, maximum load, fast fracture, and crack arrest properties during the test. The dynamic yield stress is calculated from the three-point bend formula:

$$\sigma_y = 33.33 * (\textit{general yielding load})$$

The dynamic flow stress is calculated from the average of the yield and maximum loads, also using the three-point bend formula:

[a] Each year, two sets of Charpy specimens are purchased from NIST and tested on the Charpy test machine. The results are then sent to NIST for evaluation. A letter is then issued by NIST certifying the calibration of the Charpy test machine. The accuracy of the Charpy tester is ±1 ft-lb or 5% of the dial reading whichever is greater.

$$\sigma_{flow} = 33.33 * \left(\frac{(\textit{general yielding load} + \textit{maximum load})}{2} \right)$$

The results of the Charpy V-notch impact testing are shown in Tables 4-3 through 4-10 and Figures 4-2 through 4-5, and the individual load-versus-time traces for the instrumented Charpy V-notch impact tests are presented in Appendix B. The curves were generated using a hyperbolic tangent curve-fitting program to produce the best-fit curve through the data. The hyperbolic tangent (TANH) function (test response, i.e., absorbed energy, lateral expansion, and percent shear fracture, "R," as a function of test temperature, "T") used to evaluate the surveillance data is as follows:

$$R = A + B * \tanh\left[\frac{(T - To)}{C}\right]$$

For the absorbed (impact) energy curves, the lower-shelf energy was fixed at 2.2 ft-lbs for all materials, and the upper-shelf energy was fixed at the average of all test energies exhibiting 100 percent shear for each material, consistent with the ASTM Standard E 185-82. The lateral expansion curves were generated with the lower-shelf mils lateral expansion fixed at 1 mil and the upper-shelf mils lateral expansion not constrained (i.e., not fixed). The percent shear fracture curves for each material were generated with the lower-shelves and upper-shelves fixed at 0 and 100 respectively.

The Charpy V-notch data was entered, and the coefficients *A, B, To,* and *C* are determined by the program minimizing the sum of the errors squared (least-squares fit) of the data points about the fitted curve. Using these coefficients and the above TANH function, a smooth curve is generated through the data for interpretation of the material transition region behavior. The coefficients determined for irradiated materials in Capsule SA-240-1 are shown in Table 4-11.

The transition temperature shifts and upper-shelf energy decreases for the Capsule SA-240-1 materials with respect to the unirradiated material properties are summarized in Table 4-12.

Photographs of the Charpy V-notch specimen fracture surfaces are presented in Figures 4-6 through 4-9.

Table 4-1. Conditions of Palisades Capsule SA-240-1 Thermal Monitors

Capsule Segment	Melt Temperature	Post-Irradiation Condition
Middle	536°F	Melted
Middle	558°F	Unmelted
Middle	580°F	Unmelted
Middle	590°F	Unmelted

Table 4-2. Dimensions of Reconstituted Charpy Specimens for Palisades Capsule SA-240-1

Weld Metal	Specimen ID	Width 0.394 ±0.003"	Thickness 0.394 ±0.003"	Length 2.165 +0, -0.100"	Comments
W5214	2AE5	0.394	0.394	2.163	Acceptable
	2AK5	0.394	0.394	2.163	Acceptable
	2AJ1	0.395	0.392	2.162	Acceptable
	AU5	0.395	0.392	2.162	Acceptable
	AW5	0.393	0.392	2.163	Acceptable
	2AL1	0.393	0.394	2.163	Acceptable
	AS2	0.394	0.393	2.163	Acceptable
	AU4	0.393	0.392	2.163	Acceptable
	AP5	0.393	0.393	2.163	Acceptable
	AP1	0.394	0.393	2.164	Acceptable
	2AL3	0.393	0.392	2.163	Acceptable
	2AH3	0.393	0.393	2.163	Acceptable
34B009	BV1	0.394	0.392	2.163	Acceptable
	2BI4	0.393	0.392	2.163	Acceptable
	2BF1	0.393	0.393	2.163	Acceptable
	BT1	0.393	0.394	2.162	Acceptable
	2BG5	0.393	0.394	2.163	Acceptable
	2BI1	0.391	0.393	2.163	Acceptable
	BL5	0.392	0.393	2.163	Acceptable
	2BJ1	0.392	0.394	2.164	Acceptable
	2BG4	0.393	0.393	2.163	Acceptable
	2BJ2	0.394	0.392	2.163	Acceptable
	2BD1	0.392	0.394	2.162	Acceptable
	2BG2	0.395	0.394	2.162	Acceptable
27204	PB58	0.395	0.395	2.163	Acceptable
	PB07	0.394	0.393	2.162	Acceptable
	PB45	0.393	0.393	2.162	Acceptable
	PB71	0.393	0.393	2.163	Acceptable
	PB35	0.393	0.393	2.163	Acceptable
	PB06	0.393	0.392	2.163	Acceptable
	PB54	0.392	0.392	2.162	Acceptable
	PB62	0.393	0.392	2.162	Acceptable
	PB52	0.393	0.394	2.163	Acceptable
	PB61	0.392	0.393	2.162	Acceptable
	PB57	0.392	0.394	2.162	Acceptable
	PB73	0.392	0.394	2.162	Acceptable

Table 4-3. Charpy Impact Results for Palisades Capsule SA-240-1 Irradiated Weld Metal W5214

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
2AL1	70	14	9	0
2AH3	125	15.5	6	20
AW5	175	24.5	15	10
2AJ1	200	13	10	40
AU4	200	26.5	15	35
2AL3	225	25	11	50
AP1	250	40	26	65
AU5	300	54.5	47	95
2AE5	350	49	42	95
2AK5	400	50.5*	35	100
AP5	450	52.5*	45	100
AS2	500	54.5*	43	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[17]

Table 4-4. Charpy Impact Results for Palisades Capsule SA-240-1 Irradiated Weld Metal 34B009

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
BT1	70	6.5	4	0
2BJ1	125	20.5	11	30
BL5	150	23.5	11	45
2BG5	175	32	23	35
2BF1	200	33	30	50
2BG4	225	37.5	31	55
2BJ2	250	47.5	35	75
2BI4	300	53	40	95
2BI1	350	54*	47	100
BV1	400	59.5*	49	100
2BD1	450	61.5*	43	100
2BG2	500	54.5*	42	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[17]

Table 4-5. Charpy Impact Results for Palisades Capsule SA-240-1 Irradiated Weld Metal 27204

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
PB45	70	5.5	3	0
PB62	125	16.5	12	10
PB71	175	16	18	30
PB54	200	26.5	29	55
PB07	200	33.5	27	60
PB73	225	29	24	65
PB52	250	34.5	26	55
PB35	300	36	32	65
PB06	350	44.5	43	95
PB58	400	49.5*	42	100
PB57	450	59*	52	100
PB61	500	53*	47	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[17]

Table 4-6. Charpy Impact Results for Palisades Capsule SA-240-1 Irradiated Correlation Monitor Plate Material (HSST Plate 02) Heat No. A1195-1

Specimen ID	Test Temperature, °F	Impact Energy, ft-lbs	Lateral Expansion, mil	Shear Fracture, %
O2D2-10	70	6.5	4	0
O2D2-13	125	15.5	10	20
O2D2-23	175	27.5	24	30
O2D2-17	200	26	19	35
O2D2-2	200	44.5	29	55
OCD2-22	225	44.5	30	55
O2D2-19	240	54	40	70
O2D2-8	250	70	50	80
O2D2-5	300	83*	66	100
O2D2-15	350	82.5*	72	100
O2D2-24	400	89.5*	67	100
O2D2-11	500	82.5*	65	100

* Value used to determine upper-shelf energy (USE) in accordance with ASTM Standard E 185-82.[17]

Table 4-7. Instrumented Charpy Impact Properties for Palisades Capsule SA-240-1 Irradiated Weld Metal W5214

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties			Maximum Load Properties			Fast Fracture Properties			Crack Arrest Properties			Propagation Load Properties		Total Load Properties		Yield Stress (ksi)	Flow Stress (ksi)
			Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Energy (ft-lbf)		
2AL1	70	14	168	4122	6.28	234	4444	11.00	234	4444	11.00	284	0	13.11	4444	2.11	284	13.11	137.4	142.8
2AH3	125	15.5	165	3887	4.87	260	4333	11.33	260	4333	11.33	344	0	15.10	4345	3.77	344	15.10	129.6	137.0
AW5	175	24.5	162	3680	5.33	344	4294	17.72	391	4276	21.13	456	0	23.71	4290	5.99	456	23.71	122.7	132.9
2AJ1	200	13	166	3733	5.60	166	3733	5.60	166	3733	5.60	294	1019	9.96	2714	6.74	956	12.34	124.4	124.4
AU4	200	26.5	165	3682	5.01	355	4273	17.79	405	4225	21.38	526	941	24.62	3284	8.39	769	26.18	122.7	132.6
2AL3	225	25	173	3692	4.58	270	4129	10.82	327	4110	14.74	440	1638	19.77	2473	13.49	1253	24.31	123.1	130.3
AP1	250	40	170	3593	4.74	442	4276	23.10	442	4276	23.10	548	2569	28.58	1707	17.27	1648	40.36	119.8	131.1
AU5	300	54.5	172	3505	5.69	438	4181	23.33	N/A	N/A	N/A	N/A	N/A	N/A	0	33.81	1922	57.15	116.8	128.1
2AE5	350	49	164	3519	4.73	442	4110	22.97	N/A	N/A	N/A	N/A	N/A	N/A	0	27.17	1844	50.14	117.3	127.1
2AK5	400	50.5	174	3436	5.62	438	4046	22.77	N/A	N/A	N/A	N/A	N/A	N/A	0	29.75	1806	52.52	114.5	124.7
AP5	450	52.5	162	3335	4.56	438	3894	21.58	N/A	N/A	N/A	N/A	N/A	N/A	0	32.43	1878	54.01	111.2	120.5
AS2	500	54.5	160	3271	4.50	436	3940	21.38	N/A	N/A	N/A	N/A	N/A	N/A	0	34.99	1832	56.37	109.0	120.2

Table 4-8. Instrumented Charpy Impact Properties for Palisades Capsule SA-240-1 Irradiated Weld Metal 34B009

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties			Maximum Load Properties			Fast Fracture Properties			Crack Arrest Properties			Propagation Load Properties		Total Load Properties		Yield Stress (ksi)	Flow Stress (ksi)
			Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Energy (ft-lbf)		
BT1	70	6.5	138	3873	4.48	138	3873	4.48	138	3873	4.48	188	0	6.30	3889	1.82	188	6.30	129.1	129.1
2BJ1	125	20.5	167	3809	5.01	324	4303	15.82	324	4303	15.82	394	0	18.33	4310	3.46	624	19.27	127.0	135.2
BL5	150	23.5	162	3797	5.10	342	4453	17.60	350	4439	18.20	464	678	21.54	3761	5.07	730	22.67	126.6	137.5
2BG5	175	32	159	3648	5.11	434	4382	24.11	471	4296	26.84	603	775	30.47	3521	7.32	746	31.43	121.6	133.8
2BF1	200	33	162	3646	5.04	432	4303	23.57	432	4303	23.57	558	1755	29.17	2548	9.78	1244	33.35	121.5	132.5
2BG4	225	37.5	169	3623	4.96	443	4352	23.69	506	4200	28.25	623	1723	32.72	2477	13.85	1617	37.54	120.8	132.9
2BJ2	250	47.5	164	3560	4.80	440	4172	23.15	522	4037	28.81	618	2730	34.11	1306	26.35	1730	49.51	118.7	128.9
2BI4	300	53	168	3448	5.50	434	4115	22.91	N/A	N/A	N/A	N/A	N/A	N/A	0	32.40	1792	55.31	114.9	126.0
2BI1	350	54	164	3342	4.75	442	3997	22.37	N/A	N/A	N/A	N/A	N/A	N/A	0	33.48	1918	55.85	111.4	122.3
BV1	400	59.5	166	3353	5.63	518	4034	28.44	N/A	N/A	N/A	N/A	N/A	N/A	0	31.78	2058	60.21	111.8	123.1
2BD1	450	61.5	158	3312	4.60	436	3986	21.85	N/A	N/A	N/A	N/A	N/A	N/A	0	40.36	2128	62.20	110.4	121.6
2BG2	500	54.5	160	3317	4.48	438	3963	21.68	N/A	N/A	N/A	N/A	N/A	N/A	0	35.66	1922	57.35	110.6	121.3

Table 4-9. Instrumented Charpy Impact Properties for Palisades Capsule SA-240-1 Irradiated Weld Metal 27204

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties			Maximum Load Properties			Fast Fracture Properties			Crack Arrest Properties			Propagation Load Properties		Total Load Properties		Yield Stress (ksi)	Flow Stress (ksi)
			Time (µsec)	Load (lbf)	Energy (ft-lbf)	Time (µsec)	Load (lbf)	Energy (ft-lbf)	Time (µsec)	Load (lbf)	Energy (ft-lbf)	Time (µsec)	Load (lbf)	Energy (ft-lbf)	Load (lbf)	Energy (ft-lbf)	Time (µsec)	Energy (ft-lbf)		
PB45	70	5.5	138	3689	4.00	138	3689	4.00	138	3689	4.00	182	0	5.47	3680	1.48	182	5.47	123.0	123.0
PB62	125	16.5	158	3678	4.89	251	4039	10.87	251	4039	10.87	365	646	13.93	3393	4.77	802	15.65	122.6	128.6
PB71	175	16	161	3634	4.73	220	3657	8.32	220	3657	8.32	335	980	11.17	2677	6.57	1237	14.88	121.1	121.5
PB54	200	26.5	162	3563	5.12	252	3919	10.76	284	3903	12.89	402	2036	12.90	1868	15.38	1486	26.15	118.8	124.7
PB07	200	33.5	172	3512	4.75	336	3977	15.07	336	3977	15.07	436	2627	20.39	1350	19.14	1850	34.21	117.1	124.8
PB73	225	29	164	3473	5.44	238	3797	9.96	238	3797	9.96	331	3004	15.11	794	18.63	1649	28.59	115.8	121.2
PB52	250	34.5	164	3443	4.41	346	3974	15.67	346	3974	15.67	448	2767	21.37	1208	18.75	1572	34.42	114.8	123.6
PB35	300	36	166	3393	4.90	350	3892	16.27	390	3809	18.88	592	1927	28.19	1881	19.78	1724	36.06	113.1	121.4
PB06	350	44.5	168	3275	5.24	334	3761	15.23	N/A	N/A	N/A	N/A	N/A	N/A	0	30.67	1904	45.90	109.2	117.3
PB58	400	49.5	162	3255	4.58	436	3804	21.13	N/A	N/A	N/A	N/A	N/A	N/A	0	30.41	1918	51.54	108.5	117.6
PB57	450	59	164	3165	5.07	428	3790	20.98	N/A	N/A	N/A	N/A	N/A	N/A	0	38.41	2372	59.39	105.5	115.9
PB61	500	53	166	3172	4.04	446	3675	20.11	N/A	N/A	N/A	N/A	N/A	N/A	0	34.24	1936	54.35	105.7	114.1

Table 4-10. Instrumented Charpy Impact Properties for Palisades Capsule SA-240-1 Irradiated Correlation Monitor Plate Material (HSST Plate 02) Heat No. A1195-1

Specimen ID	Test Temp (F)	Charpy Energy (ft-lbf)	Yield Properties			Maximum Load Properties			Fast Fracture Properties			Crack Arrest Properties			Propagation Load Properties		Total Load Properties		Yield Stress (ksi)	Flow Stress (ksi)
			Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Load (lbf)	Energy (ft-lbf)	Load (lbf)	Energy (ft-lbf)	Time (μsec)	Energy (ft-lbf)		
O2D2-10	70	6.5	128	3554	3.92	128	3554	3.92	128	3554	3.92	178	0	5.51	3616	1.59	178	5.51	118.5	118.5
O2D2-13	125	15.5	165	3478	5.10	253	3887	10.53	253	3887	10.53	368	621	13.27	3266	3.54	621	14.07	115.9	122.7
O2D2-23	175	27.5	156	3353	5.05	371	4078	18.83	371	4078	18.83	491	1343	22.73	2735	7.00	1023	25.84	111.8	123.8
O2D2-17	200	26	138	3215	3.78	340	3993	16.23	340	3993	16.23	458	1589	20.55	2404	8.79	992	25.02	107.2	120.1
O2D2-2	200	44.5	166	3372	5.48	532	4469	30.60	596	4432	35.42	708	1723	39.95	2709	14.14	1714	44.74	112.4	130.7
O2D2-22	225	44.5	165	3264	5.16	534	4262	29.49	564	4200	31.65	672	2155	36.47	2045	15.11	2089	44.60	108.8	125.4
O2D2-19	240	54	166	3312	5.21	612	4372	35.63	612	4372	35.63	756	2190	43.34	2183	19.91	2532	55.54	110.4	128.1
O2D2-8	250	70	160	3202	5.04	530	4296	29.24	876	3880	53.66	976	2440	58.69	1440	43.43	2966	72.66	106.7	125.0
O2D2-5	300	83	164	3167	5.05	612	4253	34.50	N/A	N/A	N/A	N/A	N/A	N/A	0	53.65	3040	88.15	105.6	123.7
O2D2-15	350	82.5	160	3080	4.85	532	4154	28.32	N/A	N/A	N/A	N/A	N/A	N/A	0	58.45	3028	86.77	102.7	120.6
O2D2-24	400	89.5	162	3008	4.84	704	4066	39.42	N/A	N/A	N/A	N/A	N/A	N/A	0	54.88	3156	94.30	100.3	117.9
O2D2-11	500	82.5	170	2866	4.61	622	3896	31.79	N/A	N/A	N/A	N/A	N/A	N/A	0	54.02	3130	85.81	95.5	112.7

Table 4-11. Hyperbolic Tangent Curve Fit Coefficients for the Palisades Capsule SA-240-1 Surveillance Materials

Material Description	Hyperbolic Tangent Curve Fit Coefficients		
	Absorbed Energy	Lateral Expansion	Percent Shear Fracture
Weld Metal W5214	A: 27.4 B: 25.2 C: 111.6 T0: 208.1	A: 22.8 B: 21.8 C: 83.5 T0: 231.7	A: 50.0 B: 50.0 C: 72.5 T0: 223.2
Weld Metal 34B009	A: 29.8 B: 27.6 C: 111.7 T0: 176.6	A: 22.9 B: 21.9 C: 88.0 T0: 184.3	A: 50.0 B: 50.0 C: 109.8 T0: 192.6
Weld Metal 27204	A: 28.0 B: 25.8 C: 145.7 T0: 215.3	A: 25.6 B: 24.6 C: 169.2 T0: 225.9	A: 50.0 B: 50.0 C: 118.4 T0: 210.1
Correlation Monitor Plate, HSST Plate 02 (Heat No. A1195-1)	A: 43.3 B: 41.1 C: 75.3 T0: 211.8	A: 35.8 B: 34.8 C: 83.1 T0: 222.2	A: 50.0 B: 50.0 C: 75.9 T0: 206.5

Table 4-12. Summary of Charpy Impact Test Results for the Palisades Capsule SA-240-1 Surveillance Materials

Material Description	30 ft-lb Transition Temperature, °F			50 ft-lb Transition Temperature, °F			35 mil Lateral Expansion Transition Temperature, °F			Upper-Shelf Energy, ft-lb		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	Decrease
Weld Metal W5214	-60.2[(a)]	219.9	280.1	-17.4[(a)]	372.7	390.1	-29.6[(a)]	284.3	313.9	102.7[(a)]	52.5	50.2
Weld Metal 34B009	-82.0[(a)]	177.4	259.4	-45.0[(a)]	280.8	325.8	-51.6[(a)]	238.6	290.2	113.9[(a)]	57.4	56.5
Weld Metal 27204	-41.2[(b)]	226.6	267.8	-6.1[(b)]	399.7	405.8	Not available.	293.7	---	108.4[(b)]	53.8	54.6
HSST Plate 02 Heat No A1195-1	45.7[(c)]	186.6	140.9	78.3[(c)]	224.2	145.9	Not available.	220.3	---	120.3[(c)]	84.4	35.9

(a) Data reported in AEA Technology Report AEA-TSD-0774.[9]

(b) Data reported in CE Report No. TR-MCC-189.[18]

(c) Data reported in NUREG/CR-6413.[11]

Figure 4-1. Photographs of Thermal Monitors Removed from Palisades Capsule SA-240-1

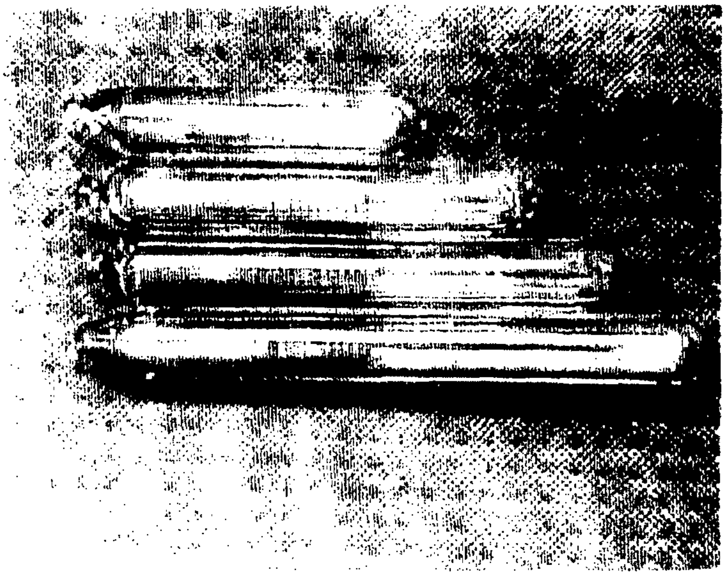


Figure 4-2. Palisades Capsule SA-240-1 Charpy Impact Data for Irradiated Weld Metal W5214

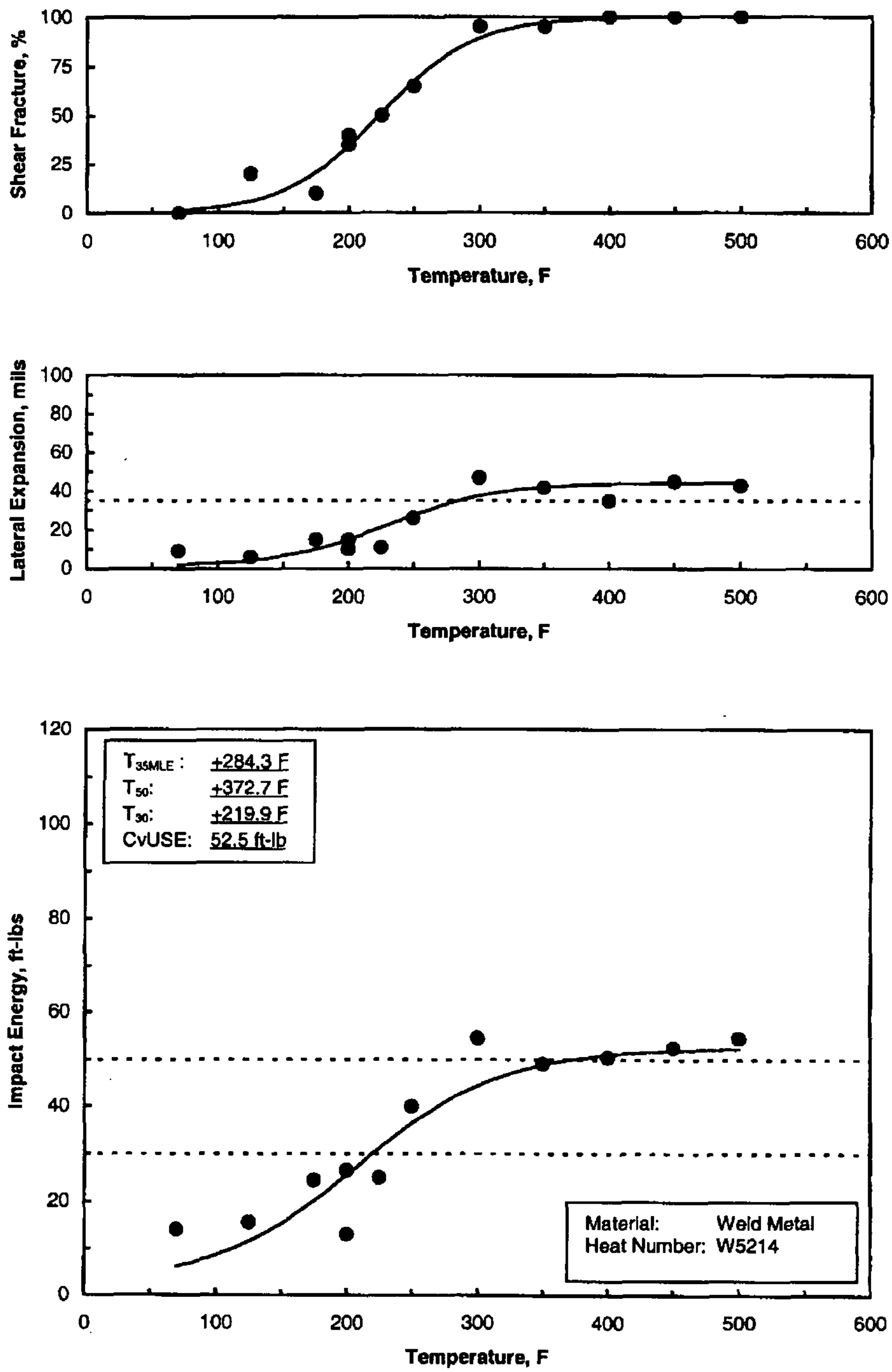


Figure 4-3. Palisades Capsule SA-240-1 Charpy Impact Data for Irradiated Weld Metal 34B009

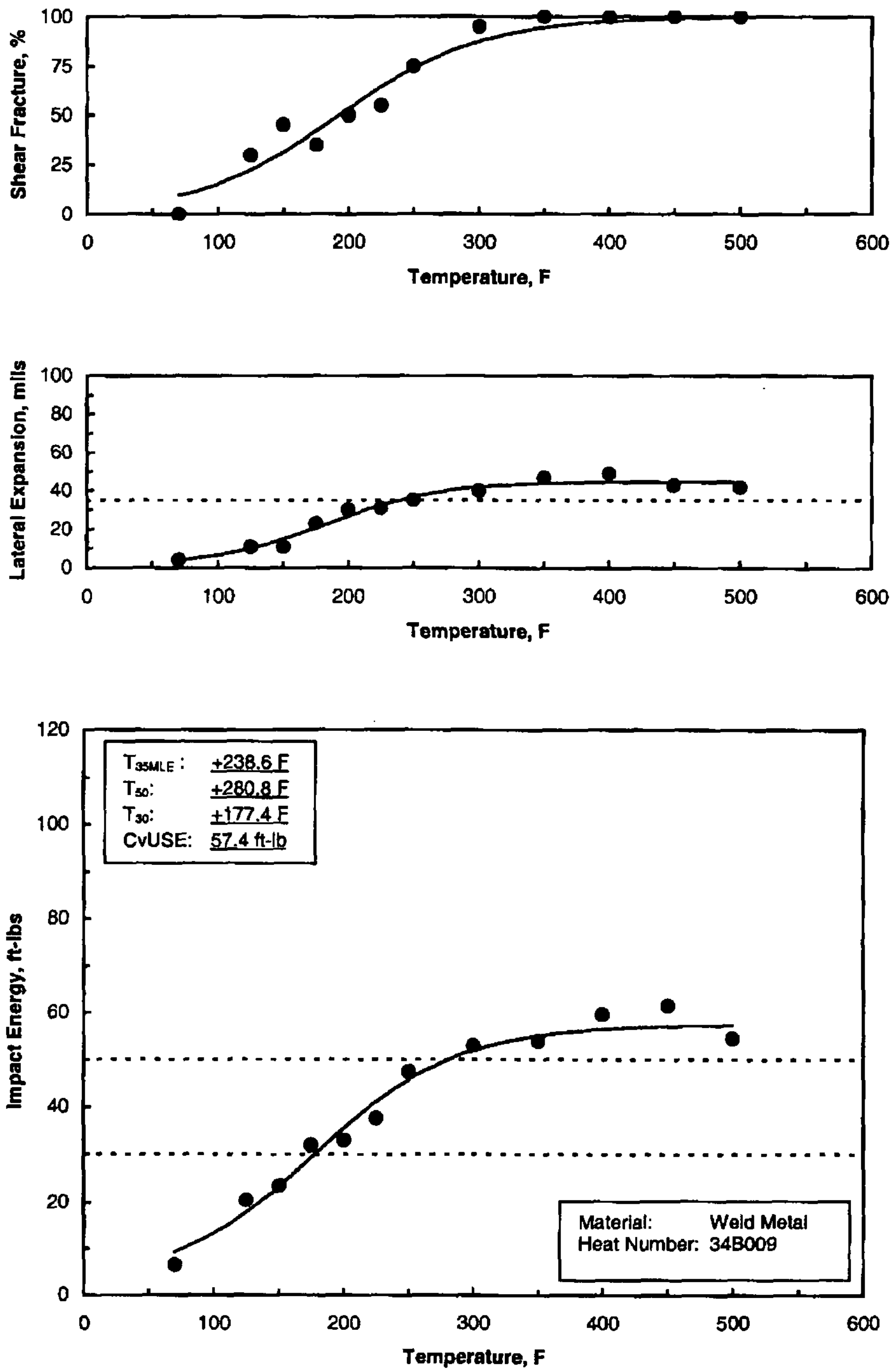


Figure 4-4. Palisades Capsule SA-240-1 Charpy Impact Data for Irradiated Weld Metal 27204

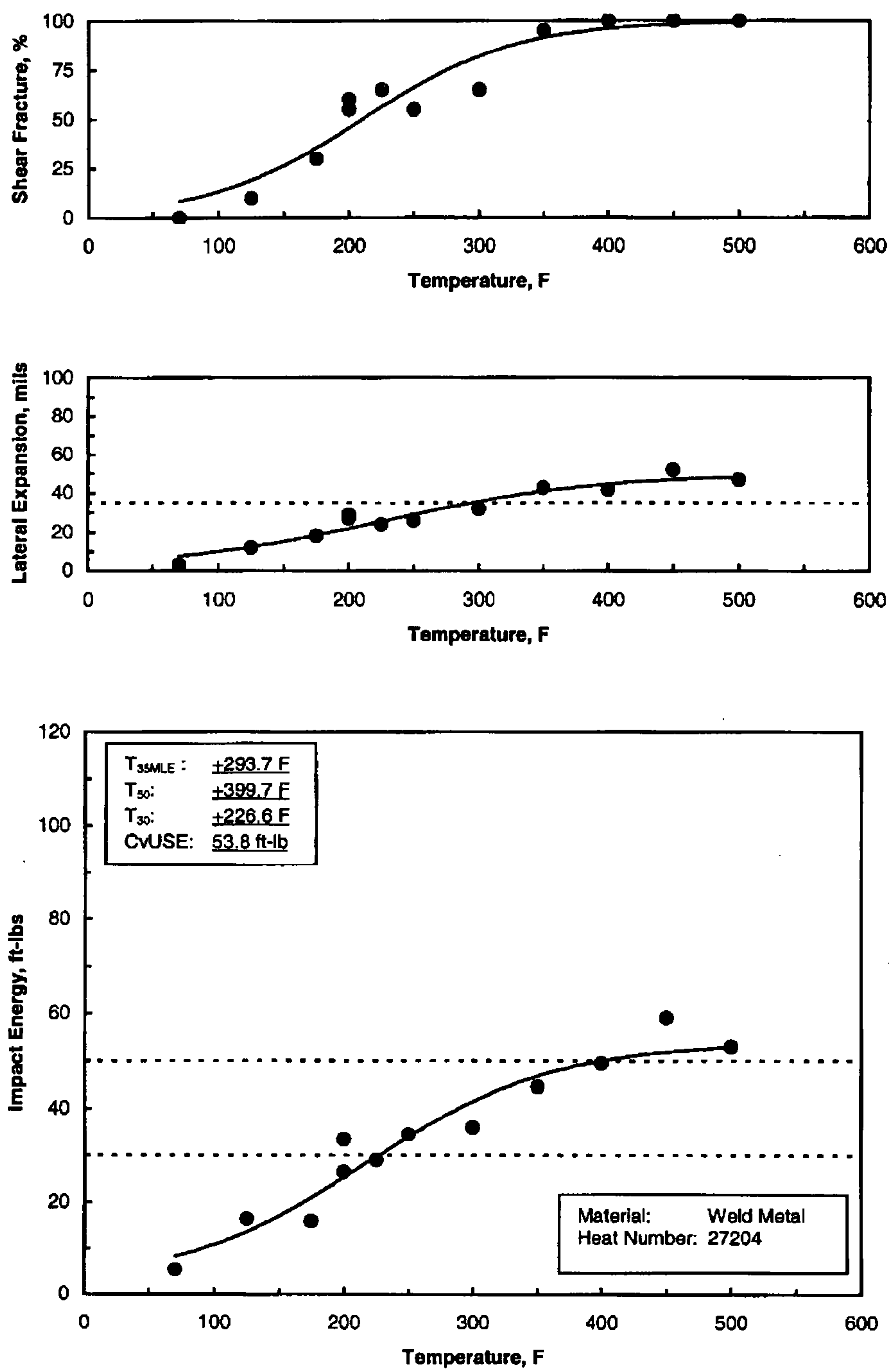


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Figure 4-5. Palisades Capsule SA-240-1 Charpy Impact Data for Irradiated Correlation Monitor Plate Material (HSST Plate 02), Heat No. A1195-1

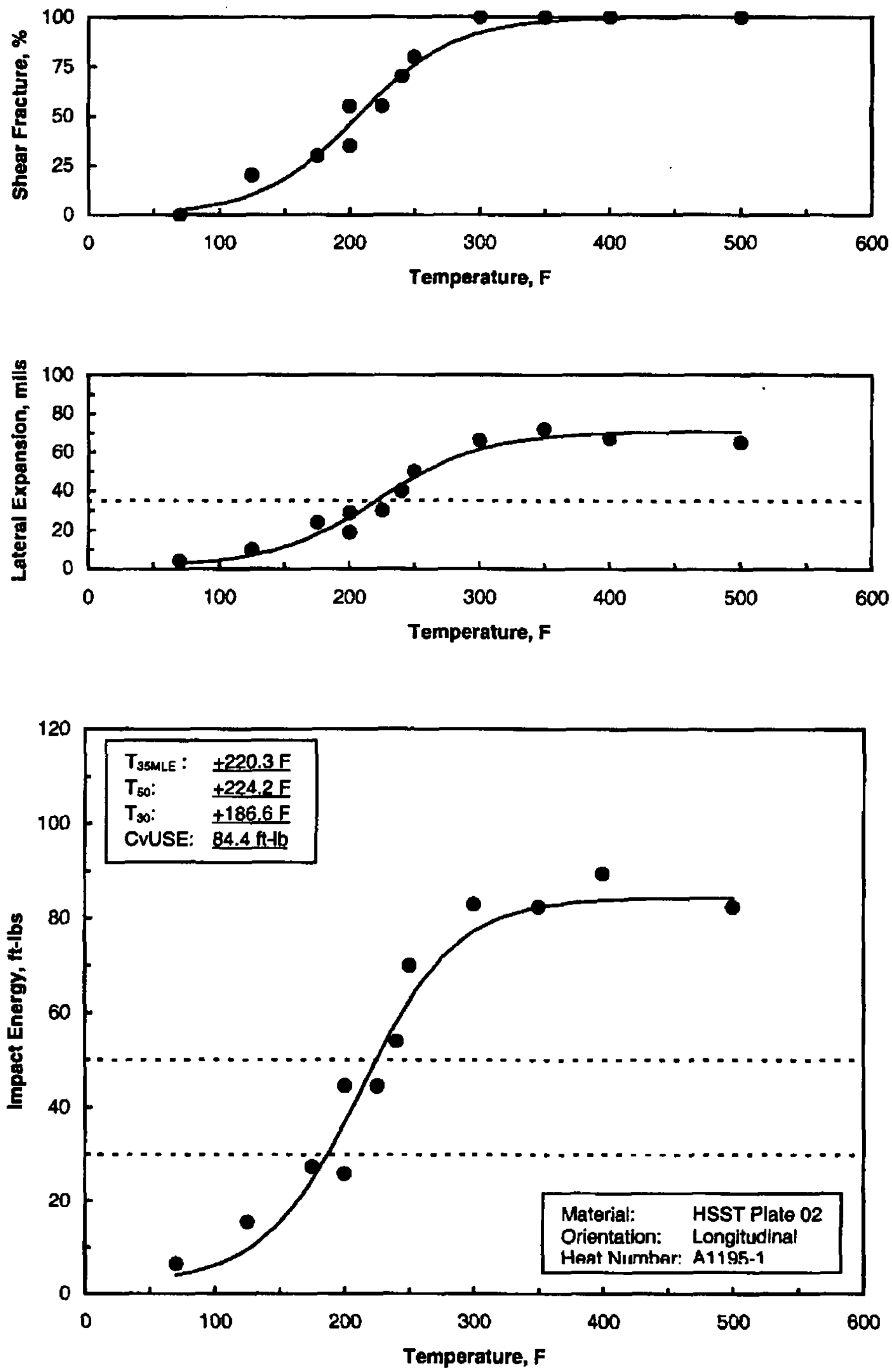

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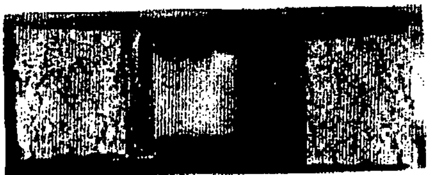
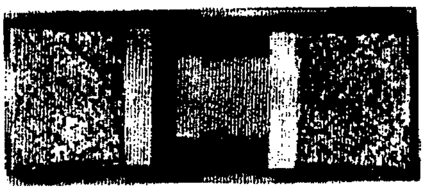
Figure 4-6. Photographs of Charpy Impact Specimen Fracture Surfaces, Weld Metal W5214 from Palisades Capsule SA-240-1

Specimen No. AL1, Test Temperature 70°F

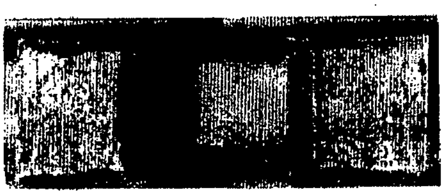


Specimen No. AH3, Test Temperature 125°F

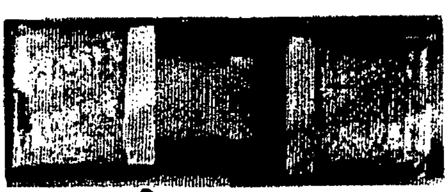


Specimen No. AW5, Test Temperature 175°F

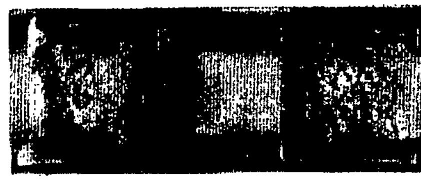
Specimen No. AJ1, Test Temperature 200°F



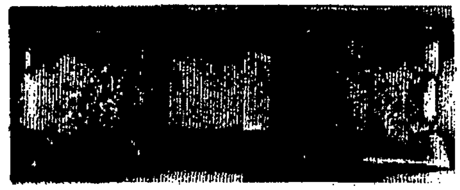
Specimen No. AU4, Test Temperature 200°F



Specimen No. AL3, Test Temperature 225°F



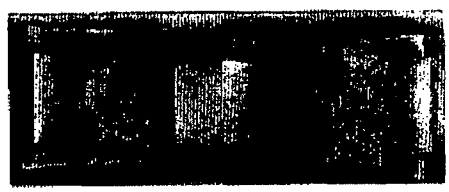
Specimen No. AP1, Test Temperature 250°F



Specimen No. AU5, Test Temperature 300°F

Specimen No. AE5, Test Temperature 350°F

Specimen No. AK5, Test Temperature 400°F



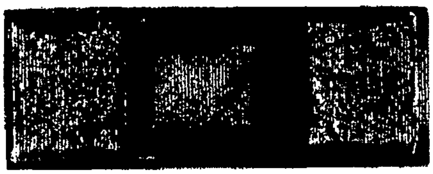
Specimen No. AP5, Test Temperature 450°F

Specimen No. AS2, Test Temperature 500°F

Figure 4-7. Photographs of Charpy Impact Specimen Fracture Surfaces, Weld Metal 34B009 from Palisades Capsule SA-240-1

Specimen No. BT1, Test Temperature 70°F

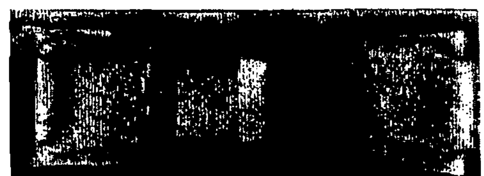
Specimen No. BJ2, Test Temperature 250°F



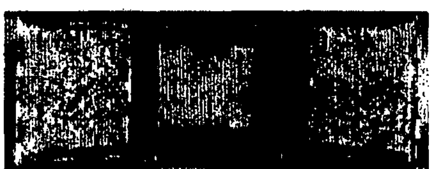
Specimen No. BJ1, Test Temperature 125°F

Specimen No. BJ4, Test Temperature 300°F

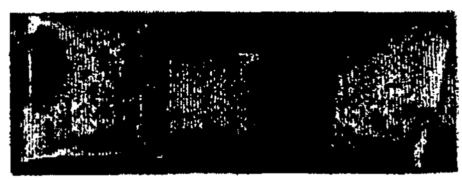
Specimen No. BL5, Test Temperature 150°F



Specimen No. BI1, Test Temperature 350°F

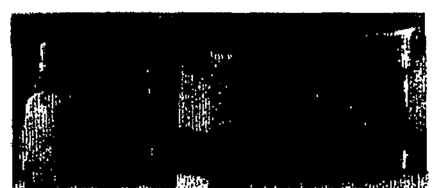


Specimen No. BG5, Test Temperature 175°F



Specimen No. BV1, Test Temperature 400°F

Specimen No. BF1, Test Temperature 200°F



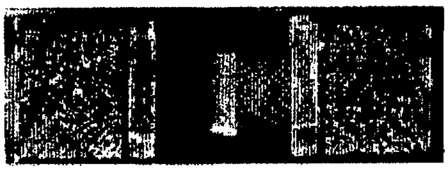
Specimen No. BD1, Test Temperature 450°F

Specimen No. BG4, Test Temperature 225°F

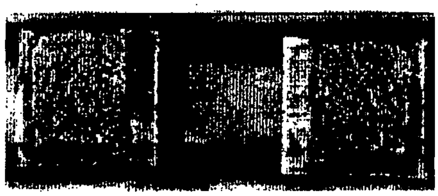
Specimen No. BG2, Test Temperature 500°F

Figure 4-8. Photographs of Charpy Impact Specimen Fracture Surfaces, Weld Metal 27204 from Palisades Capsule SA-240-1

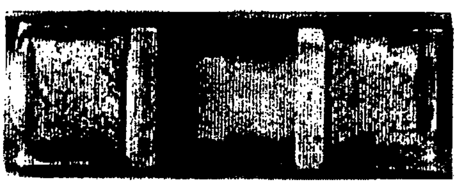
Specimen No. PB45, Test Temperature 70°F



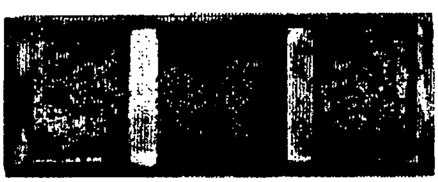
Specimen No. PB62, Test Temperature 125°F



Specimen No. PB71, Test Temperature 175°F



Specimen No. PB54, Test Temperature 200°F



Specimen No. PB07, Test Temperature 200°F

Specimen No. PB73, Test Temperature 225°F

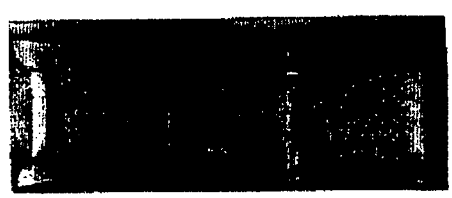
Specimen No. PB52, Test Temperature 250°F

Specimen No. PB35, Test Temperature 300°F

Specimen No. PB06, Test Temperature 350°F

Specimen No. PB58, Test Temperature 400°F

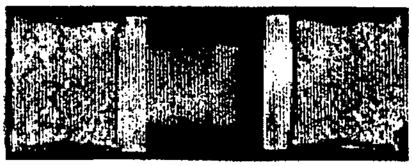
Specimen No. PB57, Test Temperature 450°F



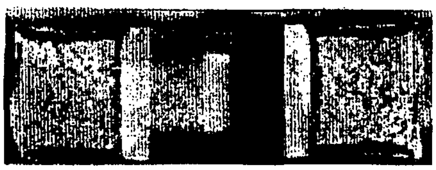
Specimen No. PB61, Test Temperature 500°F

Figure 4-9. Photographs of Charpy Impact Specimen Fracture Surfaces, Correlation Monitor Plate Material (HSST Plate 02) from Palisades Capsule SA-240-1

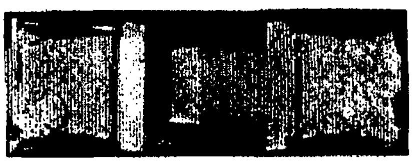
Specimen No. O2D210, Test Temperature 70°F



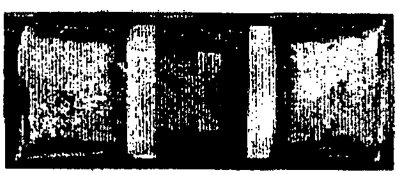
Specimen No. O2D213, Test Temperature 125°F



Specimen No. O2D223, Test Temperature 175°F

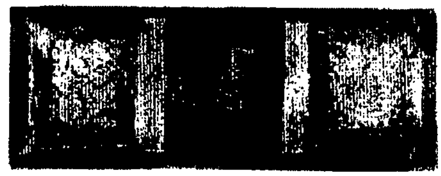


Specimen No. O2D217, Test Temperature 200°F



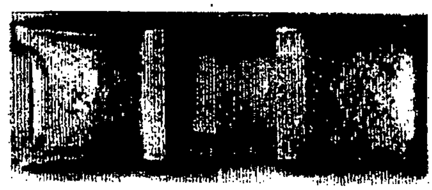
Specimen No. O2D22, Test Temperature 200°F

Specimen No. O2D222, Test Temperature 225°F

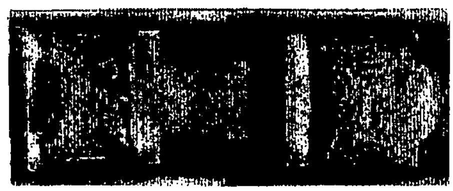


Specimen No. O2D219, Test Temperature 240°F

Specimen No. O2D28, Test Temperature 250°F

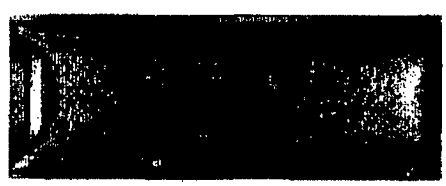


Specimen No. O2D25, Test Temperature 300°F



Specimen No. O2D215, Test Temperature 350°F

Specimen No. O2D224, Test Temperature 400°F



Specimen No. O2D211, Test Temperature 500°F

5.0 Dosimeter Measurements

5.1. Introduction

Three dosimeter sets were located in blocks that were installed in top, middle, and bottom positions of the Capsule SA-240-1 assembly. Each dosimeter set consisted of dosimeters made up of shielded and unshielded cobalt/aluminum and uranium dosimeters, shielded copper, nickel, and neptunium dosimeters, and unshielded iron and titanium dosimeters. The dosimeters were stored in vials identified by labels consisting of the position of the dosimeter holder block within the capsule assembly and the location from where the dosimeters where recovered.

5.2. Dosimeter Preparation

Vials were prepared for the dosimeters by labeling them with identifications that indicated their types and positions in the holder blocks. For example, the one top block shielded cobalt/aluminum dosimeter was labeled Palisades SA-240-1 111T Sh Co. The analyte nuclides were verified during gamma scanning.

The dosimeter wires were washed in reagent grade acetone and blotted dry with a laboratory towel. Each dosimeter wire was then measured with a certified micrometer caliper and weighed on a certified analytical balance. Each wire was then mounted in the center of a PetriSlide™ with double-sided tape.

5.3. Quantitative Gamma Spectrometry

Several of the dosimeters, placed in the PetriSlide™, were given a 300 second preliminary count on the 31% PGT gamma spectrometer. This provided information to best judge the distance at which to count the dosimeter to obtain a minimum of 10,000 counts in the photopeak of interest while keeping the counter dead time below 15%. It also provided qualitative identification of the dosimeters. This identification was made from the presence of the gamma rays in Table 5-1. The spectra were used to confirm the identities of the dosimeters.

The spectra were then measured quantitatively at the appropriate counting positions and for the appropriate count times determined from the preliminary counts.

5.4. Dosimeter Specific Activities

The associated elemental weight fractions of the dosimeters and the isotopic fractions of the target nuclides are listed in Table 5-2. The isotopic fractions of the target nuclides were obtained from the CRC Handbook of Chemistry and Physics, 63rd Edition.[19]

The dosimeter specific activities were calculated by dividing the corrected activity of the analyte nuclide by the target nuclide mass, and the results are shown in Table 5-3.

Table 5-1. Quantifying Gamma Rays

Dosimeter	Analyte
Iron	^{54}Mn @ 834 keV from ^{54}Fe
Co/Al	^{60}Co @ 1332 keV from ^{59}Co
Nickel	^{58}Co @ 811 keV from ^{58}Ni
Titanium	^{46}Sc@ 1121 keV from ^{46}Ti
Copper	^{60}Co @ 1332 keV from ^{63}Cu, very low activity compared to Co wires, wire has coppery color
^{237}Np	^{137}Cs @ 662 keV
^{238}U	^{137}Cs @ 662 keV

Table 5-2. Isotopic Fractions and Weight Fractions of Target Nuclides

Dosimeter	Target Nuclide	Isotopic Fraction of Target	Weight Fraction of Target Element
Iron	^{54}Fe	0.0570	0.999704
Cobalt	^{59}Co	1.0	0.0102
Nickel	^{58}Ni	0.6739	0.99997
Titanium	^{46}Ti	0.0793	0.99793
Copper	^{63}Cu	0.6850	0.99998
Neptunium-237	^{237}Np	1.0	Determined from ^{233}Pa
Uranium-238	^{238}U	1.0	1

Table 5-3. Specific Activities for Palisades Capsule SA-240-1 Dosimetry

Dosimeter Identification	Shielded (Yes/No)	Target Nuclide	Analyte Nuclide	Specific Activity (μCi/gm Target)	% Error (%)
Palisades, SA-240-1 111T Sh Co	Yes	Co-59	Co-60	5.651E+04	6.57
Palisades, SA-240-1 111T Co	No	Co-59	Co-60	1.469E+05	6.58
Palisades, SA-240-1 114T Sh Co	Yes	Co-59	Co-60	5.055E+04	6.70
Palisades, SA-240-1 114T Co	No	Co-59	Co-60	1.401E+05	6.53
Palisades, SA-240-1 117T Sh Co	Yes	Co-59	Co-60	5.167E+04	6.46
Palisades, SA-240-1 117T Co	No	Co-59	Co-60	1.454E+05	6.90
Palisades, SA-240-1 111T Sh Cu	Yes	Cu-63	Co-60	2.039E+01	5.26
Palisades, SA-240-1 114T Sh Cu	Yes	Cu-63	Co-60	2.093E+01	5.25
Palisades, SA-240-1 117T Sh Cu	Yes	Cu-63	Co-60	2.109E+01	5.26
Palisades, SA-240-1 111T Sh Ni	Yes	Ni-58	Co-58	8.671E+03	5.22
Palisades, SA-240-1 114T Sh Ni	Yes	Ni-58	Co-58	8.435E+03	5.23
Palisades, SA-240-1 117T Sh Ni	Yes	Ni-58	Co-58	8.914E+03	5.23
Palisades, SA-240-1 111T Fe	No	Fe-54	Mn-54	5.963E+03	5.65
Palisades, SA-240-1 114T Fe	No	Fe-54	Mn-54	6.067E+03	5.64
Palisades, SA-240-1 117T Fe	No	Fe-54	Mn-54	6.281E+03	5.59
Palisades, SA-240-1 111T Ti	No	Ti-46	Sc-46	1.315E+03	5.95
Palisades, SA-240-1 114T Ti	No	Ti-46	Sc-46	1.313E+03	5.98
Palisades, SA-240-1 117T Ti	No	Ti-46	Sc-46	1.409E+03	5.92
Palisades, SA-240-1 111T Sh U	Yes	U-238	Cs-137	3.678E+01	7.12
Palisades, SA-240-1 111T U	No	U-238	Cs-137	5.117E+01	7.59
Palisades, SA-240-1 114T Sh U	Yes	U-238	Cs-137	3.691E+01	7.48
Palisades, SA-240-1 114T U	No	U-238	Cs-137	4.954E+01	7.12
Palisades, SA-240-1 117T Sh U	Yes	U-238	Cs-137	3.765E+01	7.09
Palisades, SA-240-1 117T U	No	U-238	Cs-137	5.104E+01	7.18
Palisades, SA-240-1 111T Sh Np	Yes	Np-237	Cs-137	1.799E+02	8.08
Palisades, SA-240-1 114T Sh Np	Yes	Np-237	Cs-137	1.778E+02	8.09
Palisades, SA-240-1 117T Sh Np	Yes	Np-237	Cs-137	1.810E+02	8.09

6.0 Summary of Results

The investigation of the post-irradiation test results of the materials contained in the second supplemental surveillance capsule, Capsule SA-240-1 removed from the Consumers Power Company Palisades reactor vessel, led to the following conclusions:

1. Observation of the Capsule SA-240-1 thermal monitors indicated that the irradiated test specimens were exposed to a maximum irradiation temperature less than 558°F.

2. Thirty-six pre-machined irradiated 18mm Charpy inserts were successfully reconstituted and machined to Type A Charpy impact specimens. The reconstituted Charpy specimens were subsequently impact tested.

3. The 30 ft-lb and 50 ft-lb transition temperatures for the weld metal W5214 increased 280.1°F and 390.1°F, respectively. In addition, the C_vUSE for this material decreased 48.9%.

4. The 30 ft-lb and 50 ft-lb transition temperatures for the weld metal 34B009 increased 259.4°F and 325.8°F, respectively. In addition, the C_vUSE for this material decreased 49.6%.

5. The 30 ft-lb and 50 ft-lb transition temperatures for the weld metal 27204 increased 267.8°F and 399.7°F, respectively. In addition, the C_vUSE for this material decreased 50.4%.

6. The correlation monitor plate demonstrated similar behavior with an increase in the 30 ft-lb and 50 ft-lb transition temperatures of 140.9°F and 145.9°F, respectively. The percent decrease in the C_vUSE for this material is 29.8%.

7.0 Certification

This report is an accurate description of the testing and analysis of the Consumers Energy's Palisades Nuclear Plant second supplemental surveillance capsule (Capsule SA-240-1).

5/22/01

M. J. DeVan, Supervisory Engineer — Date
Materials & Structural Analysis Unit

This report has been reviewed for technical content and accuracy.

5-22-01

K. E. Moore, Advisory Engineer — Date
Materials & Structural Analysis Unit

Verification of independent review.

David R Coffin for ADM 5/22/01

A. D. McKim, Manager — Date
Materials & Structural Analysis Unit

This report is approved for release.

5/22/01

D. L. Howell — Date
Program Manager

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2. Code of Federal Regulation, Title 10, Part 50, *"Domestic Licensing of Production and Utilization Facilities,"* Appendix G, Fracture Toughness Requirements.

3. Code of Federal Regulation, Title 10, Part 50, *"Domestic Licensing of Production and Utilization Facilities,"* Appendix H, Reactor Vessel Material Surveillance Program Requirements.

4. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *"Nuclear Power Plant Components,"* Appendix G, Protection Against Nonductile Failure, 1989 Edition.

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14. ASTM Standard E 23-91, *"Standard Test Methods for Notched Bar Impact Testing of Metallic Materials,"* American Society for Testing and Materials, Philadelphia, Pennsylvania.

15. L. B. Gross, *"Verification of Reconstituted Charpy V-Notch Test Values,"* BAW-2184, B&W Nuclear Technologies, Inc., Lynchburg, Virginia, May 1993.

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17. ASTM Standard 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, Pennsylvania.

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APPENDIX A

Reactor Vessel Surveillance Program
Background Data and Information

A.1. Palisades Reactor Pressure Vessel

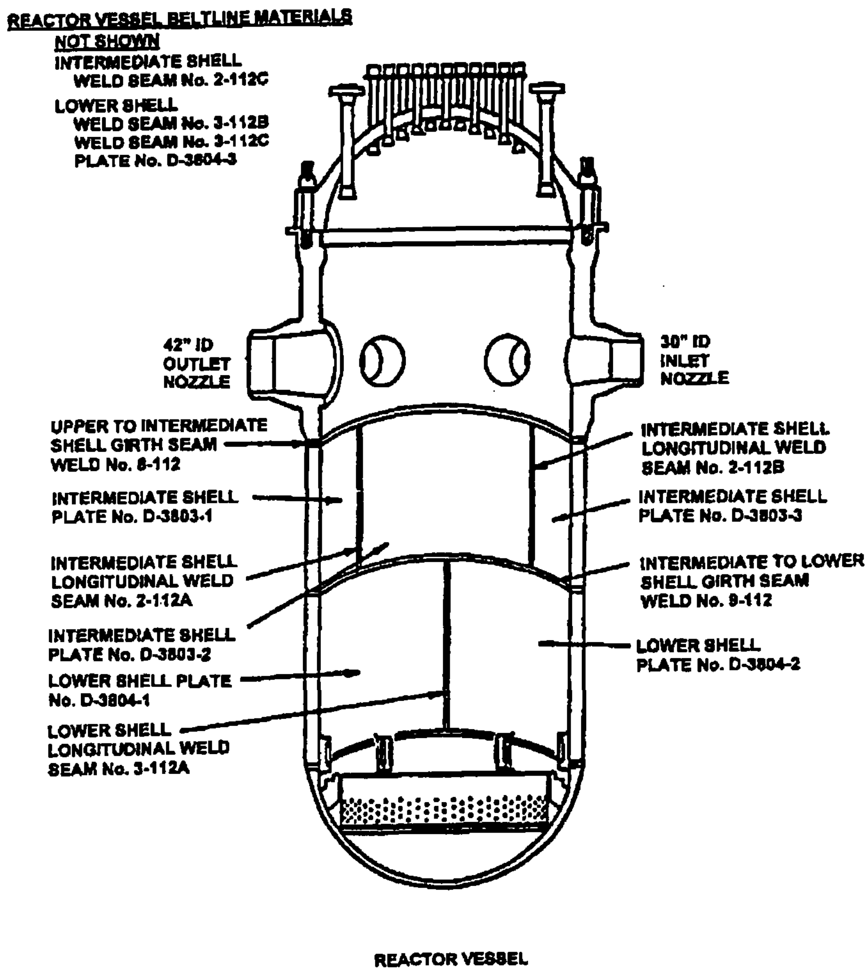
The Palisades reactor pressure vessel was fabricated by Combustion Engineering, Inc. (CE). The Palisades reactor vessel beltline region consists of two shells, containing six heats of base metal plate, six longitudinal weld seams, and two circumferential weld seams. Table A-1 presents a description of the Palisades reactor vessel beltline materials including their copper and nickel chemical contents and their unirradiated mechanical properties. The locations of the materials within the reactor vessel beltline region are shown in Figure A-1.

Table A-1. Description of the Palisades Reactor Vessel Beltline Region Materials

Fabricator Material Code	Material Heat No.	Material Type	Beltline Region Location	Chemical Composition		Toughness Properties					
				Cu, wt%	Ni, wt%	30 ft-lb, F	50 ft-lb, F	35 MLE, F	C_VUSE, ft-lbs	T_{NDT}, F	RT_{NDT}, F
D-3803-1	C1279-3	A 302 Gr. B Mod.	Intermediate Shell	0.24	0.51	---	---	---	102	-30	-5
D-3803-2	A0313-2	A 302 Gr. B Mod.	Intermediate Shell	0.24	0.52	---	---	---	87	-30	-30
D-3803-3	C1279-1	A 302 Gr. B Mod.	Intermediate Shell	0.24	0.50	---	---	---	102	-30	-5
D-3804-1	C1308-1	A 302 Gr. B Mod.	Lower Shell	0.19	0.48	---	---	---	72	-30	0
D-3804-2	C1308-3	A 302 Gr. B Mod.	Lower Shell	0.19	0.50	---	---	---	76	-40	-30
D-3804-3	B5294-2	A 302 Gr. B Mod.	Lower Shell	0.12	0.55	---	---	---	73	-30	-25
2-112A, B, C	W5214/ 3617*	ASA Weld/ Linde 1092	Intermediate Shell Longitudinal Welds	0.213	1.01	---	---	---	118	---	--56
9-112	27204/ 3687*	ASA Weld/ Linde 124	Intermediate to Lower Shell Circ. Weld	0.203	1.018	---	---	---	98	---	-56
3-112A, B, C	34B009, W5214/ 3692*	ASA Weld/ Linde 1092	Lower Shell Longitudinal Welds	0.192/ 0.213	0.98/ 1.01	---	---	---	111/ 118	---	-56

* Weld wire heat number and flux lot identifiers.

Figure A-1. Location and Identification of Materials Used in the Fabrication of Palisades Reactor Pressure Vessel



APPENDIX B

Instrumented Charpy V-Notch Specimen Test Results
Load-Time Traces

Figure B-1. Load-Time Trace for Charpy V-Notch Impact Specimen 2AL1

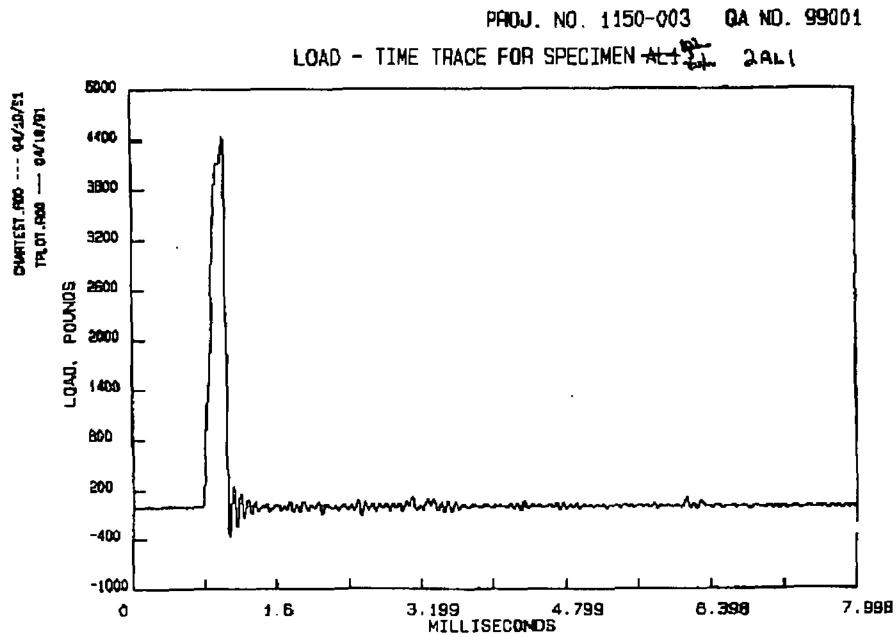


Figure B-2. Load-Time Trace for Charpy V-Notch Impact Specimen 2AH3

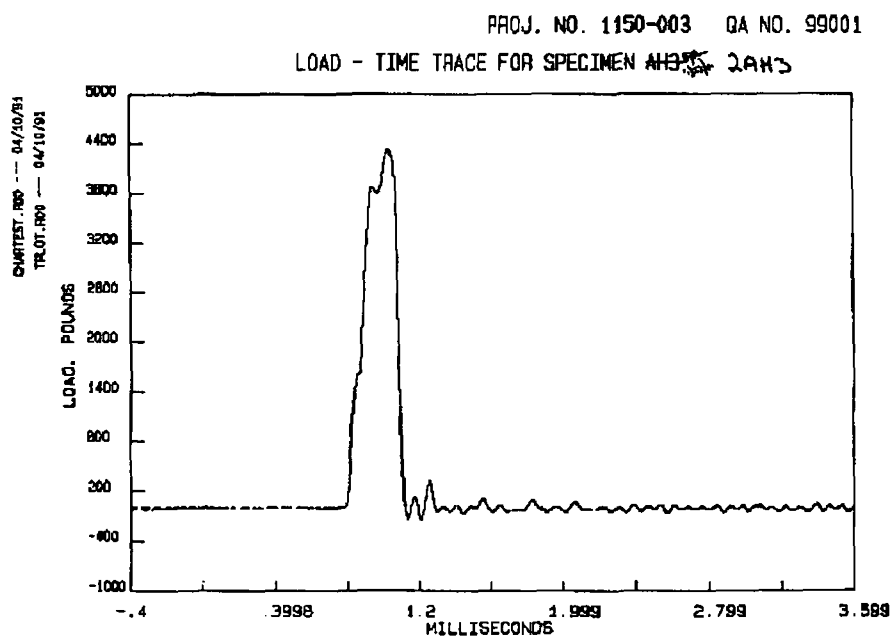


Figure B-3. Load-Time Trace for Charpy V-Notch Impact Specimen AW5

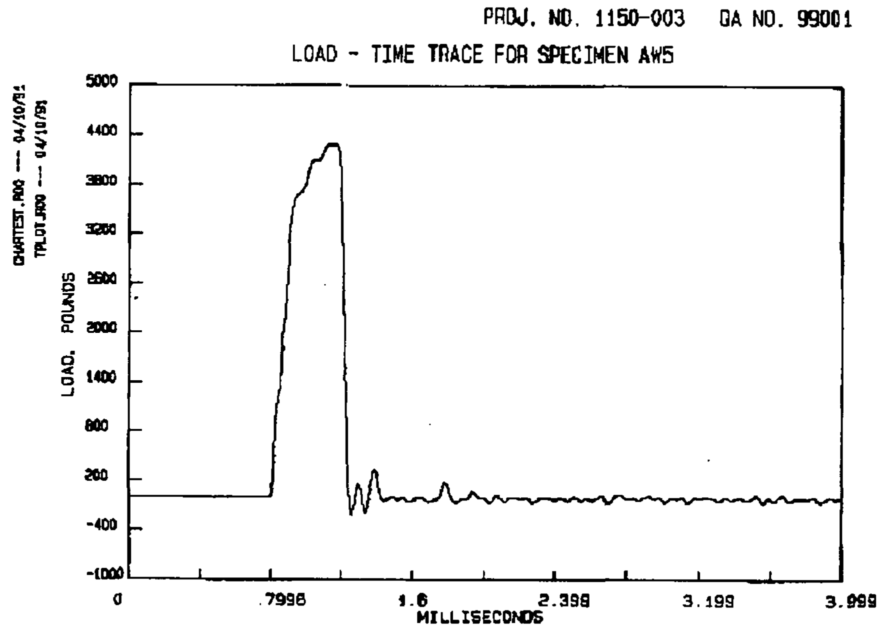


Figure B-4. Load-Time Trace for Charpy V-Notch Impact Specimen 2AJ1

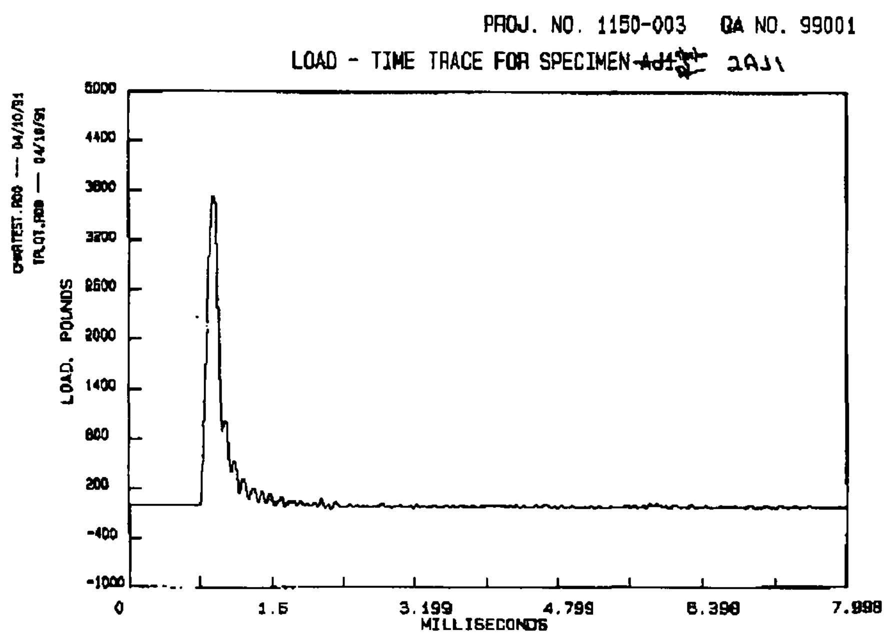


Figure B-5. Load-Time Trace for Charpy V-Notch Impact Specimen AU4

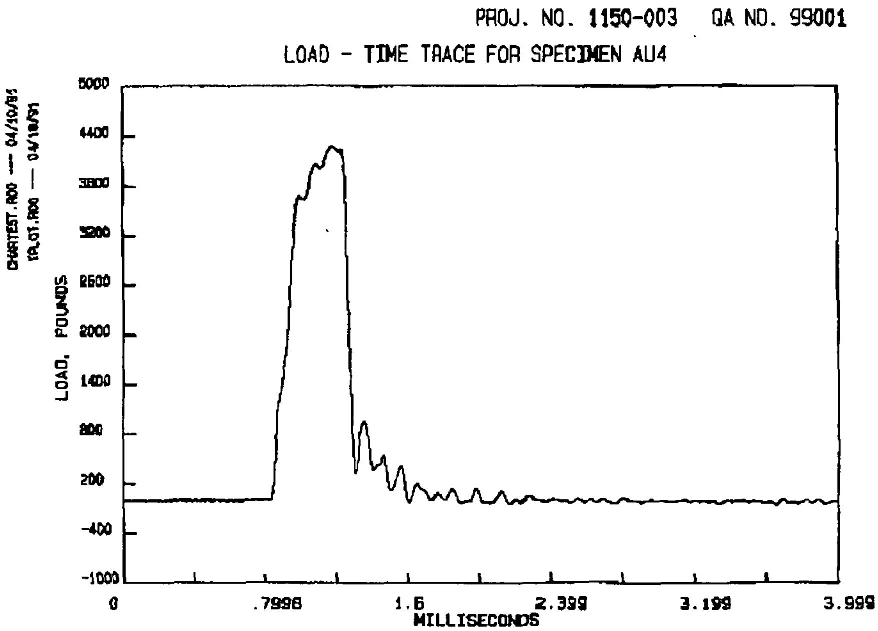


Figure B-6. Load-Time Trace for Charpy V-Notch Impact Specimen 2AL3

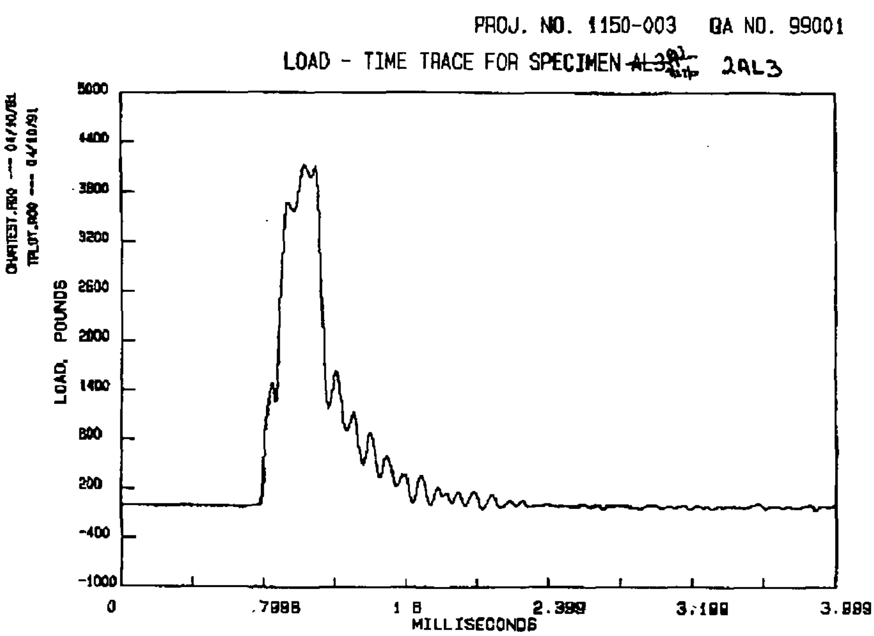


Figure B-7. Load-Time Trace for Charpy V-Notch Impact Specimen AP1

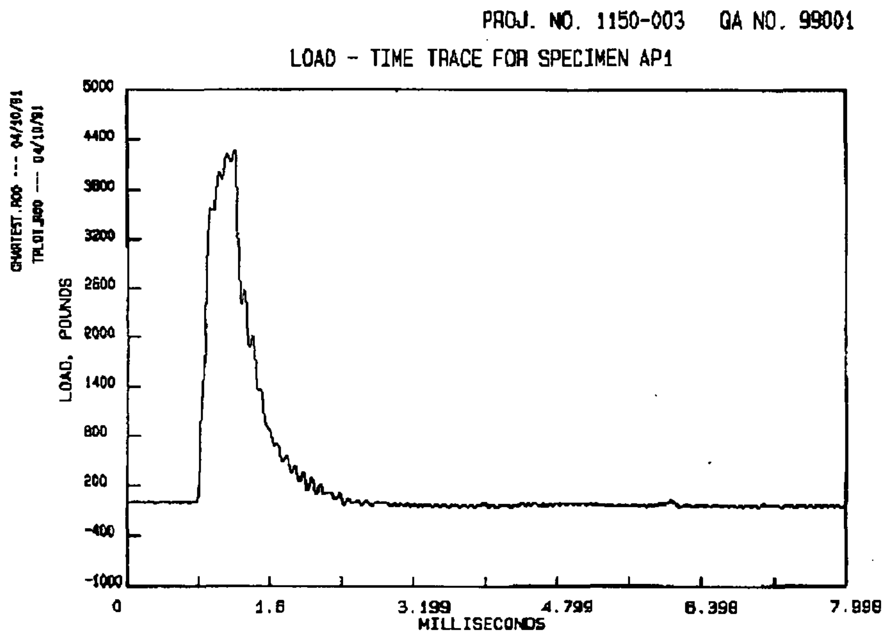


Figure B-8. Load-Time Trace for Charpy V-Notch Impact Specimen AU5

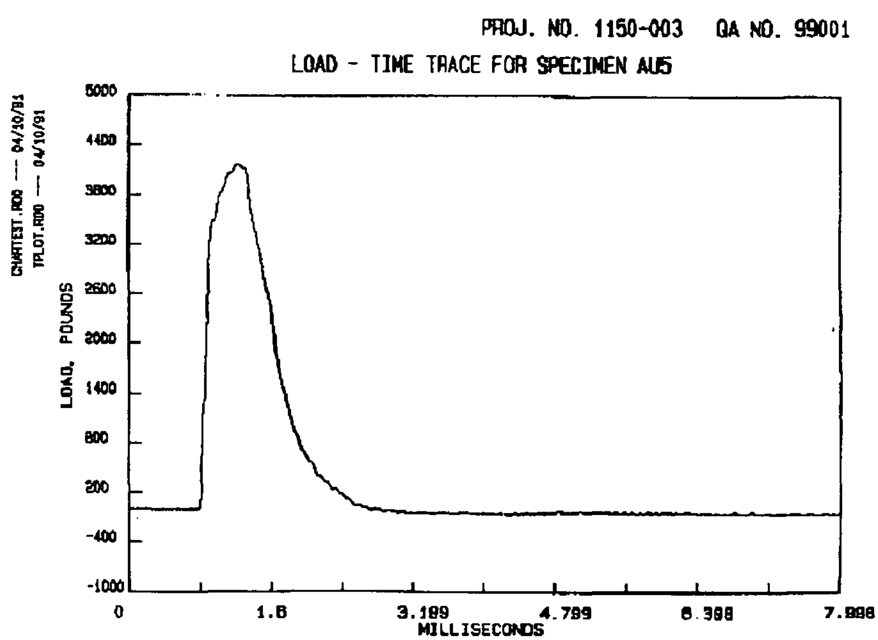


Figure B-9. Load-Time Trace for Charpy V-Notch Impact Specimen 2AE5

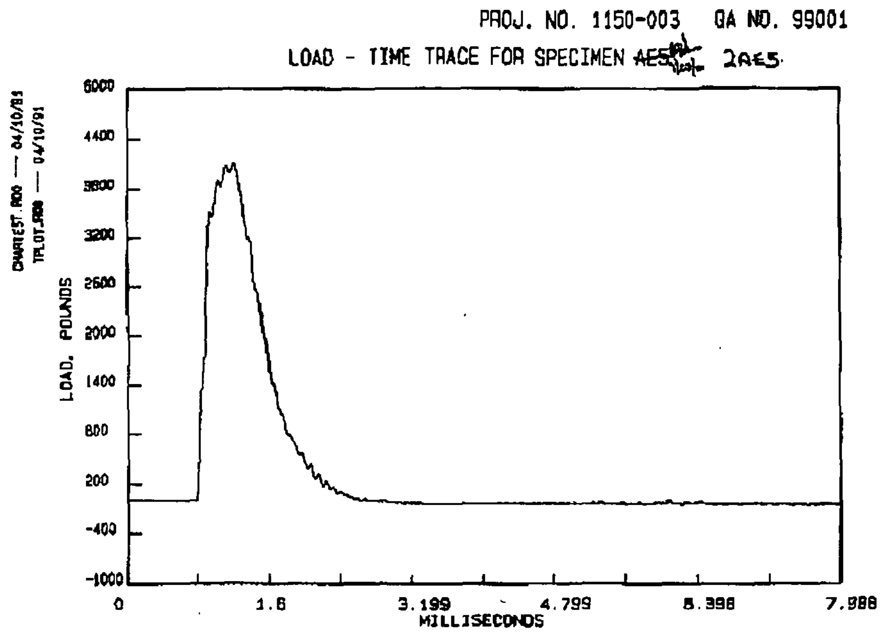


Figure B-10. Load-Time Trace for Charpy V-Notch Impact Specimen 2AK5

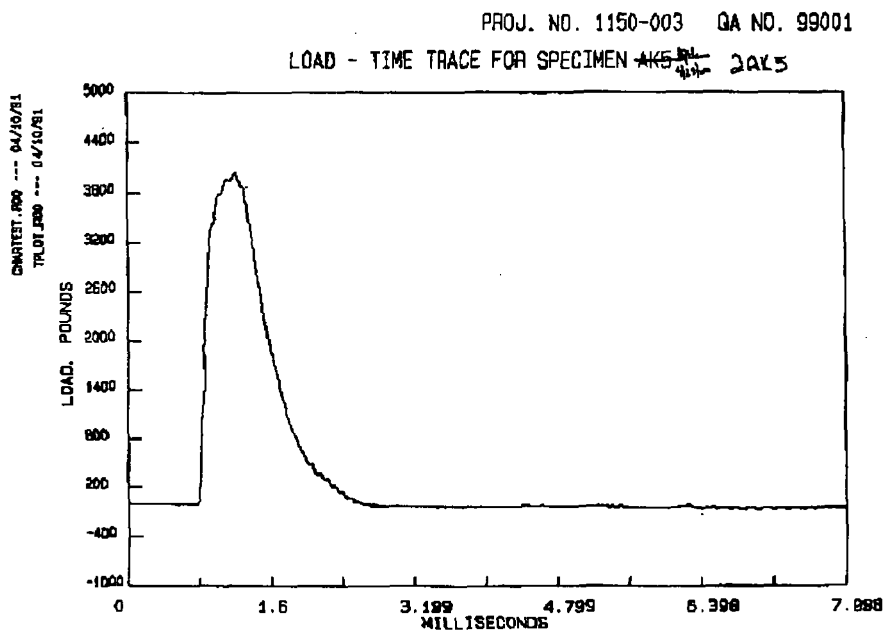


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Figure B-11. Load-Time Trace for Charpy V-Notch Impact Specimen AP5

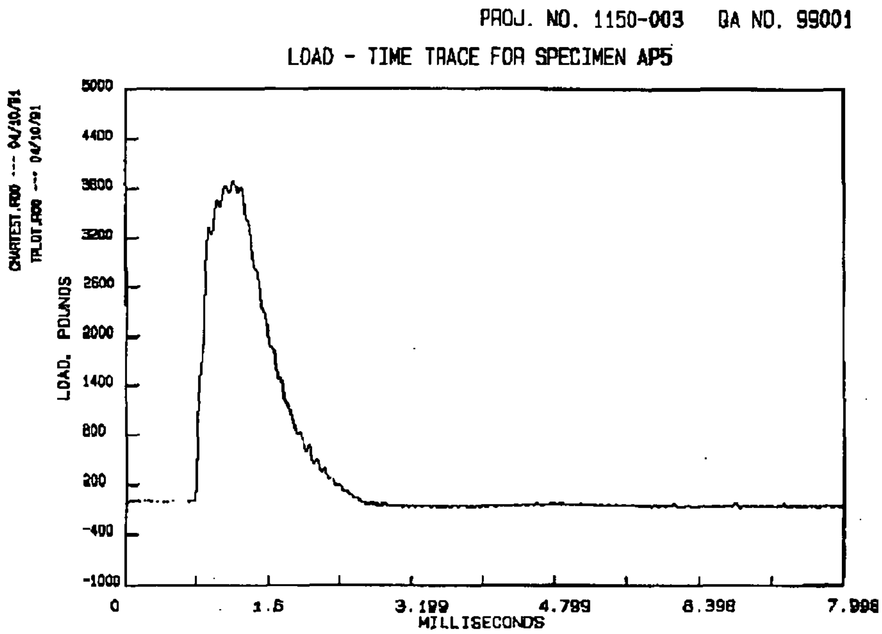

Figure B-12. Load-Time Trace for Charpy V-Notch Impact Specimen AS2

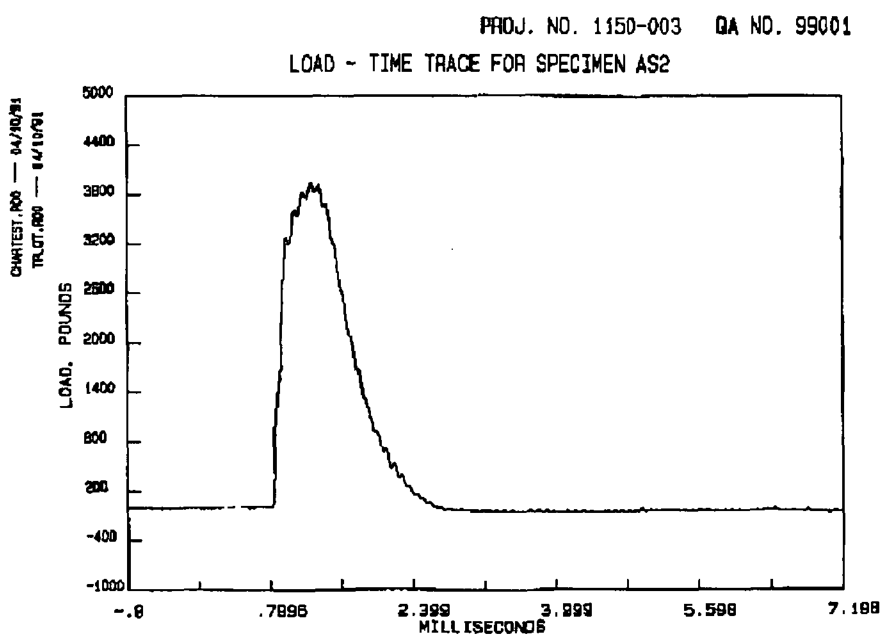

Figure B-13. Load-Time Trace for Charpy V-Notch Impact Specimen BT1

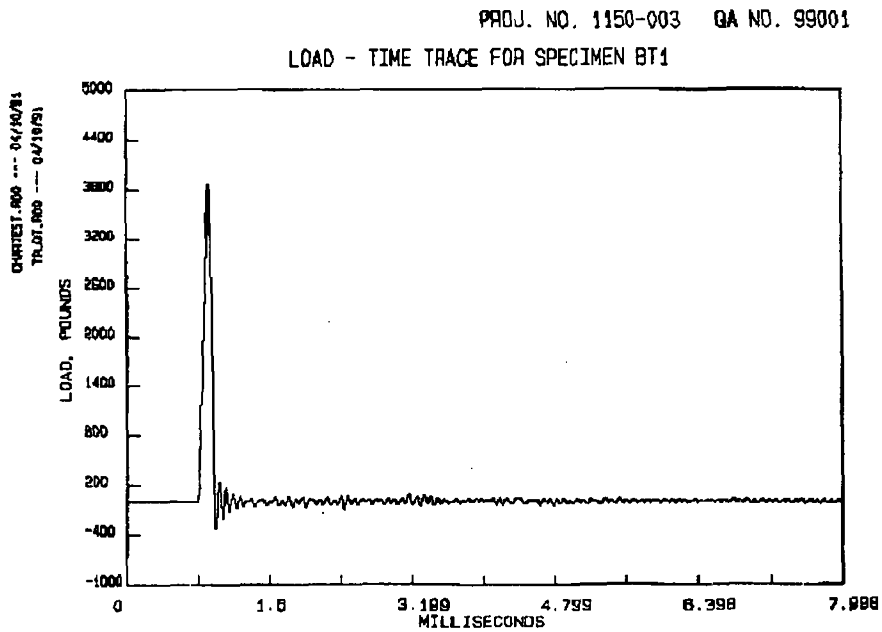

Figure B-14. Load-Time Trace for Charpy V-Notch Impact Specimen 2BJ1

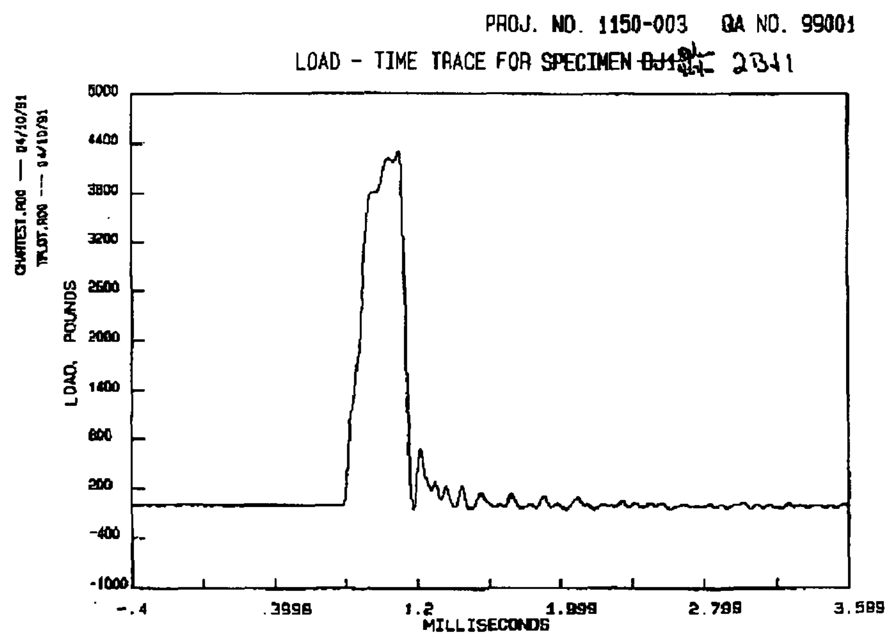

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Figure B-15. Load-Time Trace for Charpy V-Notch Impact Specimen BL5

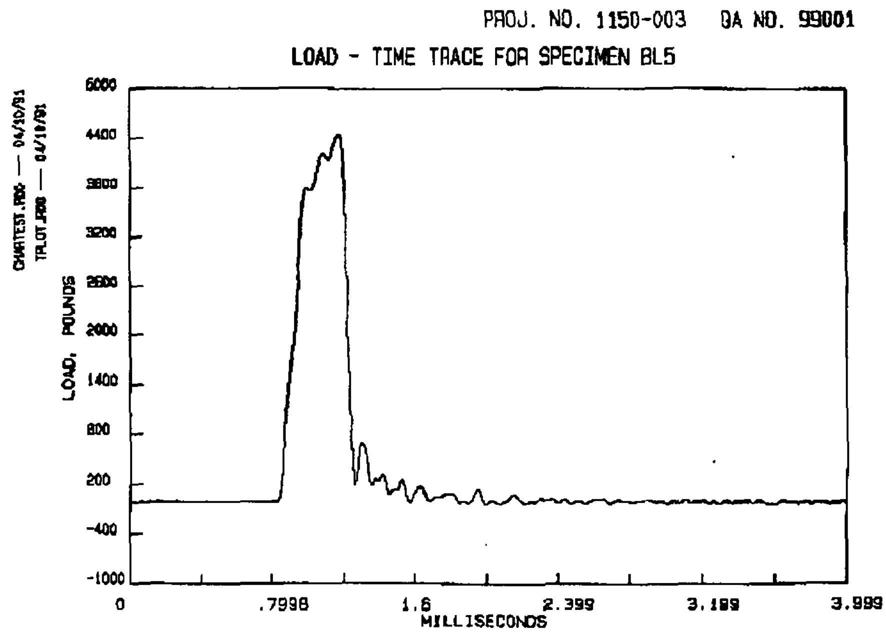


Figure B-16. Load-Time Trace for Charpy V-Notch Impact Specimen 2BG5

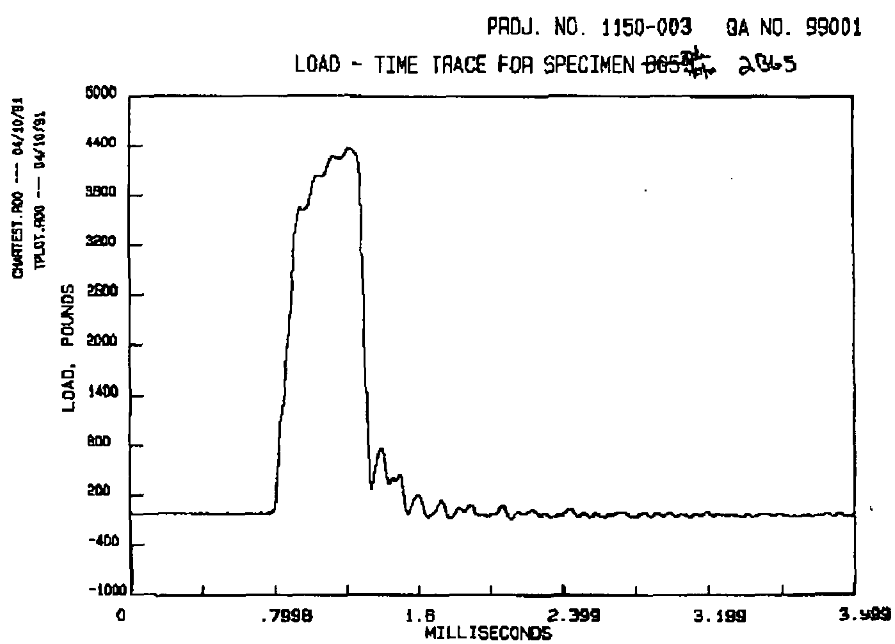


Figure B-17. Load-Time Trace for Charpy V-Notch Impact Specimen 2BF1

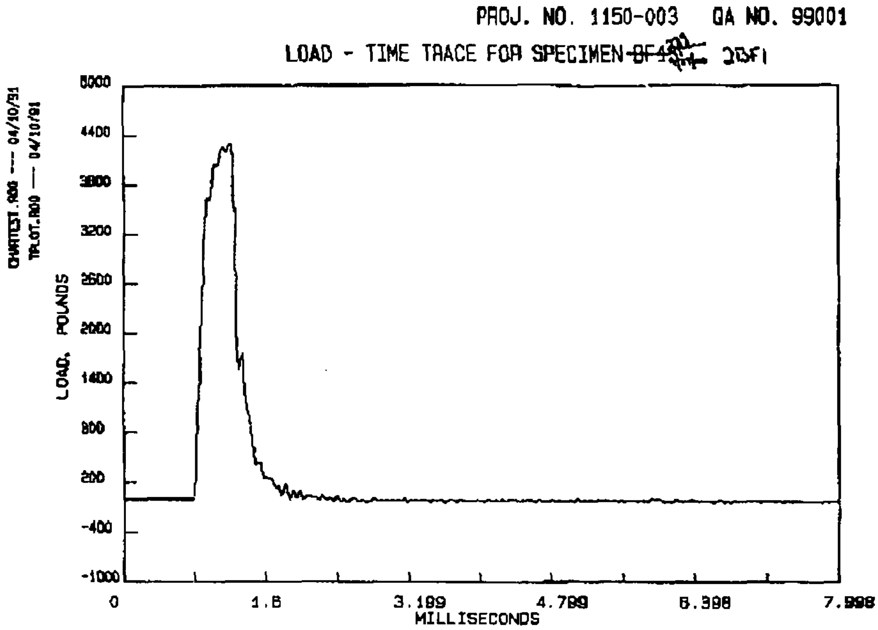


Figure B-18. Load-Time Trace for Charpy V-Notch Impact Specimen 2BG4

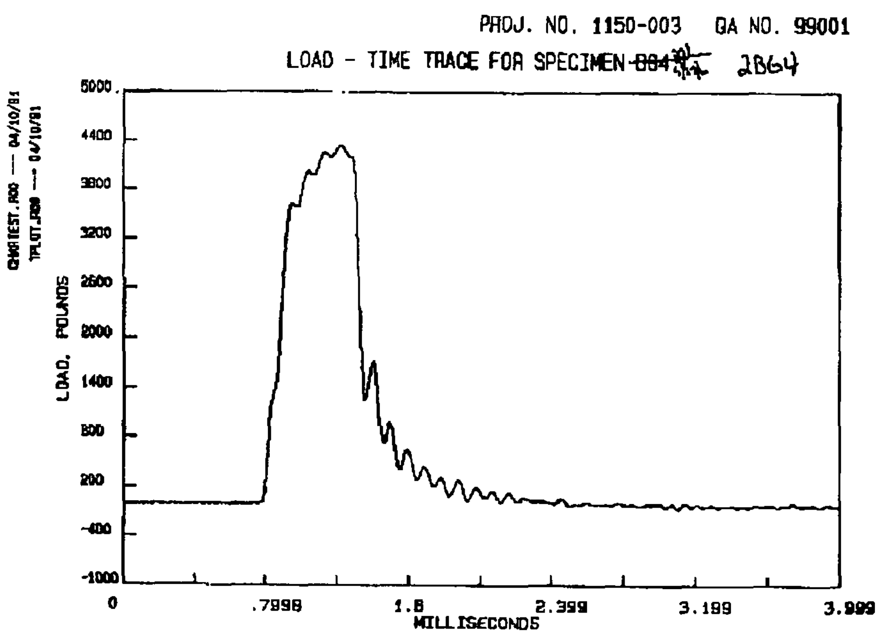


Figure B-19. Load-Time Trace for Charpy V-Notch Impact Specimen 2BJ1

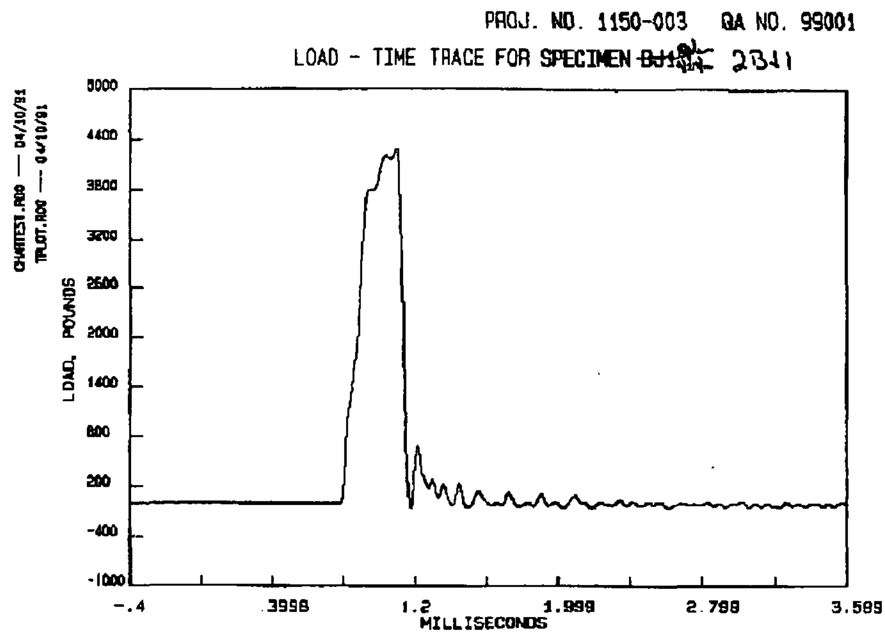


Figure B-20. Load-Time Trace for Charpy V-Notch Impact Specimen 2BI4

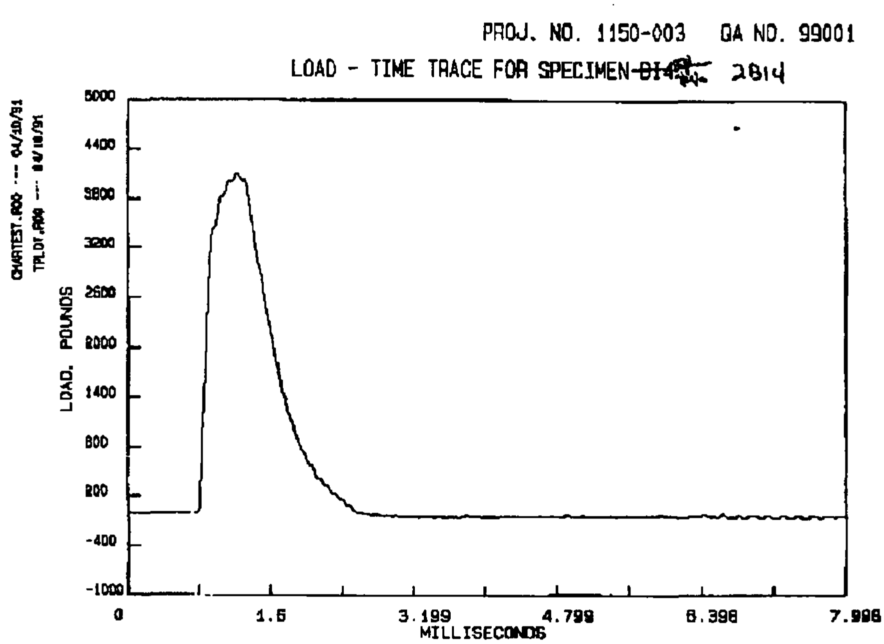


Figure B-21. Load-Time Trace for Charpy V-Notch Impact Specimen 2BI1

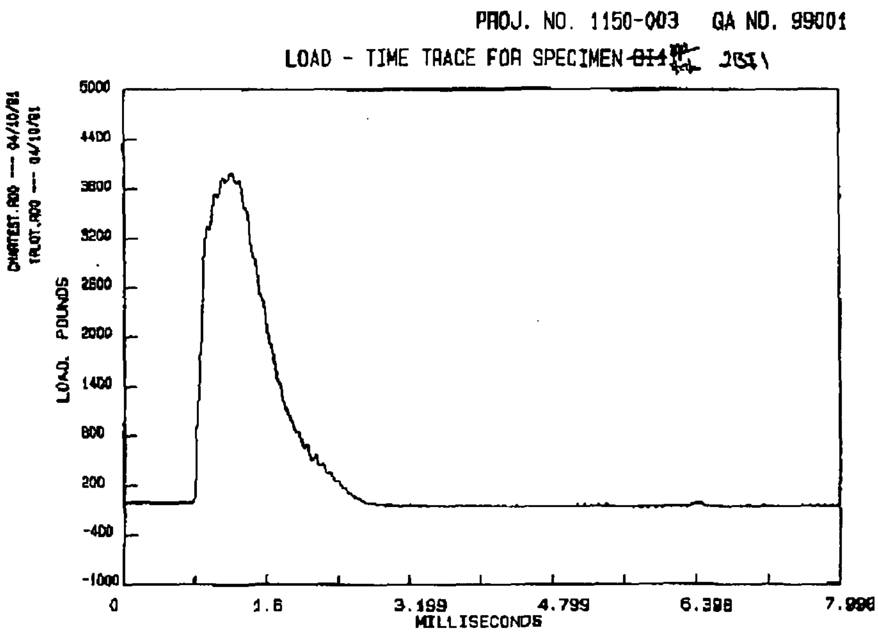


Figure B-22. Load-Time Trace for Charpy V-Notch Impact Specimen BV1

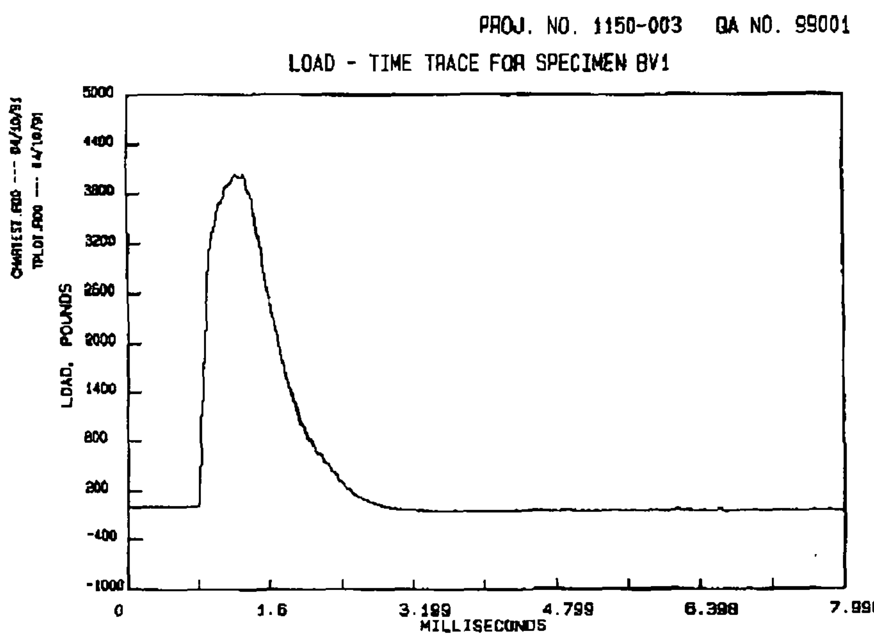


Figure B-23. Load-Time Trace for Charpy V-Notch Impact Specimen 2BD1

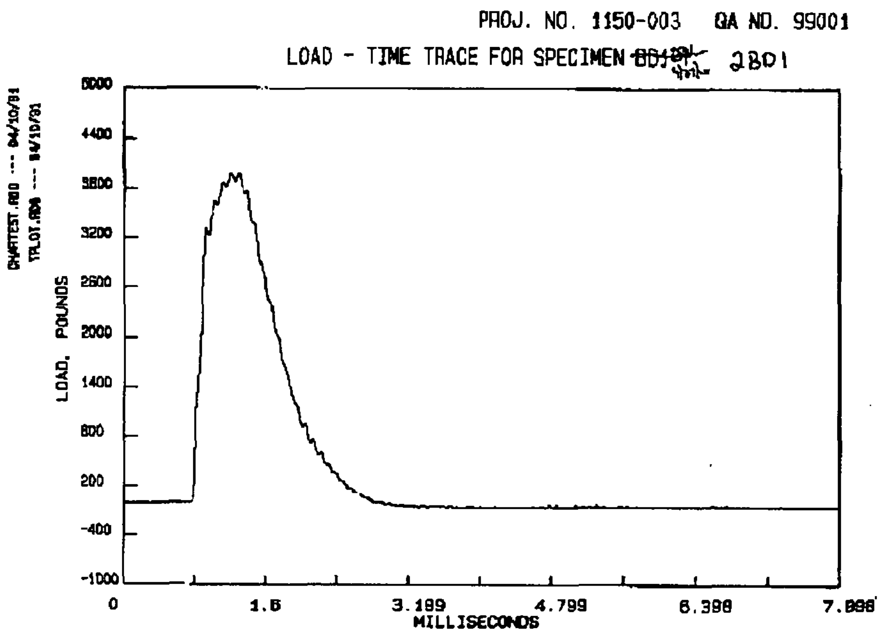


Figure B-24. Load-Time Trace for Charpy V-Notch Impact Specimen 2BG2

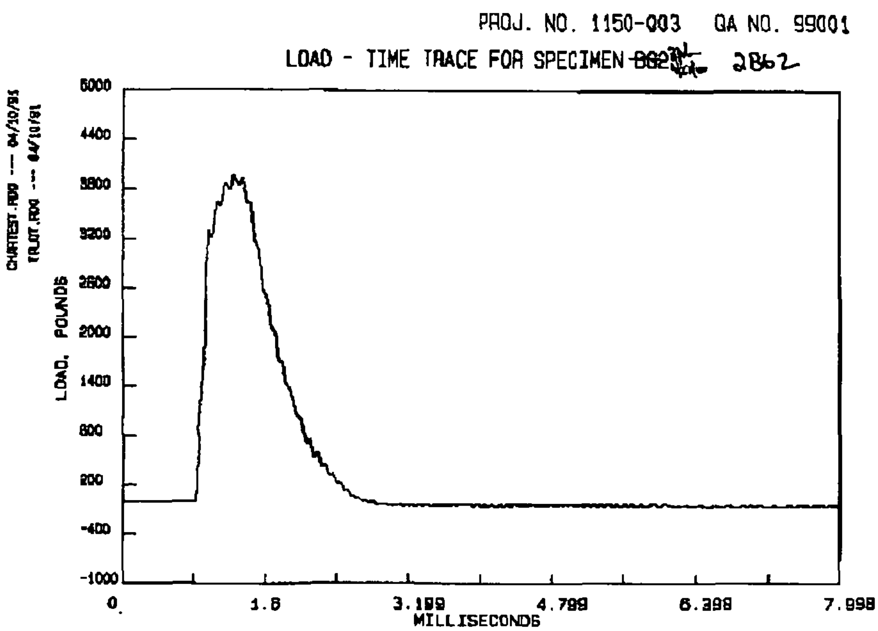


Figure B-25. Load-Time Trace for Charpy V-Notch Impact Specimen PB45

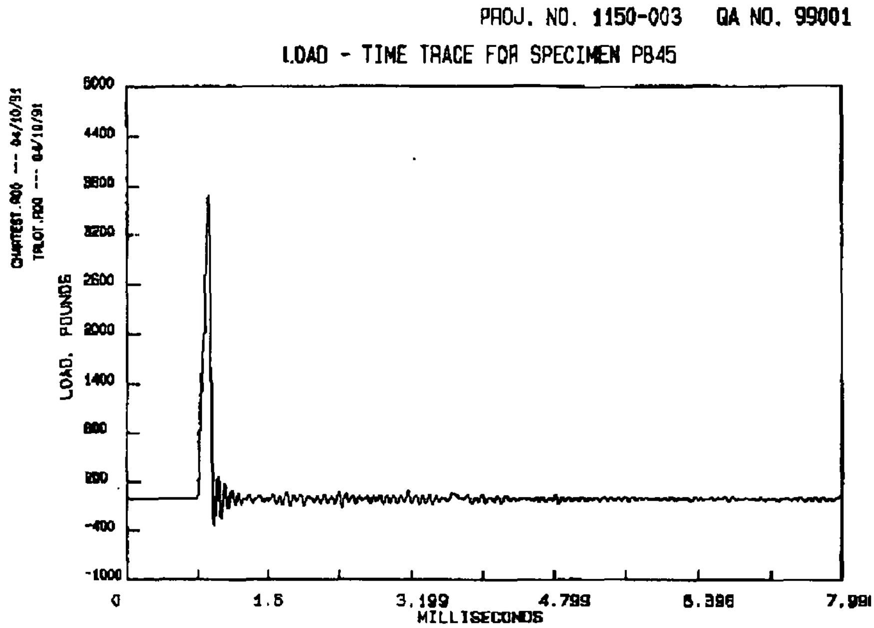


Figure B-26. Load-Time Trace for Charpy V-Notch Impact Specimen PB62

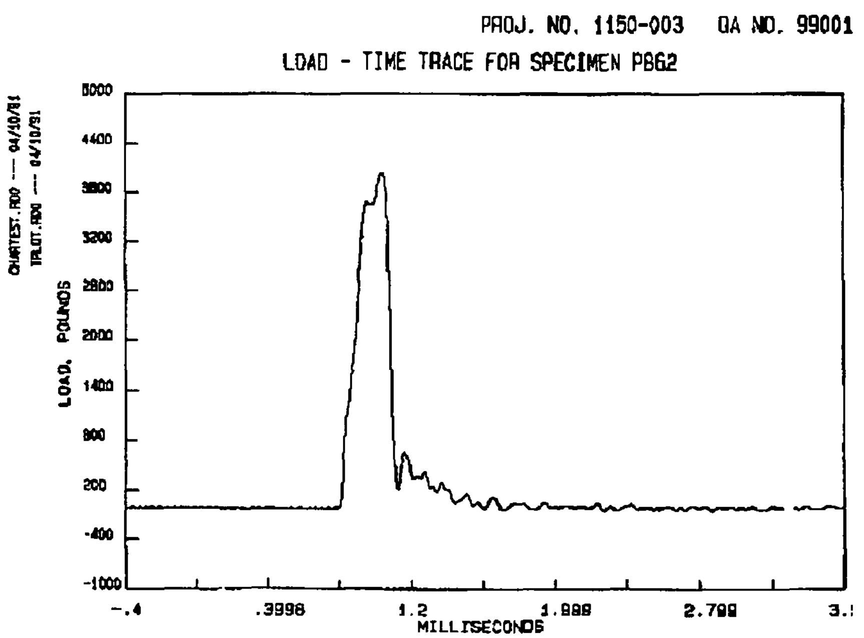


Figure B-27. Load-Time Trace for Charpy V-Notch Impact Specimen PB71

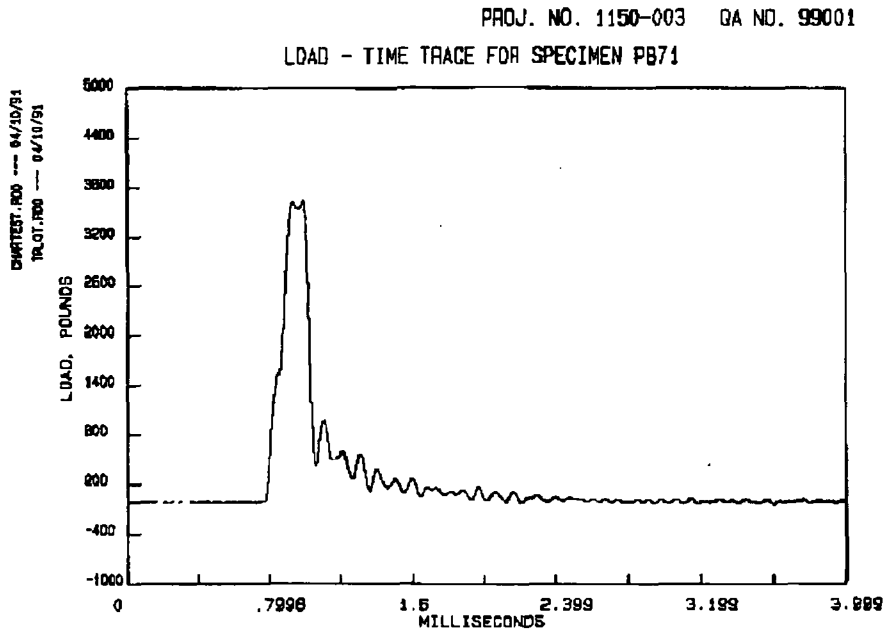


Figure B-28. Load-Time Trace for Charpy V-Notch Impact Specimen PB54

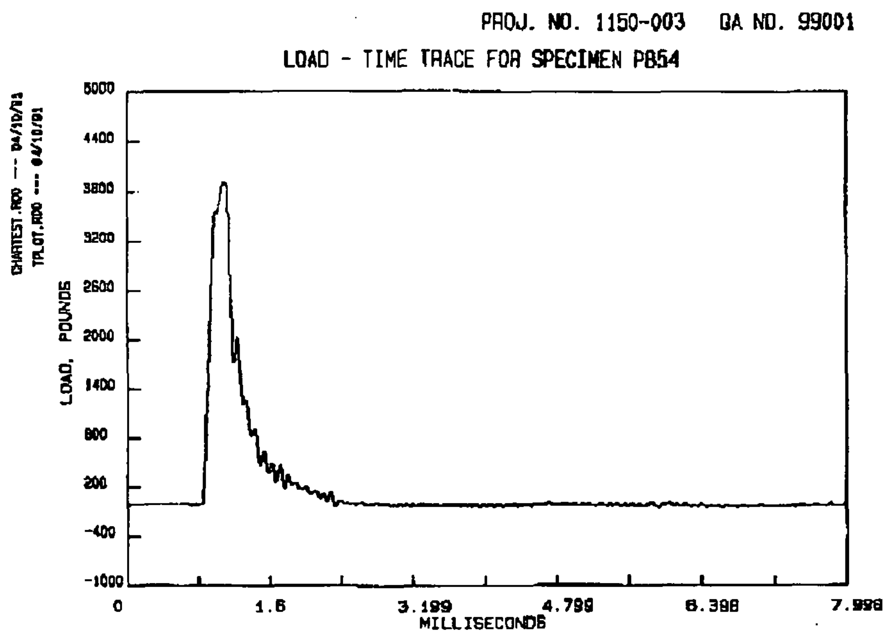


Figure B-29. Load-Time Trace for Charpy V-Notch Impact Specimen PB07

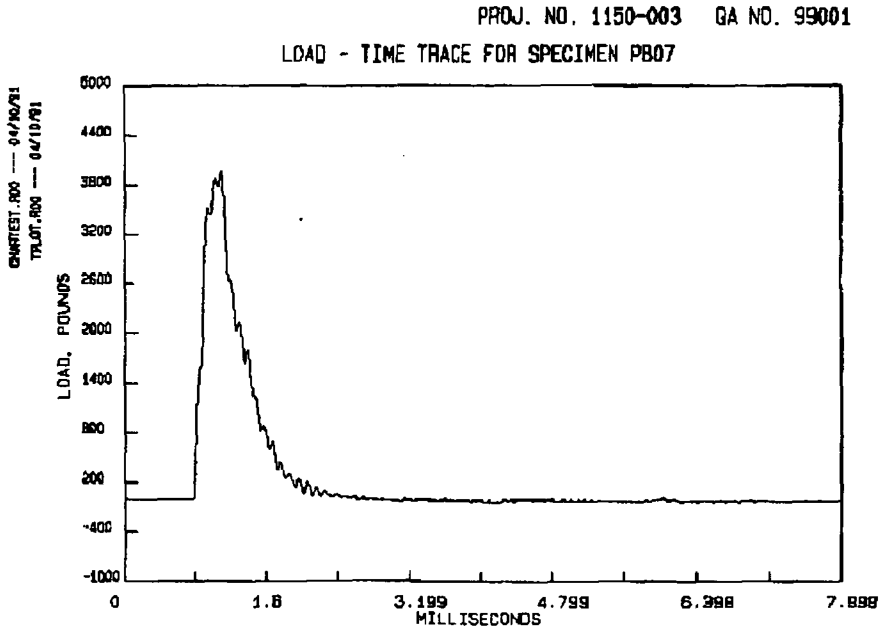


Figure B-30. Load-Time Trace for Charpy V-Notch Impact Specimen PB73

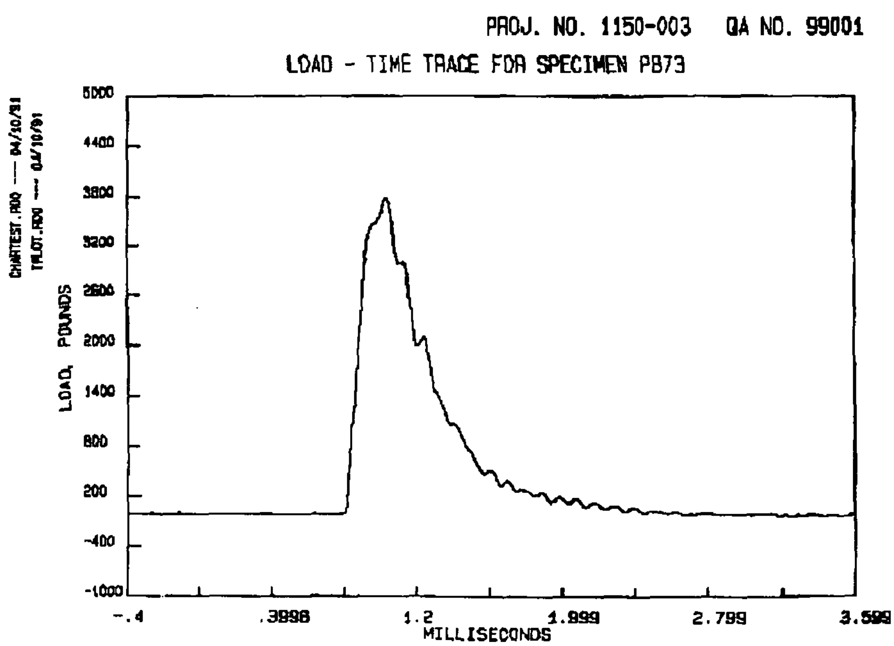


Figure B-31. Load-Time Trace for Charpy V-Notch Impact Specimen PB52

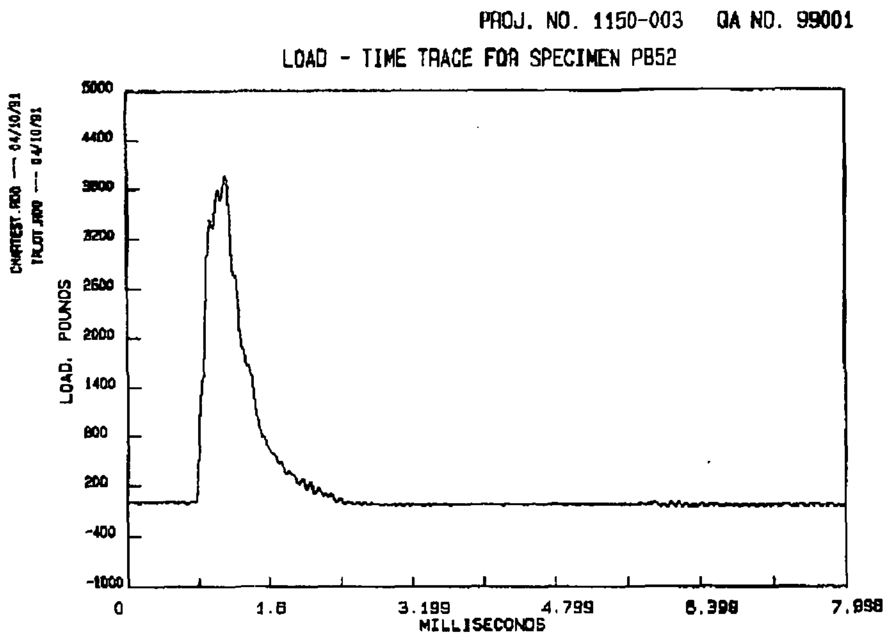


Figure B-32. Load-Time Trace for Charpy V-Notch Impact Specimen PB35

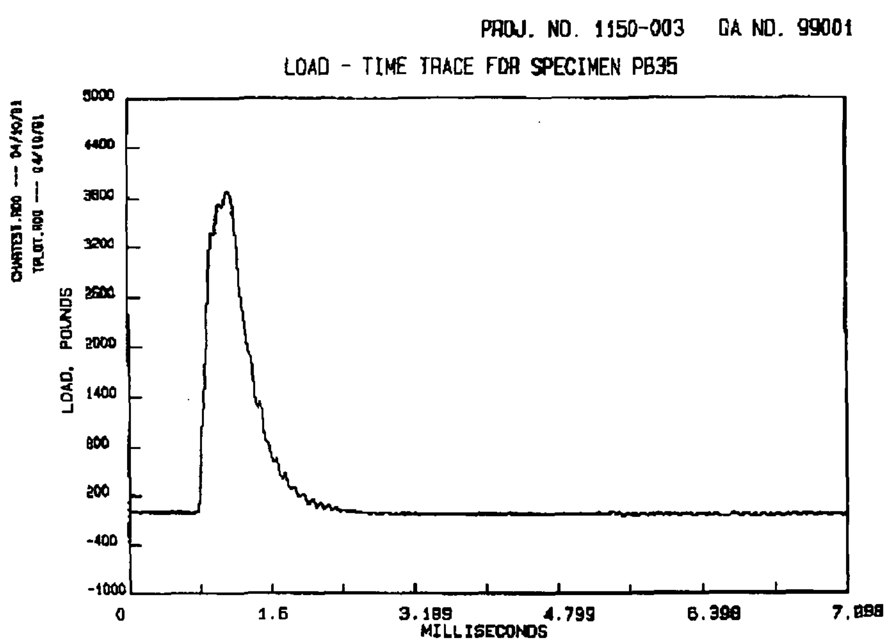


Figure B-33. Load-Time Trace for Charpy V-Notch Impact Specimen PB06

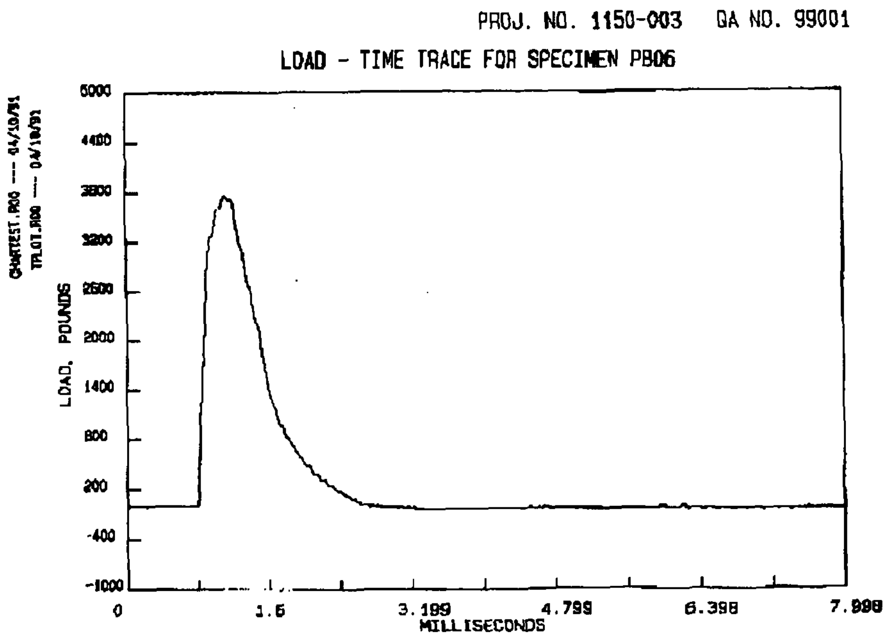


Figure B-34. Load-Time Trace for Charpy V-Notch Impact Specimen PB58

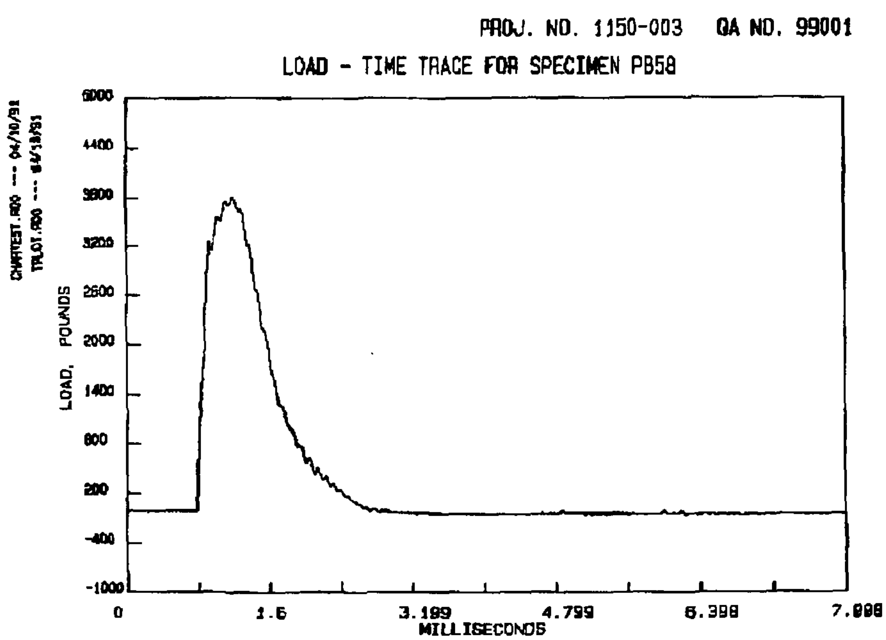


Figure B-35. Load-Time Trace for Charpy V-Notch Impact Specimen PB57

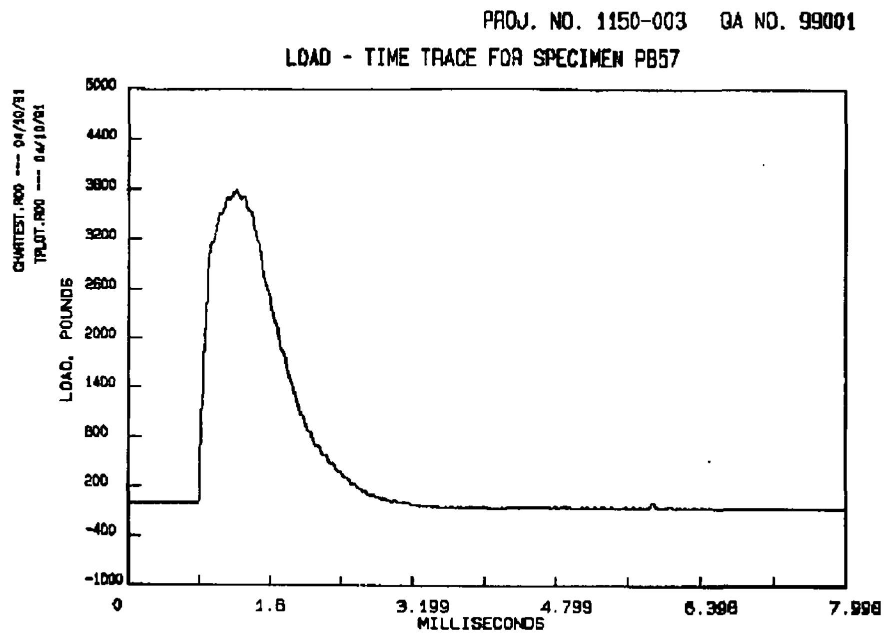


Figure B-36. Load-Time Trace for Charpy V-Notch Impact Specimen PB61

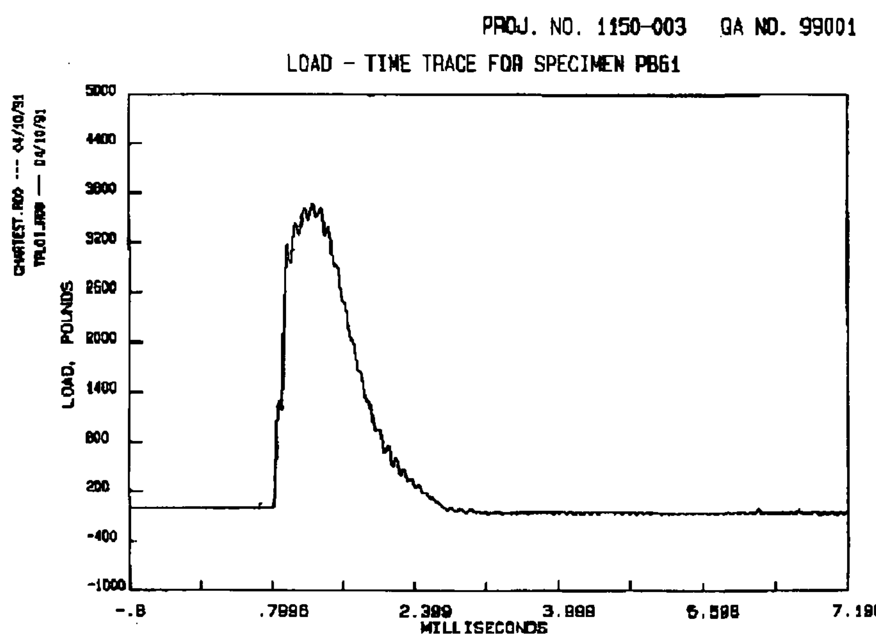


Figure B-37. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-10

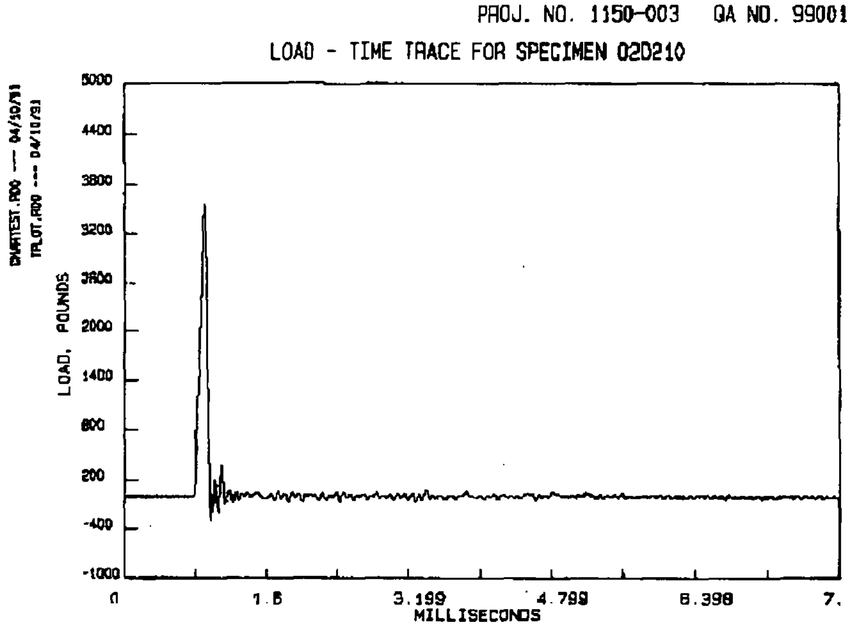


Figure B-38. Load-Time Trace for Charpy V-Notch Impact Specimen 02D2-13

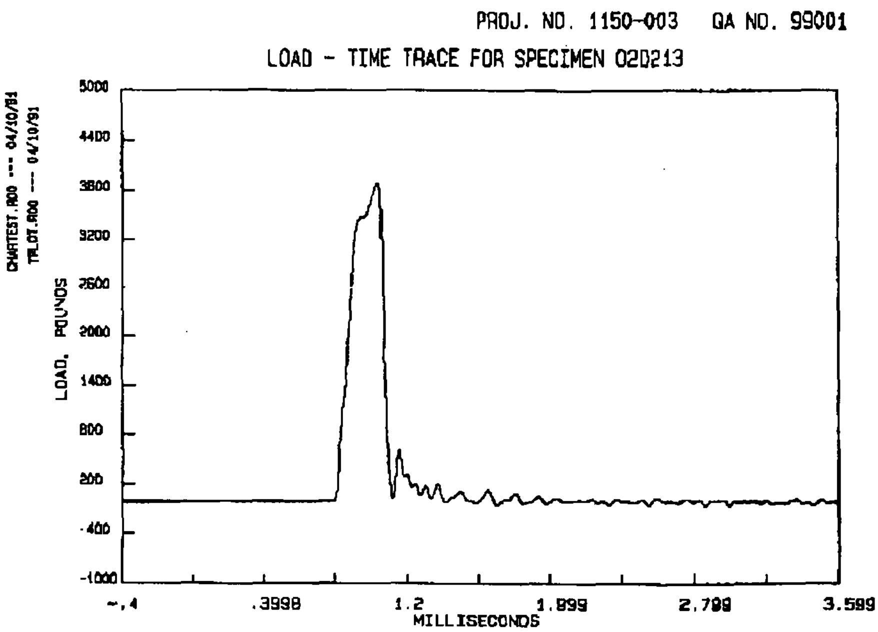


Figure B-39. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-23

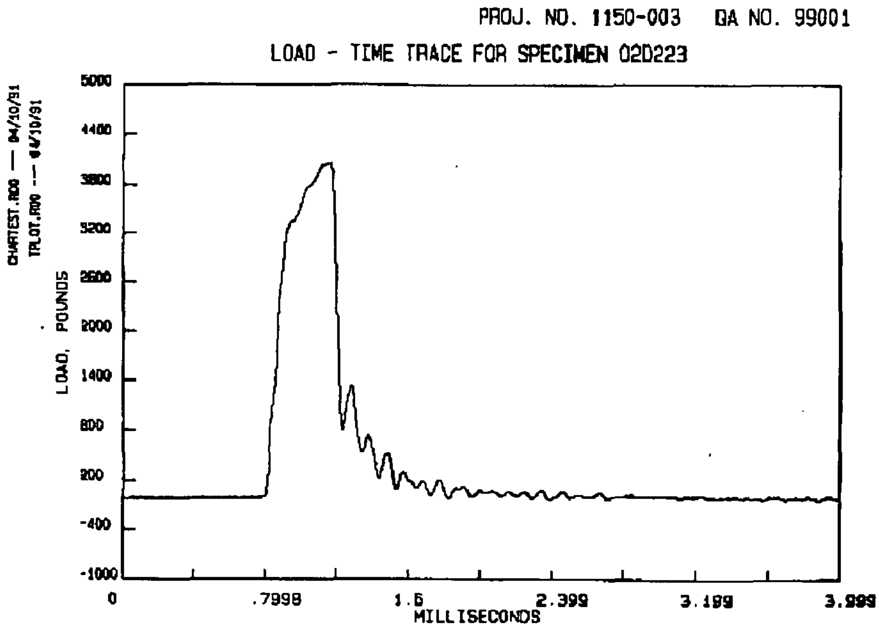


Figure B-40. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-17

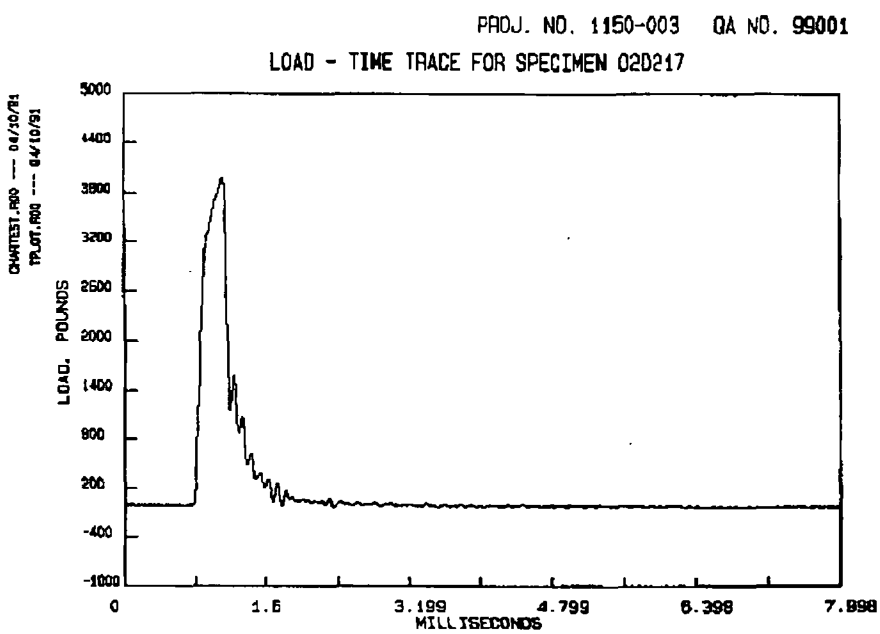


Figure B-41. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-2

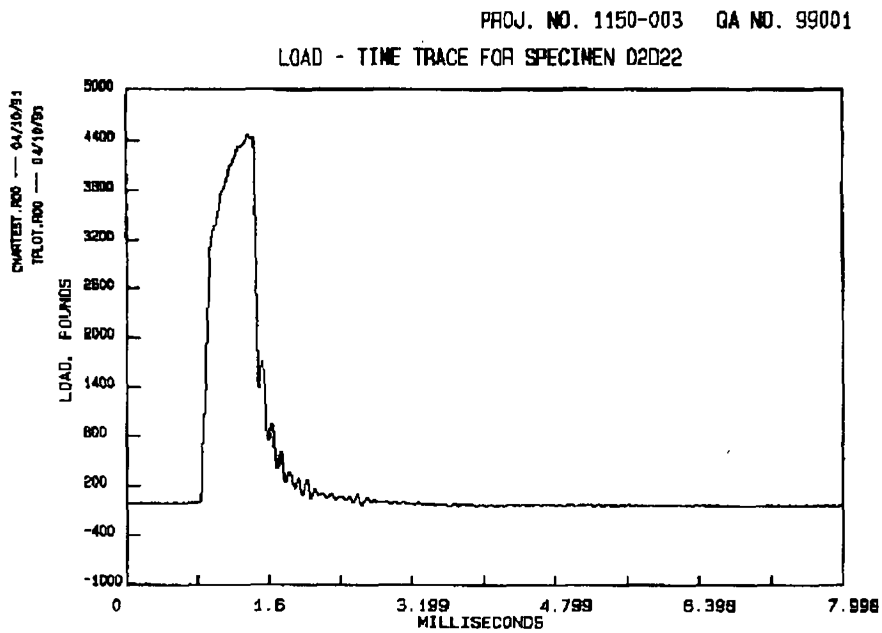


Figure B-42. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-22

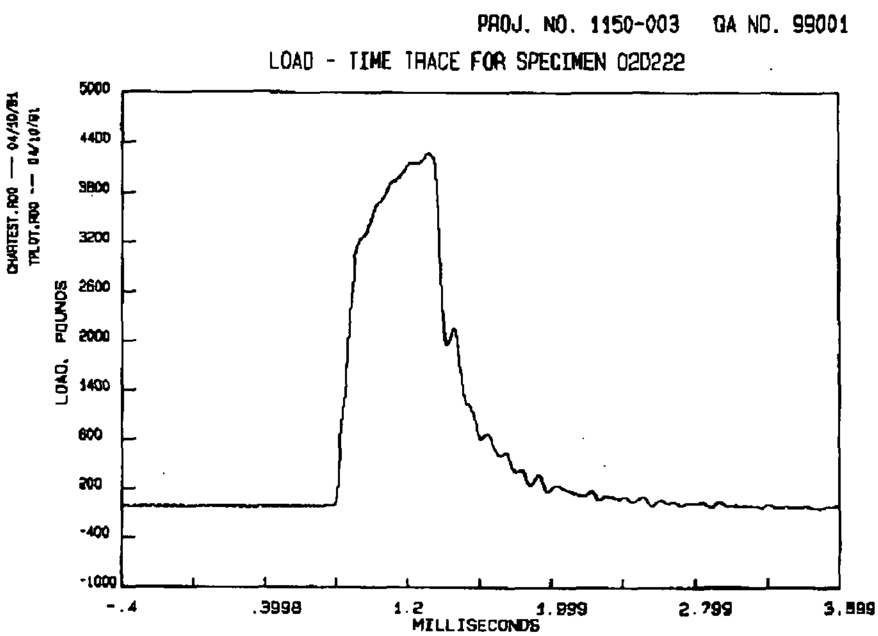


Figure B-43. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-19

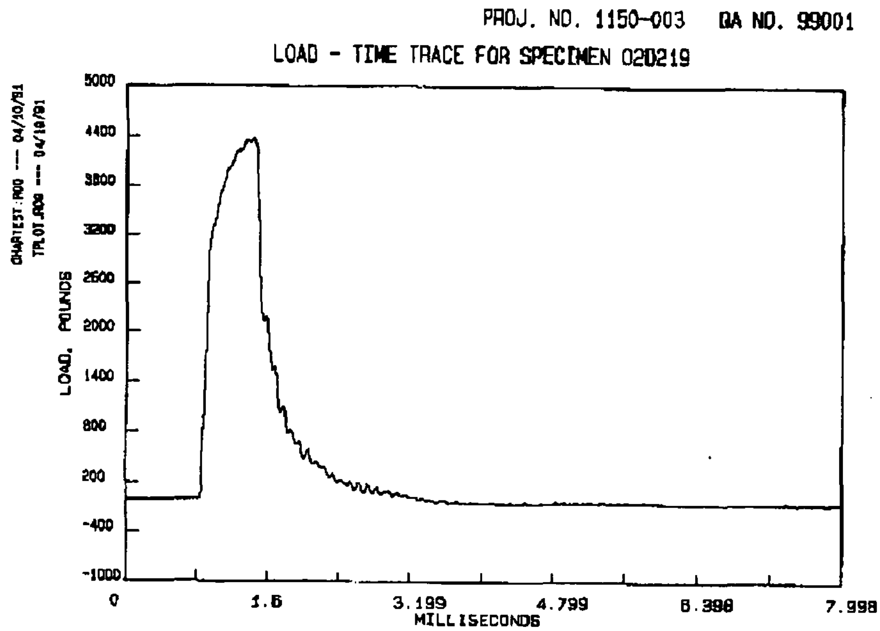


Figure B-44. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-8

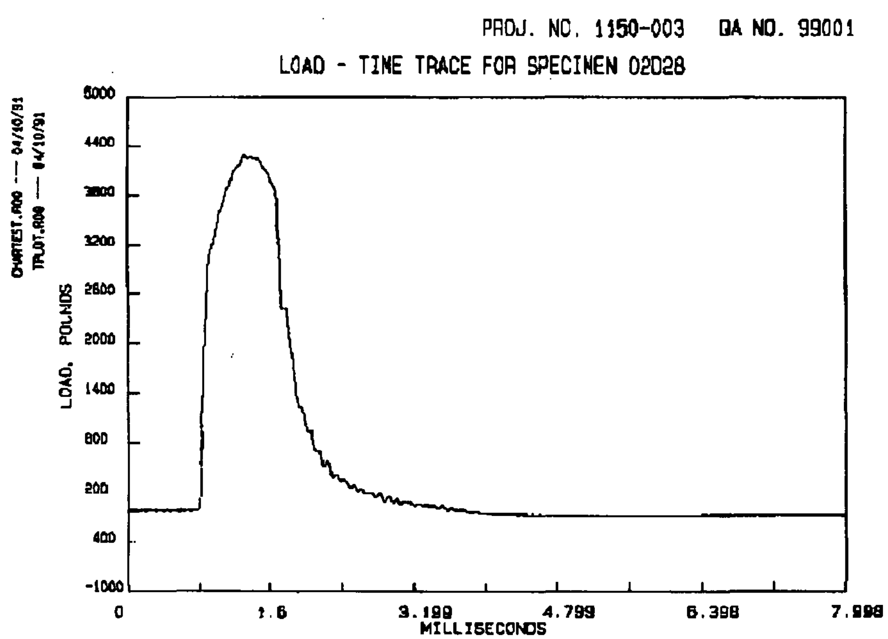


Figure B-45. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-5

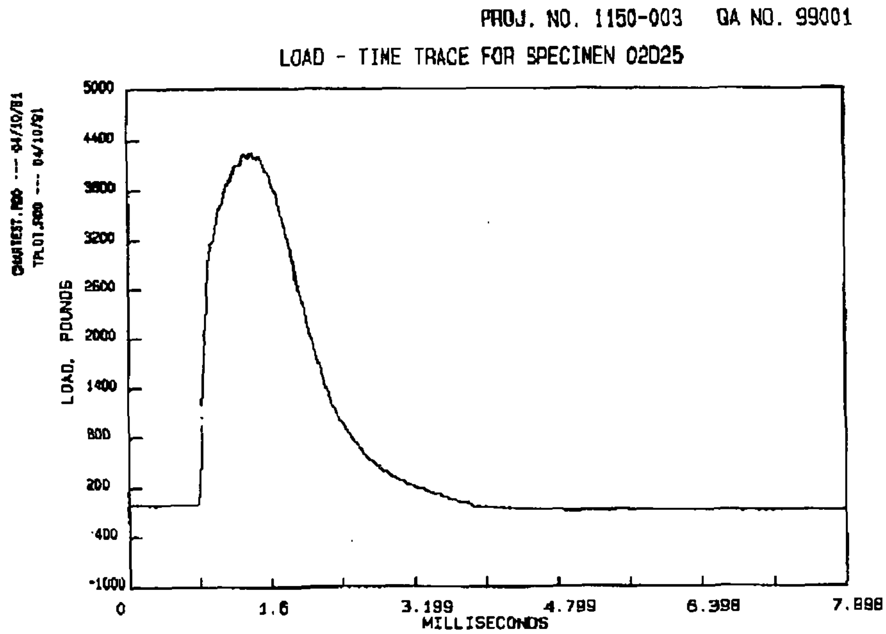


Figure B-46. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-15

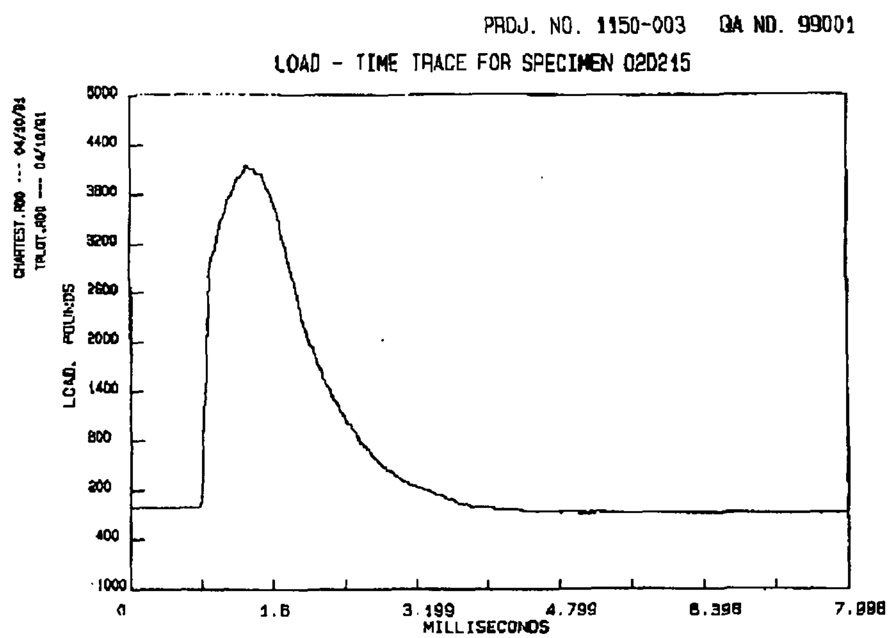


Figure B-47. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-24

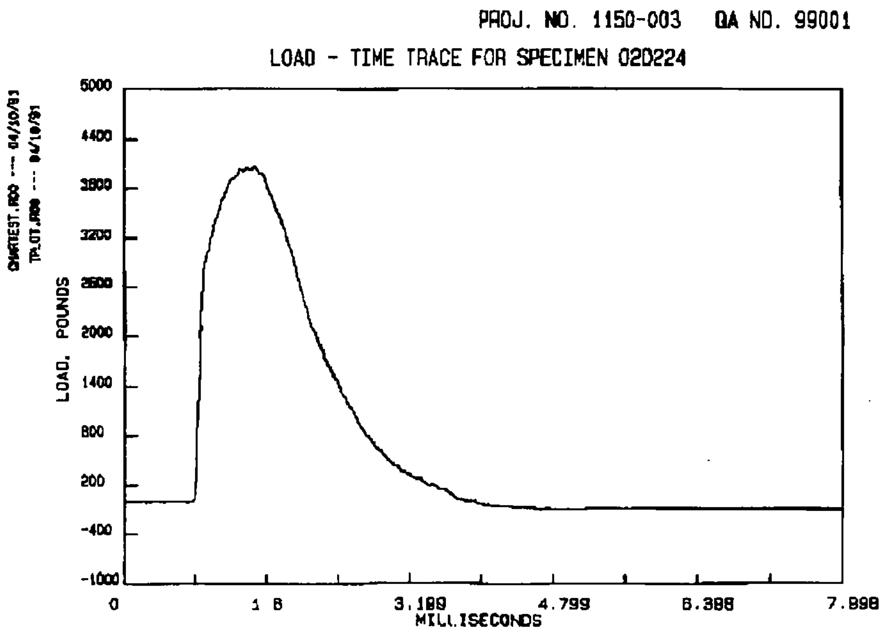
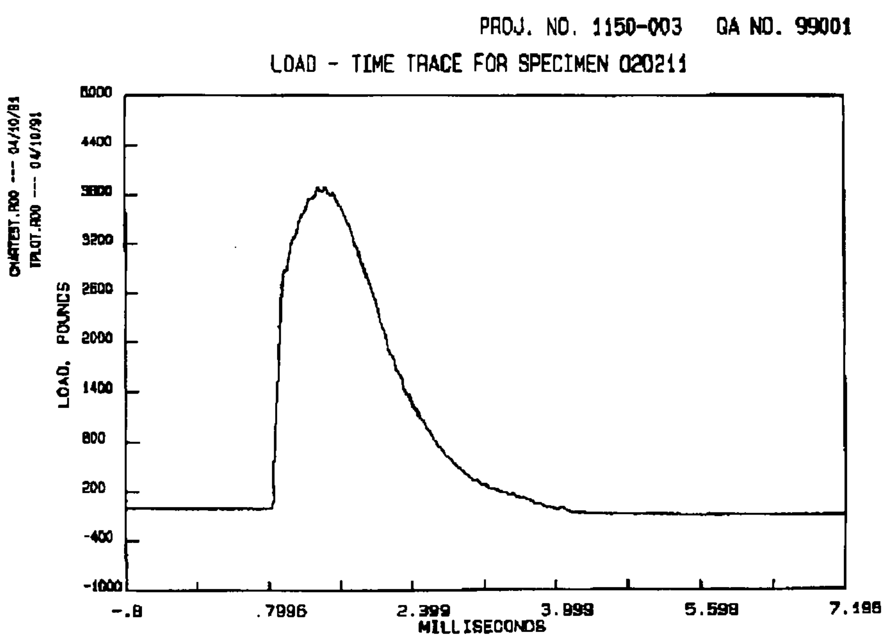


Figure B-48. Load-Time Trace for Charpy V-Notch Impact Specimen O2D2-11



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