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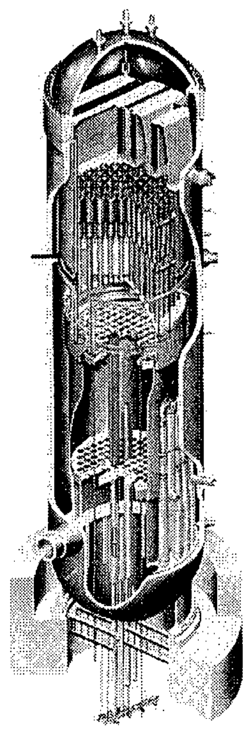
BWRVIP-87NP, Revision 1: BWR Vessel and Internals Project

Testing and Evaluation of BWR Supplemental Surveillance Program Capsules D, G, and H



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Testing and Evaluation of BWR Supplemental Surveillance Program Capsules D, G, and H

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BWRVIP-87: BWR Vessel and Internals Project, Testing and Evaluation of BWR Supplemental Surveillance Program Capsules D, G, and H, EPRI, Palo Alto, CA and BWRVIP: 2000. 1000890, authored by G.E. Nuclear Energy, Principal Investigator L. Tilly and ATI Consulting, Principal Investigator T. Hardin.

REPORT SUMMARY

Each boiling water reactor (BWR) has a surveillance program for monitoring changes in reactor pressure vessel (RPV) material properties due to neutron irradiation. This report describes testing and evaluation of BWR Supplemental Surveillance Program (SSP) capsules D, G, and H. These results will be used to monitor embrittlement as part of the BWR Vessel and Internals Project (BWRVIP) Integrated Surveillance Program (ISP).

Background
Light water reactor (LWR) vessel materials are subject to radiation-induced embrittlement, manifested by an increase in the ductile-brittle transition temperature of the material and by a drop in toughness in the ductile shelf region of the Charpy curve. Changes in the mechanical properties of surveillance specimens determine the degree of embrittlement.

BWR surveillance programs consist of surveillance capsules installed inside the RPV that include specimens from RPV plate, weld, and weld heat affected zone materials. These specimens are removed at intervals and tested to monitor material property changes. In the late 1980s, several U. S. BWR plants initiated the SSP to provide additional data to supplement those from the individual plant programs. The SSP consists of three capsules inserted into the Cooper RPV and six capsules inserted into the Oyster Creek RPV. The SSP capsules D, G, and H were inserted into Oyster Creek in February 1993 and removed in September 1996.

Objectives
- To document results of the neutron dosimetry and Charpy-V notch ductility tests for materials contained in the SSP capsules D, G, and H.
- To compare results with the embrittlement trend prediction of U.S. Nuclear Regulatory Commission (USNRC) Regulatory Guide 1.99, Rev. 2.

Approach
The capsules were inserted into the Oyster Creek reactor at a location of sufficient lead factor to provide the desired fluence. In September 1996, the capsules were removed from the Oyster Creek RPV and transported to facilities for testing and evaluation. Dosimetry was used to gather information about the neutron fluence accrual of the specimens, and thermal monitors were placed in the capsule to approximate the highest temperature during irradiation. Testing of Charpy V-notch specimens were performed according to ASTM standards.

Results

The report includes specimen chemical compositions, capsule neutron exposure, specimen temperatures during irradiation, and Charpy V-notch test results. Photographs of the Charpy specimen fracture surfaces also are provided. The project compared irradiated Charpy data for the specimens to unirradiated data to determine the shift in Charpy curves due to irradiation. Results indicate a shift lower than the predictions of Regulatory Guide 1.99, Revision 2, for all but three of the materials. Flux wires were measured and fluence was determined for each specimen set within the three capsules. Revision 1 of this report deletes the original fluence evaluation, which has been superseded by the re-evaluation reported in BWRVIP-128. Thermal monitor results demonstrated that the maximum temperature to which the specimens were exposed was between 518°F (270°C) and 536°F (280°C).

EPRI Perspective

Neutron irradiation exposure reduces the toughness of reactor vessel steel plates, welds, and forgings. Results of this work will be used in the BWRVIP ISP (TR-114228) that will integrate individual BWR surveillance programs into a single program. Data generated from the SSP specimens will provide significant additional data of high quality to monitor BWR vessel embrittlement. The ISP and the use of the SSP capsule specimen data will result in significant cost savings to the BWR fleet and provide more accurate monitoring of embrittlement in BWRs.

Keywords

Reactor pressure vessel integrity
Reactor vessel surveillance program
Radiation embrittlement
BWR
Charpy testing
Mechanical properties

ABSTRACT

This report describes the testing and evaluation of BWR Supplemental Surveillance Program (SSP) capsules D, G, and H. These capsules were installed in the Oyster Creek reactor in February 1993 and removed in September 1996. The capsules contained flux wires for neutron fluence measurement, thermal monitors to measure temperature, and Charpy test specimens for material property evaluations. The flux wires were evaluated to determine the fluence experienced by the test specimens. Thermal monitors were evaluated to determine the maximum temperature experienced by the specimens. Charpy V-notch impact testing was performed to establish the mechanical properties of the irradiated surveillance materials.

RECORD OF REVISIONS

Revision Number	Revisions
BWRVIP-87	Original Report (1000890).
Revision 1	The report as originally published (1000890) was revised to incorporate changes resulting from the updated fluence analysis for this capsule reported by *BWRVIP-128, Updated Fluence Calculations for Supplemental Surveillance Capsules D, G, and H Using RAMA Fluence Methodology*. In addition, the best estimate chemistry values and Charpy V-notch reference temperatures of some materials were updated to reflect analyses conducted since this report was first published. As a result, the values reported in this report are now consistent with the values used for implementation of the BWRVIP Integrated Surveillance Program data book BWRVIP-135 and other SSP capsule reports. Other editorial changes, clarifications and corrections for typographical errors were made as required. Details of the revisions can be found in Appendix D. All changes except corrections to typographical errors are marked with margin bars.

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1 INTRODUCTION

Part of the effort to assure reactor vessel integrity involves evaluation of the fracture toughness of the vessel ferritic materials. The key values that characterize fracture toughness are the reference temperature of nil-ductility transition (RT_{NDT}) and the upper shelf energy (USE). These are defined in 10CFR50 Appendix G [3] and in Appendix G of the ASME Boiler and Pressure Vessel Code, Section XI [4]. Appendix H of 10CFR50 [3] and ASTM E185-82 [5] establish the methods to be used for testing of the Supplemental Surveillance Program (SSP) test materials.

Nine (9) capsules containing test specimens were placed in two host reactors as part of the SSP. Three capsules (designated A, B, and C) were placed into the Cooper reactor, and the remaining six capsules (designated D through I) were placed into the Oyster Creek reactor. This report addresses the first set of capsules (Capsules D, G, and H) of the SSP removed and tested under this program. These capsules were removed from the Oyster Creek host reactor in September 1996 and shipped to the GE Vallecitos Nuclear Center (VNC) for testing. The surveillance capsules contained flux wires for neutron flux monitoring, Charpy V-notch impact test specimens fabricated using materials from a variety of sources, and thermal monitors.

The results of testing SSP capsules D, G, and H are presented in this report. The irradiated material properties are compared to the unirradiated properties to determine the effect of irradiation on material toughness for both base and weld materials, through Charpy testing.

The information and the associated evaluations provided in this report have been performed in accordance with the requirements of 10CFR50 Appendix B.

Implementation Requirements

The results documented in this report will be utilized by the BWRVIP ISP and by individual utilities to demonstrate compliance with 10CFR50, Appendix H, Reactor Vessel Material Surveillance Program Requirements. Therefore, the implementation requirements of 10CFR50, Appendix H govern and the implementation requirements of Nuclear Energy Institute (NEI) 03-08, Guideline for the Management of Materials Issues, are not applicable.

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MATERIALS

The chemical compositions, material descriptions, and unirradiated (baseline) mechanical properties of the materials irradiated in Oyster Creek Capsules D, G, and H are summarized below.

Chemical Compositions

The materials irradiated in Capsules D, G, and H are illustrated in Tables 2-1, 2-2 and 2-3. The capsules contained 30 sets of Charpy V-notch specimens representing 21 different materials. Chemical compositions are presented in weight percent. The majority of the materials included in these capsules were archive materials from BWR reactor pressure vessels. Other materials in these capsules are typical of those used in the construction of many operating nuclear reactor pressure vessels. With the exception of CE-1 (WM) and CE-2 (WM), the materials in Capsules D and G represent different sets of the same materials. The relatively high copper levels in many of these steels are representative of many older reactor vessels.

Table 2-1
Materials Irradiated in SSP (Oyster Creek) Capsule D

Identity	Material	Cu	Ni	P	S	Si
EP2	Japanese/EPRI Plate (SA533B-1)	0.06	0.59	0.006	0.008	0.22
A1224-1	Grand Gulf Plate (SA533B-1)	0.03	0.65	0.012	0.012	0.28
C2331-2	Cooper Plate (SA533B-1)	0.16	0.62	0.014	0.020	0.24
P2130-2	Nine Mile Point 1 Plate (SA302B, Mod)	0.172	0.584	0.018	0.028	0.17
C3278-2	FitzPatrick Plate (SA533B-1)	0.11	0.61	0.013	0.018	0.23
CE-1 (WM)	CE/EPRI Linde 1092 #1 Weld (Submerged Arc Weld)	0.22	1.00	0.014	0.009	0.21
5P6214B	Grand Gulf Weld (Submerged Arc Weld)	0.01	0.90	0.012	0.017	0.43
34B009	Millstone 1 Weld (Submerged Arc Weld)	0.15	1.81	0.017	0.016	0.21
DP2-21	Quad Cities 2 Weld (Electroslag Weld)	0.11	0.24	0.015	0.017	0.13
406L44	Quad Cities 1 Weld (Submerged Arc Weld)	0.29	0.69	0.016	0.018	0.47

Table 2-2
Materials Irradiated in SSP (Oyster Creek) Capsule G

Identity	Material	Cu	Ni	P	S	Si
EP2	Japanese/EPRI Plate (SA533B-1)	0.06	0.59	0.006	0.008	0.22
A1224-1	Grand Gulf Plate (SA533B-1)	0.03	0.65	0.012	0.012	0.28
C2331-2	Cooper Plate (SA533B-1)	0.16	0.62	0.014	0.020	0.24
P2130-2	Nine Mile Point 1 Plate (SA302B, Mod)	0.172	0.584	0.018	0.028	0.17
C3278-2	FitzPatrick Plate (SA533B-1)	0.11	0.61	0.013	0.018	0.23
CE-2 (WM)	CE/EPRI Linde 1092 #2 Weld (Submerged Arc Weld)	0.21	0.86	0.012	0.012	0.23
5P6214B	Grand Gulf Weld (Submerged Arc Weld)	0.01	0.90	0.012	0.017	0.43
34B009	Millstone 1 Weld (Submerged Arc Weld)	0.15	1.81	0.017	0.016	0.21
GP2-21	Quad Cities 2 Weld (Electroslag Weld)	0.11	0.24	0.015	0.017	0.13
406L44	Quad Cities 1 Weld (Submerged Arc Weld)	0.29	0.69	0.016	0.018	0.47

Table 2-3
Materials Irradiated in SSP (Oyster Creek) Capsule H

Identity	Material	Cu	Ni	P	S	Si
B&W-1 (BM)	B&W/EPRI Plate (SA302B, Mod)	0.155[1]	0.63	0.012	0.017	0.20
C3985-2	Hatch 1 Plate (SA533B-1)	0.11	0.60	0.015	0.017	0.27
C1079-1	Millstone 1 Plate (SA302B, Mod)	0.22	0.51	0.018	0.028	0.22
A0610-1	Quad Cities 1 Plate (SA302B, Mod)	0.17	0.52	0.015	0.018	0.19
A1195-1	HSST-02 Plate (SA533B-1)	0.15	0.70	0.014	0.020	0.22
BMF	B&W/EPRI Forging (SA508-2)	0.04	0.75	0.006	0.012	0.25
A0421	ASTM Standard Plate (SA302B)	0.19	0.17	0.017	0.025	0.27
HP2-BW	B&W Linde 80 Weld (Submerged Arc Weld)	0.26	0.56	0.014	0.011	0.53
HP2-6	Humboldt Bay 3 Weld (Submerged Arc Weld)	0.27	0.06	0.016	0.016	0.28
5P6756	River Bend Weld (Submerged Arc Weld)	0.06	0.93	0.009	0.015	0.40

Note:

1. Previously reported as 0.11 in BWRVIP-78. Revised to the best estimate value determined from all available surveillance data, based on discussions with M. Devan of FTI.

Material Description

Tables 2-4 and 2-5 contain information about the specimens in SSP (Oyster Creek) Capsules D, G, and H including fabricator, and copper and nickel content. Table 2-4 presents plate materials and Table 2-5 presents weld materials. The sequence of materials has been ordered to indicate increasing copper content.

Table 2-4
Plate Materials Irradiated in SSP (Oyster Creek) Capsules D, G, and H

Identity (Capsule)	Material Source	Material Type	Cu	Ni	Source (RPV Fabricator)
A1224-1 (D&G)	Grand Gulf	SA533B-1	0.03	0.65	GE (CBIN)
BMF (H)	B&W EPRI	SA508-2	0.04	0.75	EPRI (B&W)
EP2 (D&G)	Japanese/EPRI	SA533B-1	0.06	0.59	CRIEPI
C3985-2 (H)	Hatch 1	SA533B-1	0.11	0.60	GE (CE)
C3278-2 (D&G)	FitzPatrick	SA533B-1	0.11	0.61	GE (CE)
B&W-1 (BM) (H)	B&W/EPRI	SA302B, Mod	0.155[1]	0.63	EPRI (B&W)
C2331-2 (D&G)	Cooper	SA533B-1	0.16	0.62	GE (CE)
A1195-1 (H)	HSST-02	SA533B-1	0.15	0.70	ORNL (Lukens Steel)
P2130-2 (D&G)	Nine Mile Point 1	SA302B, Mod	0.172	0.584	GE (CE)
A0610-1 (H)	Quad Cities 1	SA302B, Mod	0.17	0.52	GE (B&W)
A0421 (H)	ASTM Standard	SA302B	0.19	0.17	GE (U.S. Steel)
C1079-1 (H)	Millstone 1	SA302B, Mod	0.22	0.51	GE (CE)

Note:

1. Previously reported as 0.11 in BWRVIP-78. Revised to the best estimate value determined from all available surveillance data, based on discussions with M. Devan of FTI.

Table 2-5
Weld Materials Irradiated in SSP (Oyster Creek) Capsules D, G, and H

Identity (Capsule)	Material Source	Weld Type	Cu	Ni	Source (RPV Fabricator)
5P6214B (D&G)	Grand Gulf	Submerged Arc Weld	0.01	0.90	GE (CBIN)
5P6756 (H)	River Bend	Submerged Arc Weld	0.06	0.93	GE (CBIN)
DP2-21 & GP2-21 (D&G)	Quad Cities 2	Electroslag Weld	0.11	0.24	GE (B&W)
34B009 (D&G)	Millstone 1	Submerged Arc Weld	0.15	1.81	GE (CE)
CE-2 (WM) (G)	CE/EPRI	Submerged Arc Weld, Linde 1092 Flux	0.21	0.86	EPRI (CE)
CE-1 (WM) (D)	CE/EPRI	Submerged Arc Weld, Linde 1092 Flux	0.22	1.00	EPRI (CE)
HP2-BW (H)	B&W	Submerged Arc Weld, Linde 80	0.26	0.56	B&W
HP2-6 (H)	Humboldt Bay 3	Submerged Arc Weld	0.27	0.06	GE (CE)
406L44 (D&G)	Quad Cities 1	Submerged Arc Weld	0.29	0.69	GE (B&W)

Unirradiated Properties

CVN Baseline Properties

Tables 2-6, 2-7 and 2-8 provide a summary of the baseline (unirradiated) Charpy V-notch properties of the SSP (Oyster Creek) Capsules D, G, and H materials, respectively. In these tables and throughout this report, T_{30} is the 30 ft-lb (40.7 J) transition temperature; T_{50} is the 50 ft-lb (67.8 J) transition temperature; T_{35mil} is the 35 mil (0.89 mm) lateral expansion temperature; and USE is the average energy absorption at full shear. The values provided in these tables were obtained from CVGRAPH [6, 18] hyperbolic tangent curve fits. Plate values are transverse orientation with the exception of A0421 ASTM Standard material that is of longitudinal orientation.

Table 2-6
Baseline CNV Properties of SSP (Oyster Creek) Capsule D

Material Identity	Material	T_{30} °F (°C)	T_{50} °F (°C)	T_{35mil} °F (°C)	Upper Shelf Energy (USE) Ft-lb (J)
EP2	Japanese/EPRI Plate (SA533B-1)	-41.6 (-40.9)	0.7 (-17.4)	-17.9 (-27.7)	109.5 (148.5)
A1224-1	Grand Gulf Plate (SA533B-1)	-20.9 (-29.4)	5.9 (-14.5)	10.9 (-11.7)	147.3 (199.7)
C2331-2	Cooper Plate (SA533B-1)	-13.3 (-25.2)	30.1 (-1.1)	34.1 (1.2)	100.0 (135.6)
P2130-2	Nine Mile Point 1 Plate (SA302B, Mod)	-2.8 (-19.3)	41.6 (5.3)	22.8 (-5.1)	68.2 (92.5)
C3278-2	FitzPatrick Plate (SA533B-1)	-34.4 (-36.9)	5.4 (-14.8)	15.1 (-9.4)	113.3 (153.6)
CE-1 (WM)	CE/EPRI Linde 1092 #1 Weld (Submerged Arc Weld)	-41.0 (-40.6)	-5.9 (-21.1)	-39.7 (-39.8)	104.3 (141.4)
5P6214B	Grand Gulf Weld (Submerged Arc Weld)	-26.8 (-32.7)	7.0 (-13.9)	9.2 (-12.7)	91.5 (124.1)
34B009	Millstone 1 Weld (Submerged Arc Weld)	-65.0 (-53.9)	-29.5 (-34.2)	-21.0 (-29.4)	104.4 (141.5)
DP2-21	Quad Cities 2 Weld (Electroslag Weld)	-23.1 (-30.6)	17.9 (-7.8)	22.4 (-5.3)	104.0 (141.0)
406L44	Quad Cities 1 Weld (Submerged Arc Weld)	-8.8 (-22.7)	51.1 (10.6)	39.2 (4.0)	73.3 (99.4)

Table 2-7
Baseline CNV Properties of SSP (Oyster Creek) Capsule G

Material Identity	Material	T_{30} °F (°C)	T_{50} °F (°C)	T_{35mil} °F (°C)	Upper Shelf Energy (USE) Ft-lb (J)
EP2	Japanese/EPRI Plate (SA533B-1)	-41.6 (-40.9)	0.7 (-17.4)	-17.9 (-27.7)	109.5 (148.5)
A1224-1	Grand Gulf Plate (SA533B-1)	-20.9 (-29.4)	5.9 (-14.5)	10.9 (-11.7)	147.3 (199.7)
C2331-2	Cooper Plate (SA533B-1)	-13.3 (-25.2)	30.1 (-1.1)	34.1 (1.2)	100.0 (135.6)
P2130-2	Nine Mile Point 1 Plate (SA302B, Mod)	-2.8 (-19.3)	41.6 (5.3)	22.8 (-5.1)	68.2 (92.5)
C3278-2	FitzPatrick Plate (SA533B-1)	-34.4 (-36.9)	5.4 (-14.8)	15.1 (-9.4)	113.3 (153.6)
CE-2 (WM)	CE/EPRI Linde 1092 #2 (Submerged Arc Weld)	-96.1 (-71.2)	-45.7 (-43.2)	-62.9 (-52.7)	119.3 (161.7)
5P6214B	Grand Gulf Weld (Submerged Arc Weld)	-26.8 (-32.7)	7.0 (-13.9)	9.2 (-12.7)	91.5 (124.1)
34B009	Millstone 1 Weld (Submerged Arc Weld)	-65.0 (-53.9)	-29.5 (-34.2)	-21.0 (-29.4)	104.4 (141.5)
GP2-21	Quad Cities 2 Weld (Electroslag Weld)	23.1 (-30.6)	17.9 (-7.8)	22.4 (-5.3)	104.0 (141.0)
406L44	Quad Cities 1 Weld (Submerged Arc Weld)	-8.8 (-22.7)	51.1 (10.6)	39.2 (4.0)	73.3 (99.4)

Table 2-8
Baseline CNV Properties of SSP (Oyster Creek) Capsule H

Material Identity	Material	T_{30} °F (°C)	T_{50} °F (°C)	T_{35mil} °F (°C)	Upper Shelf Energy (USE) Ft-lb (J)
B&W-1 (BM)	B&W/EPRI Plate (SA302B, Mod)	-0.7 (-18.2)	40.4 (4.7)	32.9 (0.5)	124.8 (169.2)
C3985-2	Hatch 1 Plate (SA533B-1)	-11.7 (-24.3)	27.0 (-2.8)	31.1 (-0.5)	112.8 (152.9)
C1079-1	Millstone 1 Plate (SA302B, Mod)	9.7 (-12.4)	76.6 (24.8)	57.1 (13.9)	61.2 (83.0)
A0610-1	Quad Cities 1 Plate (SA302B, Mod)	-33.5 (-36.4)	-4.1 (-20.1)	-1.5 (-18.6)	101.2 (137.2)
A1195-1	HSST-02 Plate (SA533B-1)	39.8 (4.3)	78.7 (25.9)	79.6 (26.4)	99.7 (135.2)
BMF	B&W/EPRI Forging (SA508-2)	-31.5 (-35.3)	-5.9 (-21.1)	-12.5 (-24.7)	125.8 (170.6)
A0421	ASTM Standard Plate (SA302B)	38.1 (3.4)	83.2 (28.4)	60.2 (15.7)	68.8 (93.3)
HP2-BW	B&W Linde 80 Weld (Submerged Arc Weld)	40.0 (4.4)	94.9 (34.9)	80.9 (27.2)	75.8 (102.8)
HP2-6	Humboldt Bay 3 Weld (Submerged Arc Weld)	-74.0 (-58.9)	-29.3 (-34.1)	-24.6 (-31.4)	110.3 (149.5)
5P6756	River Bend Weld (Submerged Arc Weld)	-67.1 (-55.1)	-21.3 (-29.6)	-20.3 (-29.1)	104.4 (141.5)

3
TEST SPECIMEN DESCRIPTION

An inventory of the Charpy specimens contained in SSP (Oyster Creek) Capsules D, G, and H is provided in Table 3-1.

Table 3-1
Quantities of Specimens in SSP (Oyster Creek) Capsules D, G, and H

Identity: Specimen Code	Capsule	Material	Charpy Specimen Quantity
EP2: EP2-41…83[1]	D	Japanese/EPRI Plate (SA533B-1)	10
A1224-1: DP1-67	D	Grand Gulf Plate (SA533B-1)	10
C2331-2: DP1-30	D	Cooper Plate (SA533B-1)	10
P2130-2: DP1-11	D	Nine Mile Point 1 Plate (SA302B, Mod)	10
C3278-2: DP1-28	D	FitzPatrick Plate (SA533B-1)	10
CE-1 (WM): C111.131[2]	D	CE/EPRI Linde 1092 #1 (Submerged Arc Weld)	10
5P6214B: DP2-67	D	Grand Gulf Weld (Submerged Arc Weld)	10
34B009: DP2-15	D	Millstone 1 Weld (Submerged Arc Weld)	10
DP2-21: DP2-21[3]	D	Quad Cities 2 Weld (Electroslag Weld)	10
406L44: DP2-20	D	Quad Cities 1 Weld (Submerged Arc Weld)	10
EP2: EP2-49…85[4]	G	Japanese/EPRI Plate (SA533B-1)	10
A1224-1: GP1-67	G	Grand Gulf Plate (SA533B-1)	10
C2331-2: GP1-30	G	Cooper Plate (SA533B-1)	10
P2130-2: GP1-11	G	Nine Mile Point 1 Plate (SA302B, Mod)	10
C3278-2: GP1-28	G	FitzPatrick Plate (SA533B-1)	10
CE-2 (WM): C212.232[5]	G	CE/EPRI Linde 1092 #2 (Submerged Arc Weld)	10

Table 3-1
Quantities of Specimens in SSP (Oyster Creek) Capsules D, G, and H (Continued)

Identity: Specimen Code	Capsule	Material	Charpy Specimen Quantity
5P6214B: GP2-67	G	Grand Gulf Weld (Submerged Arc Weld)	10
34B009: GP2-15	G	Millstone 1 Weld (Submerged Arc Weld)	10
GP2-21: GP2-21[3]	G	Quad Cities 2 Weld (Electroslag Weld)	10
406L44: GP2-20	G	Quad Cities 1 Weld (Submerged Arc Weld)	10
B&W-1 (BM): B11.20[6]	H	B&W/EPRI Plate (SA302B, Mod)	10
C3985-2: HP1-36	H	Hatch 1 Plate (SA533B-1)	10
C1079-1: HP1-15	H	Millstone 1 Plate (SA302B, Mod)	10
A0610-1: HP1-20	H	Quad Cities 1 Plate (SA302B, Mod)	10
A1195-1: HP1-H2	H	HSST-02 Plate (SA533B-1)	10
BMF: A01.10[7]	H	B&W/EPRI Forging (SA508-2)	10
A0421: Y41.Y4C[8]	H	ASTM Standard Plate (SA302B)	10
HP2-BW: HP2-BW[3]	H	B&W Linde 80 Weld (Submerged Arc Weld)	10
HP2-6: HP2-6[3]	H	Humboldt Bay 3 Weld (Submerged Arc Weld)	10
5P6756: HP2-72	H	River Bend Weld (Submerged Arc Weld)	10

Notes:

1. Charpy specimen codes: EP2-41, -42, -45, -46, -57, -67, -68, -71, -72, -83
2. Charpy specimen codes: C111, C113, C115, C117, C119, C122, C124, C126, C128, C131
3. The heat number of these materials is unknown. The specimen code has been used as the specimen identity for clarity.
4. Charpy specimen codes: EP2-49, -50, -53, -54, -59, -75, -76, -79, -80, -85
5. Charpy specimen codes: C212, C214, C216, C218, C221, C223, C225, C227, C229, C232
6. Charpy specimen codes: B11, B12, B13, B14, B15, B16, B17, B18, B19, B20
7. Charpy specimen codes: A01, A02, A03, A04, A05, A06, A07, A08, A09, A10
8. Charpy specimen codes: Y41, Y42, Y43, Y44, Y45, Y46, Y47, Y4A, Y4B, Y4C

Charpy V-Notch Specimens

The Charpy specimens were full-size Charpy V-notch specimens machined to dimensions as specified in ASTM Specification E185-82 [5]. Plate specimens were removed from both the 1/4T and 3/4T positions, and were machined in the transverse direction, with several exceptions discussed below. Weld specimens were removed from all thicknesses of the welded plate except for the surface 0.5 inch (1.3 cm) and the weld root, with several exceptions discussed below. Specimens were machined perpendicular to the length of the weld, with the notch perpendicular to the surface, as specified in ASTM Specification E185-82.

The ASTM Standard material, A0421 specimens were taken from all thicknesses of the plate, and were cut in the longitudinal direction.

The B&W Linde 80 weld (HP2-BW) material was provided in a block with no weld root. The outer surface was removed and discarded. The specimens were fabricated from the remaining material to dimensions as specified in ASTM Specification E185-82.

The EPRI materials [EP2, CE-1 (WM), CE-2 (WM), B&W-1 (BM), and BMF] were provided as finished specimens from several sources.

Dosimeters

Since numerous sets of specimens were placed in each capsule and the capsules are up to 20 inches in vertical height, full length copper and iron flux wires were included. These wires were cut to lengths corresponding to the locations of each specimen set and analyzed separately so that a precise fluence was determined for each set of specimens. In most cases, however, there was little difference in fluence in a given capsule.

Capsules D and G each had an additional cylinder of special dosimetry. Table 3-2 presents an inventory of the special dosimetry.

Radiometric analysis of the dosimetry is discussed in Section 4.

Table 3-2
Special Dosimetry in SSP (Oyster Creek) Capsules D, G, and H

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Thermal Monitors

The temperature monitors are quartz tubes containing small cylinders or wires of eutectic material designed to melt within 4°F (2°C) of a specified temperature. The BWR annulus between the vessel wall and the core shroud in the region of the surveillance capsules contains a mix of water returning from the core and feedwater. Depending on feedwater temperature, this annulus region is between 525°F (274°C) and 535°F (279°C). Therefore, temperature monitors designed to melt at specific temperatures provided in Table 3-3 were included in SSP (Oyster Creek) Capsule D.

Table 3-3
Thermal Monitors Contained in SSP (Oyster Creek) Capsule D

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4
MATERIAL IRRADIATION

This chapter describes the irradiation facility, specimen loading within the capsules, and radiometric analysis of the dosimetry.

Reactor Facility

Capsules D, G, and H of the Supplemental Surveillance Program were irradiated in the Oyster Creek Nuclear Generating Station owned and operated by AmerGen, Inc. Oyster Creek has a typical BWR core configuration with minor fuel management applied. Capsules D, G, and H were not part of the reactor vessel complement, but were inserted for the purpose of irradiating SSP materials. A plan view of the Oyster Creek reactor vessel demonstrating the location of the SSP capsules is shown in Figure 4-1.

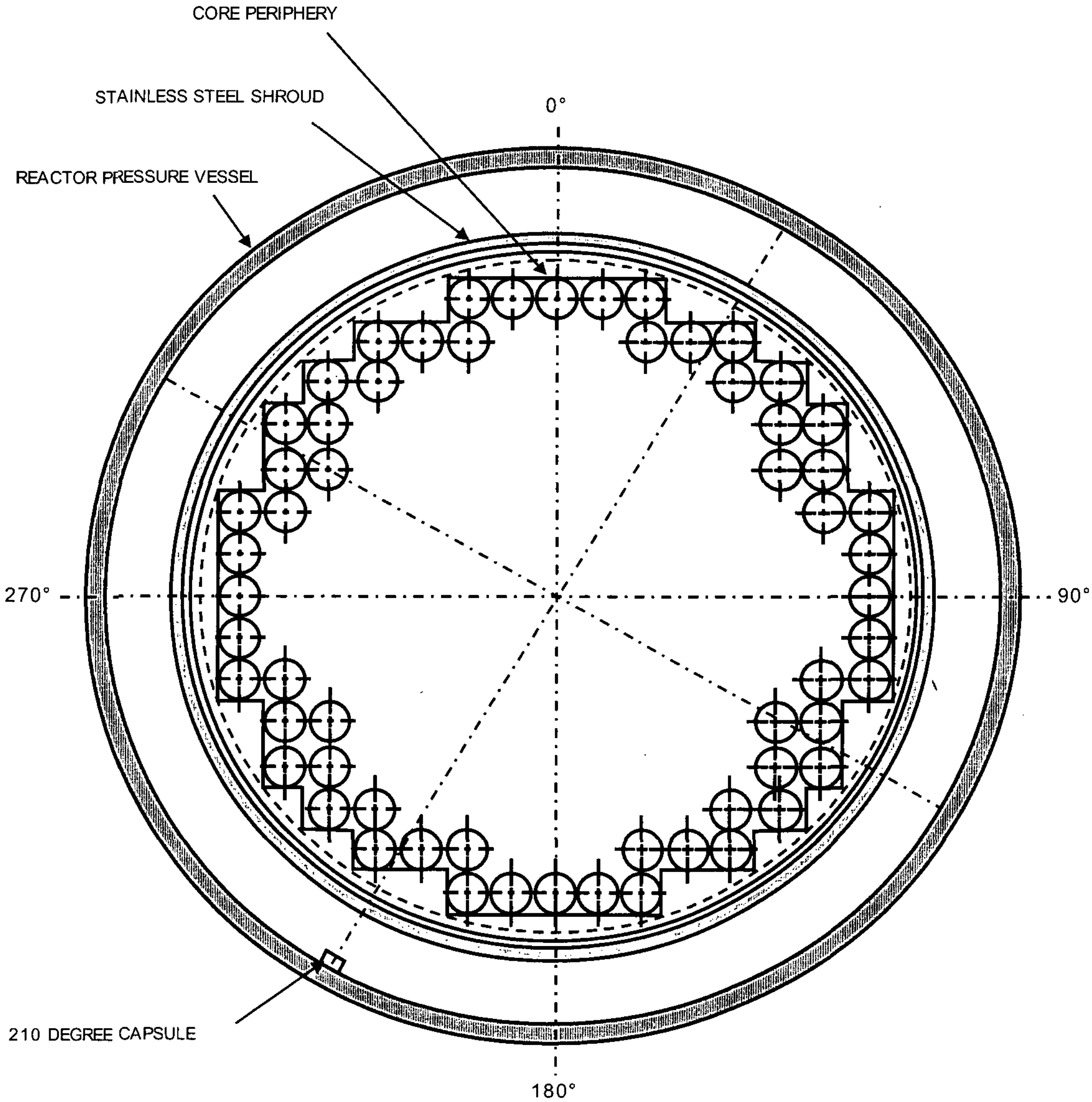

Figure 4-1
Oyster Creek Reactor Pressure Vessel Cross-Section at Core Midplane

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Figure 4-2
SSP (Oyster Creek) Capsule D, G, and H Installation Orientation

Capsule Design

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Specimen Loading

The location of Charpy V-notch specimens (by group) in the SSP (Oyster Creek) Capsules D, G, and H is provided in Figures 4-3, 4-4, and 4-5, respectively. The specimens were stacked in two columns, with the V-notch facing the reactor core. Full length (approximately 20 inch) iron and copper dosimeter wires were installed in each V-notch. Figure 4-6 provides the orientation of the G/H capsule installation with respect to the vessel wall and reactor core. The location of the special dosimetry contained in Capsules D and G, and thermal monitors contained in Capsule D are provided in Figures 4-3 and 4-4. Figure 4-7 provides the orientation of the special dosimetry wires within the capsule. It may be noted that, while azimuths are provided in Figure 4-7, a known dosimetry capsule orientation is not necessary, as it can be determined from the induced radioactivities after irradiation. Figure 4-2 depicts the capsule holders as installed in the Oyster Creek reactor pressure vessel.

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Figure 4-3
Charpy Specimen, Thermal Monitor, and Dosimetry Locations for SSP (Oyster Creek) Capsule D

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Figure 4-4
Charpy Specimen and Dosimetry Locations for SSP (Oyster Creek) Capsule G

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Figure 4-5
Charpy Specimen Locations for SSP (Oyster Creek) Capsule H

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Figure 4-6
SSP (Oyster Creek) Capsule G/H Orientation

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Figure 4-7
SSP (Oyster Creek) Capsule D and G Special Dosimetry Orientation

Neutron Dosimetry

Two sets of iron and copper flux wires were provided from each of the three capsules. In addition, two special dosimetry capsules containing niobium, iron (4 wires), copper, nickel, titanium, cobalt (Al + 4660 ppm Co), silver foil, and silver wire (Al + 1.08% silver) flux monitors were provided from Capsules D and G. A uranium-235 (uranium sealed in quartz tube) wire was also present in the Capsule D special dosimetry capsule. The special dosimetry monitors were encased in gadolinium, which acted as a thermal neutron shield. The nuclear reactions utilized by these dosimeters are:

Nb-93 (n,n') Nb-93m
Fe-54 (n,p) Mn-54
Cu-63 (n,α) Co-60
U-235 (n,f) Cs-137
Co-59 (n,γ) Co-60
Ag-109 (n,γ) Ag-110m
Ti-46 (n,p) Sc-46
Ni-58 (n,p) Co-58

The copper and iron flux wires were all longer than 19.65 inches, the height of the Charpy specimens in each capsule. The Charpy specimens were loaded in sets of ten, each 3.93 inches in height, with ten sets included in each capsule, five on each side. The flux wires ran along the extent of each of the five sets and any additional length was bent over to keep the wires in place. The wires were cut into 19 one-inch pieces. The remaining length of wire was cut at the bends resulting in one horizontal and as many as two vertical pieces. The six sets of flux wires were identified as Capsule D-Left, Capsule D-Right, Capsule G-Left, Capsule G-Right, Capsule H-Left, and Capsule H-Right. The two special dosimetry capsules were identified as Capsule D and Capsule G monitors for counting purposes. Capsule D was located closest to the RPV, about 6 inches (centerline distance) (15.2 cm) from the vessel wall. Capsules G and H were piggybacked, with Capsule H being closer to the vessel wall. Capsule H was about 6.25 inches (15.9 cm) from the wall and Capsule G was about 6.75 inches (17.1 cm) from the wall. Capsule H did not contain a dosimetry monitor.

All of the Fe and Cu wires were counted, as were the Fe, Cu, Nb, U, Al-Co, Ag and Al-Ag wires from the special dosimetry capsules. The short half-life wires, Ti and Ni, were not counted since the activities were too low. This was because the wires were pulled from the reactor almost four years before they were counted. The dosimeter wire weights are presented in Tables 4-1, 4-2, 4-3 and 4-4. The left and right sets of flux wires in each capsule are identified in these tables as DL, DR, GL, GR, HL, and HR.

Each wire was cleaned with 4N or 8N HNO_3, followed by rinses with water and acetone. Except for Nb, each wire was then weighed and mounted on a counting card. The wires were then analyzed for radioactivity content by gamma spectrometry.

Because Nb is analyzed via low energy x-rays which are easily self-absorbed in a wire, a different specimen preparation technique was used. Each niobium wire was dissolved in a minimum amount of HF + HNO_3. After diluting to 10.0 ml with water, a 0.100 ml aliquot was pipetted onto a 2-cm Whatman 541 disk. After drying, the disk was sealed between sheets of clear plastic tape.

The 170-cc Ge calibrated gamma detector was utilized in conjunction with a Nuclear Data, Inc. 6700 computer/multichannel analyzer system for all but the Nb wires. The 170-cc Ge gamma detector was used in conjunction with Canberra Industries GENIE-2000 analyzer system for the Nb wires. The counting systems used for the analysis of each dosimeter type are given in Table 4-5. The measurements were performed, except for Nb93, between September 29, 1999 and November 12, 1999, 1120-1164 days after the end of irradiation. Where possible, at least 50,000 counts were accumulated in the peak of interest. The detector systems were calibrated with standards procured from the National Institute of Standards and Technology (NIST) and Amersham Corporation. The Nb wires were counted on July 20, 2000, 1415 days after end of irradiation.

This work was performed in conformance with the following ASTM standards: E181 [8], E261 [9], E263 [10], E1297 [11], E523 [12], E844 [13], and E1005 [14].

Table 4-1
Dosimetry Wires: Capsule D

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Table 4-2
Dosimetry Wires: Capsule G

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Table 4-3
Dosimetry Wires: Capsule H

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Table 4-4
Dosimetry Wires: Capsules D and G Monitors

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Table 4-5
Counting Systems for Radioactivity Analysis

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Table 4-6 lists the nuclear parameters associated with the dosimeters. The fluxes obtained from the three dosimetry wires were consistent and within the uncertainties of the cross section data.

Table 4-6
Dosimeter Nuclear Parameters

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Capsule Neutron Exposure Determination

The fluence analysis originally reported in this capsule report has been superseded by the updated fluence analysis of *BWRVIP-128* [19]. A complete discussion of the revised fluence analysis is provided in *BWRVIP-128*. The following tables summarize the results from that analysis.

Table 4-7
Calculated Neutron Fluence and Rated Power Flux (>1.0 MeV) in Capsule D

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Table 4-8
Calculated Neutron Fluence and Rated Power Flux (>1.0 MeV) in Capsule G

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Table 4-9
Calculated Neutron Fluence and Rated Power Flux (>1.0 MeV) in Capsule H

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Specimen Temperatures During Irradiation

Capsule D contained five alloy thermal monitors as discussed in Section 3 and defined in Table 3-3. Examination of the monitors indicated that two of the thermal monitors were melted. Evidence exists that two of the monitors were inadvertently switched during the capsule loading prior to installation into the reactor. The monitor placed in the 518°F (270°C) sleeve did not melt while the monitor placed in the 536°F (280°C) sleeve did melt. Measurements of the quartz tubes containing the eutectic material also indicate that the 518°F and 536°F monitors were interchanged within the sleeves. The thermal monitor results therefore demonstrated that the maximum temperature to which the specimens were exposed was between 518°F and 536°F.

5 RESULTS

Charpy V-Notch Testing

Impact Test Procedure

The testing of the Charpy V-notch specimens was performed in accordance with 10CFR50, Appendices G [3] and H [3] and ASTM Specification E185-82 [5].

The Charpy impact tests were performed per ASTM Specification E23-98 [17] on a Tinius-Olsen Model 84 impact machine. The maximum energy capacity of this machine is 300 ft-lb (407J), which produces a test velocity of 19.3 ft/sec (5.9 m/sec). The test apparatus (Tinius Olsen machine) and operator were qualified using NIST Standard Reference Material specimens.

Charpy V-notch tests were conducted at temperatures between -50°F (-46°C) and 400°F (204°C). The cooling fluid used for irradiated specimens (and typical for unirradiated specimens) tested at temperatures at or below 60°F (16°C) was ethyl alcohol. At temperatures between 60°F (16°C) and 200°F (93°C), water was used as the temperature conditioning fluid. The specimens were heated in silicon oil for test temperatures above 200°F (93°C). Several exceptions are noted: six specimens were tested at an air temperature of 75°F (24°C), and silicon oil was also used for temperatures between 125°F (52°C) and 200°F (93°C) for EP2 specimens. Cooling of the conditioning fluids was achieved by heat exchange with liquid nitrogen through a copper coil; heating was achieved using an immersion heater. The bath of fluid was mechanically stirred to maintain uniform temperatures. The fluid temperature was measured using an Omega Model DP460 (Serial Number 96090059) digital temperature read-out connected to a calibrated Type K chromel-alumel thermocouple positioned near the samples. After equilibration at the test temperature for at least five minutes, the specimens were manually transferred with centering tongs to the Charpy test machine and impacted in less than five seconds.

Lateral expansion and percent shear were measured according to specified methods defined in ASTM E23-98. For each Charpy V-notch specimen the lateral expansion was determined using a Brown & Sharpe dial caliper Model 579-1 (ID 27906). Percent shear was determined in accordance with Appendix X1 of ASTM E23-98, which involved determining the percent shear value from comparison of the cleavage surface against Figure A6.1. Photographs were taken of both fracture surfaces of the irradiated specimens, which are presented in Appendix C, with the following exception. Photographs of the EP2 specimens include one fracture surface only.

Impact Test Results

The results of Charpy V-notch impact tests performed on the various materials contained in the SSP (Oyster Creek) capsules D, G, and H are presented in Appendix A, Tables A-1 through A-30. Photographs of the fracture surfaces illustrating the transition in fracture appearance for each irradiated material are provided in Appendix C, Figures C-1 through C-30. The fractures generally show an increasingly ductile or tougher appearance with increasing test temperature.

Analysis of Impact Test Results

A hyperbolic tangent curve-fitting program named CVGRAPH [6, 18] developed by ATI Consulting was used to fit the Charpy V-notch energy data. The impact energy curve-fits from CVGRAPH are provided in Appendix B. Lower shelf energy was fixed at 2.5 ft-lbs (3.4 J) in all cases. Upper shelf energy was fixed at the average of all test energies (at least 3) exhibiting shear greater than or equal to 95%, consistent with ASTM Standard E185-82 [5]. In cases where there were not three data points exhibiting greater than 95% shear, an engineering judgement was made whether the upper shelf should remain free or be fixed at the average of those points with greater than 95% shear.

Irradiated Versus Unirradiated CVN Properties

Tables 5-1, 5-2, and 5-3 summarize the T_{30} [30 ft-lb (40.7 J) Transition Temperature], T_{50} [50 ft-lb (67.8 J) Transition Temperature], T_{35mil} [35 mil (0.89 mm) Lateral Expansion Temperature], and Upper Shelf Energy for the unirradiated and irradiated materials and show the change from baseline values for Capsules D, G, and H, respectively. These tables have been sequenced by capsule. The unirradiated and irradiated values are taken from the CVGRAPH fits provided in Appendix B. It may be noted that the materials in Capsules D and G [with the exception of CE-1(WM) and CE-2(WM)] are the same.

Table 5-1
Effect of Irradiation (E>1.0 MeV) on the Notch Toughness Properties of Capsule D Materials

Material Identity[1]	T_{30}, 30 ft-lb (40.7 J) Transition Temperature			T_{35mil}, 35 mil (0.89 mm) Lateral Expansion Temperature			T_{50}, 50 ft-lb (67.8 J) Transition Temperature			CVN Upper Shelf Energy (USE)		
	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{30} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{35mil} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{50} °F (°C)	Unirrad ft-lb (J)	Irradiated ft-lb (J)	Change ft-lb (J)
EP2	-41.6 (-40.9)	-3.6 (-19.8)	38.0 (21.1)	-17.9 (-27.7)	20.7 (-6.3)	38.6 (21.4)	0.7 (-17.4)	37.0 (2.8)	36.3 (20.2)	109.5 (148.5)	101.1 (137.1)	-8.4 (-11.4)
A1224-1	-20.9 (-29.4)	-11.3 (-24.1)	9.6 (5.3)	10.9 (-11.7)	19.6 (-6.9)	8.7 (4.8)	5.9 (-14.5)	23.7 (-4.6)	17.8 (9.9)	147.3 (199.7)	148.0 (200.7)	0.7 (1.0)
C2331-2	-13.3 (-25.2)	48.7 (9.3)	62.0 (34.4)	34.1 (1.2)	86.3 (30.2)	52.2 (29.0)	30.1 (-1.1)	92.8 (33.8)	62.7 (34.8)	100.0 (135.6)	89.3 (121.1)	-10.7 (-14.5)
P2130-2	-2.8 (-19.3)	50.1 (10.1)	52.9 (29.4)	22.8 (-5.1)	67.2 (19.6)	44.4 (24.7)	41.6 (5.3)	90.2 (32.3)	48.6 (27.0)	68.2 (92.5)	74.6 (101.1)	6.4 (8.7)
C3278-2	-34.4 (-36.9)	1.2 (-17.1)	35.6 (19.8)	15.1 (-9.4)	49.9 (9.9)	34.8 (19.3)	5.4 (-14.8)	52.1 (11.2)	46.7 (25.9)	113.3 (153.6)	104.1 (141.1)	-9.2 (-12.5)

1. Fluence is unique to each specimen set:
   EP2 = 1.0044×10^{18} n/cm^2
   A1224-1 = 1.0164×10^{18} n/cm^2
   C2331-2 = 1.0118×10^{18} n/cm^2
   P2130-2 = 1.0112×10^{18} n/cm^2
   C3278-2 = 0.9931×10^{18} n/cm^2

Table 5-1
Effect of Irradiation (E>1.0 MeV) on the Notch Toughness Properties of Capsule D Materials (Continued)

Material Identity[1]	T_{30}, 30 ft-lb (40.7 J) Transition Temperature			T_{35mil}, 35 mil (0.89 mm) Lateral Expansion Temperature			T_{50}, 50 ft-lb (67.8 J) Transition Temperature			CVN Upper Shelf Energy (USE)		
	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{30} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{35mil} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{50} °F (°C)	Unirrad ft-lb (J)	Irradiated ft-lb (J)	Change ft-lb (J)
CE-1(WM)	-41.0 (-40.6)	86.8 (30.4)	127.8 (71.0)	-39.7 (-39.8)	111.9 (44.4)	151.6 (84.2)	-5.9 (-21.1)	131.6 (55.3)	137.5 (76.4)	104.3 (141.4)	80.3 (108.9)	-24.0 (-32.5)
5P6214B	-26.8 (-32.7)	-23.7 (-30.9)	3.1 (1.7)	9.2 (-12.7)	7.6 (-13.6)	-1.6 (-0.9)	7.0 (-13.9)	25.9 (-3.4)	18.9 (10.5)	91.5 (124.1)	89.0 (120.7)	-2.5 (-3.4)
34B009	-65.0 (-53.9)	37.7 (3.2)	102.7 (57.1)	-21.0 (-29.4)	78.8 (26.0)	99.8 (55.4)	-29.5 (-34.2)	83.1 (28.4)	112.6 (62.6)	104.4 (141.5)	76.7 (104.0)	-27.7 (-37.5)
DP2-21	-23.1 (-30.6)	10.2 (-12.1)	33.3 (18.5)	22.4 (-5.3)	50.6 (10.3)	28.2 (15.6)	17.9 (-7.8)	54.8 (12.7)	36.9 (20.5)	104.0 (141.0)	93.8 (127.2)	-10.2 (-13.8)
406L44	-8.8 (-22.7)	119.2 (48.4)	128.0 (71.1)	39.2 (4.0)	206.3 (96.8)	167.1 (92.8)	51.1 (10.6)	396.3 (202.4)	345.2 (191.8)	73.3 (99.4)	50.2 (68.1)	-23.1 (-31.3)

1. Fluence is unique to each specimen set:
CE-1(WM) = 1.0202×10^{18} n/cm^2
5P6214B = 1.0317×10^{18} n/cm^2
34B009 = 1.0261×10^{18} n/cm^2
DP2-21 = 1.0222×10^{18} n/cm^2
406L44 = 1.0018×10^{18} n/cm^2

Table 5-2
Effect of Irradiation (E>1.0 MeV) on the Notch Toughness Properties of Capsule G Materials

Material Identity[1]	T_{30}, 30 ft-lb (40.7 J) Transition Temperature			T_{35mil}, 35 mil (0.89 mm) Lateral Expansion Temperature			T_{50}, 50 ft-lb (67.8 J) Transition Temperature			CVN Upper Shelf Energy (USE)		
	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{30} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{35mil} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{50} °F (°C)	Unirrad ft-lb (J)	Irradiated ft-lb (J)	Change ft-lb (J)
EP2	-41.46 (-40.9)	-14.45 (-25.8)	27.01 (15.1)	-17.9 (-27.7)	13.21 (-10.5)	31.10 (17.2)	0.7 (-17.4)	32.2 (0.1)	31.5 (17.5)	109.5 (148.5)	104.9 (142.2)	-4.6 (-6.3)
A1224-1	-20.9 (-29.4)	-0.6 (-18.1)	20.3 (11.3)	10.9 (-11.7)	25.1 (-3.8)	14.2 (7.9)	5.9 (-14.5)	31.3 (-0.4)	25.4 (14.1)	147.3 (199.7)	144.4 (195.8)	-2.9 (-3.9)
C2331-2	-13.3 (-25.2)	78.7 (25.9)	92.0 (51.1)	34.1 (1.2)	118.2 (47.9)	84.1 (46.7)	30.1 (-1.1)	127.2 (52.9)	97.1 (53.9)	100.0 (135.6)	81.6 (110.6)	-18.4 (-25.0)
P2130-2	-2.8 (-19.3)	75.1 (23.9)	77.9 (43.3)	22.8 (-5.1)	93.7 (34.3)	70.9 (39.4)	41.6 (5.3)	124.9 (51.6)	83.3 (46.3)	68.2 (92.5)	64.3 (87.2)	-3.9 (-5.3)
C3278-2	-34.4 (-36.9)	-7.2 (-21.8)	27.2 (15.1)	15.1 (-9.4)	33.8 (1.0)	18.7 (10.4)	5.4 (-14.8)	39.4 (4.1)	34.0 (18.9)	113.3 (153.6)	99.0 (134.2)	-14.3 (-19.4)

1. Fluence is unique to each specimen set:
   EP2 = 1.8831×10^{18} n/cm^2
   A1224-1 = 1.8758×10^{18} n/cm^2
   C2331-2 = 1.8487×10^{18} n/cm^2
   P2130-2 = 1.8163×10^{18} n/cm^2
   C3278-2 = 1.7569×10^{18} n/cm^2

Table 5-2
Effect of Irradiation (E>1.0 MeV) on the Notch Toughness Properties of Capsule G Materials (Continued)

Material Identity[1]	T_{30}, 30 ft-lb (40.7 J) Transition Temperature			T_{35mil}, 35 mil (0.89 mm) Lateral Expansion Temperature			T_{50}, 50 ft-lb (67.8 J) Transition Temperature			CVN Upper Shelf Energy (USE)		
	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{30} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{35mil} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{50} °F (°C)	Unirrad ft-lb (J)	Irradiated ft-lb (J)	Change ft-lb (J)
CE-2(WM)	-96.1 (-71.2)	68.8 (20.4)	164.9 (91.6)	-62.9 (-52.7)	103.5 (39.7)	166.4 (92.4)	-45.7 (-43.2)	126.7 (52.6)	172.4 (95.8)	119.3 (161.7)	70.1 (95.0)	-49.2 (-66.7)
5P6214B	-26.8 (-32.7)	7.2 (-13.8)	34.0 (18.9)	9.2 (-12.7)	28.5 (-1.9)	19.3 (10.7)	7.0 (-13.9)	40.3 (4.6)	33.3 (18.5)	91.5 (124.1)	85.3 (115.7)	-6.2 (-8.4)
34B009	-65.0 (-53.9)	40.9 (4.9)	105.9 (58.8)	-21.0 (-29.4)	67.8 (19.9)	88.8 (49.3)	-29.5 (-34.2)	69.3 (20.7)	98.8 (54.9)	104.4 (141.5)	104.6 (141.8)	0.2 (0.3)
GP2-21	-23.1 (-30.6)	55.0 (12.8)	78.1 (43.4)	22.4 (-5.3)	79.7 (26.5)	57.3 (31.8)	17.9 (-7.8)	90.1 (32.3)	72.2 (40.1)	104.0 (141.0)	96.9 (131.4)	-7.1 (-9.6)
406L44	-8.8 (-22.7)	147.9 (64.4)	156.7 (87.1)	39.2 (4.0)	178.8 (81.6)	139.6 (77.6)	51.1 (10.6)	Note 2	Note 2	73.3 (99.4)	49.4 (67.0)	-23.9 (-32.4)

1. Fluence is unique to each specimen set:
   CE-2(WM) = 1.9503×10^{18} n/cm^2
   5P6214B = 1.9461×10^{18} n/cm^2
   34B009 = 1.9173×10^{18} n/cm^2
   GP2-21 = 1.8783×10^{18} n/cm^2
   406L44 = 1.8270×10^{18} n/cm^2
2. This material did not achieve 50 ft-lbs.

Table 5-3
Effect of Irradiation (E>1.0 MeV) on the Notch Toughness Properties of Capsule H Materials

Material Identity[1]	T_{30}, 30 ft-lb (40.7 J) Transition Temperature			T_{35mil}, 35 mil (0.89 mm) Lateral Expansion Temperature			T_{50}, 50 ft-lb (67.8 J) Transition Temperature			CVN Upper Shelf Energy (USE)		
	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{30} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{35mil} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{50} °F (°C)	Unirrad ft-lb (J)	Irradiated ft-lb (J)	Change ft-lb (J)
B&W-1(BM)	-0.7 (-18.2)	53.6 (12.0)	54.3 (30.2)	32.9 (0.5)	75.1 (23.9)	42.2 (23.4)	40.4 (4.7)	87.7 (30.9)	47.3 (26.3)	124.8 (169.2)	102.8 (139.4)	-22.0 (-29.8)
C3985-2	-11.7 (-24.3)	19.4 (-7.0)	31.1 (17.3)	31.1 (-0.5)	55.6 (13.1)	24.5 (13.6)	27.0 (-2.8)	62.5 (16.9)	35.5 (19.7)	112.8 (152.9)	110.5 (149.8)	-2.3 (-3.1)
C1079-1	9.7 (-12.4)	102.3 (39.1)	92.6 (51.4)	57.1 (13.9)	128.9 (53.8)	71.8 (39.9)	76.6 (24.8)	216.0 (102.2)	139.4 (77.4)	61.2 (83.0)	55.3 (75.0)	-5.9 (-8.0)
A0610-1	-33.5 (-36.4)	24.9 (-3.9)	58.4 (32.4)	-1.5 (-18.6)	58.0 (14.4)	59.5 (33.1)	-4.1 (-20.1)	67.4 (19.7)	71.5 (39.7)	101.2 (137.2)	85.0 (115.2)	-16.2 (-22.0)
A1195-1	39.8 (4.3)	104.8 (40.4)	65.0 (36.1)	79.6 (26.4)	137.4 (58.6)	57.8 (32.1)	78.7 (25.9)	151.8 (66.6)	73.1 (40.6)	99.7 (135.2)	91.8 (124.5)	-7.9 (-10.7)

1. Fluence is unique to each specimen set:
B&W-1(BM) = 1.6250×10^{18} n/cm^2
C3985-2 = 1.6240×10^{18} n/cm^2
C1079-1 = 1.6006×10^{18} n/cm^2
A0610-1 = 1.5720×10^{18} n/cm^2
A1195-1 = 1.5224×10^{18} n/cm^2

Table 5-3
Effect of Irradiation (E>1.0 MeV) on the Notch Toughness Properties of Capsule H Materials (Continued)

Material Identity	T_{30}, 30 ft-lb (40.7 J) Transition Temperature			T_{35mil}, 35 mil (0.89 mm) Lateral Expansion Temperature			T_{50}, 50 ft-lb (67.8 J) Transition Temperature			CVN Upper Shelf Energy (USE)		
	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{30} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{35mil} °F (°C)	Unirrad °F (°C)	Irradiated °F (°C)	ΔT_{50} °F (°C)	Unirrad ft-lb (J)	Irradiated ft-lb (J)	Change ft-lb (J)
BMF	-31.5 (-35.3)	-20.0 (-28.9)	11.5 (6.4)	-12.5 (-24.7)	7.2 (-13.8)	19.7 (10.9)	-5.9 (-21.1)	17.2 (-8.2)	23.1 (12.9)	125.8 (170.6)	119.8 (162.4)	-6.0 (-8.2)
A0421	38.1 (3.4)	106.2 (41.2)	68.1 (37.8)	60.2 (15.7)	112.3 (44.6)	52.1 (28.9)	83.2 (28.4)	144.9 (62.7)	61.7 (34.3)	68.8 (93.3)	66.0 (89.5)	-2.8 (-3.8)
HP2-BW	40.0 (4.4)	196.4 (91.3)	156.4 (86.9)	80.9 (27.2)	252.0 (122.2)	171.1 (95.1)	94.9 (34.9)	347.4 (175.2)	252.5 (140.3)	75.8 (102.8)	53.0 (71.9)	-22.8 (-30.9)
HP2-6	-74.0 (-58.9)	22.3 (-5.4)	96.3 (53.5)	-24.6 (-31.4)	65.2 (18.4)	89.8 (49.9)	-29.3 (-34.1)	84.8 (29.3)	114.1 (63.4)	110.3 (149.5)	80.0 (108.5)	-30.3 (-41.1)
5P6756	-67.1 (-55.1)	-3.4 (-19.7)	63.7 (35.4)	-20.3 (-29.1)	12.5 (-10.8)	32.8 (18.2)	-21.3 (-29.6)	22.3 (-5.4)	43.6 (24.2)	104.4 (141.5)	84.6 (114.7)	-19.8 (-26.8)

1. Fluence is unique to each specimen set:
   - BMF = 1.6867×10^{18} n/cm^2
   - A0421 = 1.6861×10^{18} n/cm^2
   - HP2-BW = 1.6615×10^{18} n/cm^2
   - HP2-6 = 1.6275×10^{18} n/cm^2
   - 5P6756 = 1.5766×10^{18} n/cm^2

Discussion

The materials irradiated in SSP (Oyster Creek) Capsules D, G, and H exhibited a wide range of radiation embrittlement sensitivity. All but three of the materials experienced less embrittlement than that predicted using U.S. Nuclear Regulatory Commission (USNRC) Regulatory Guide 1.99, Rev. 2 [1] (including margin), based on a unique fluence ($E > 1.0$ MeV) for each set of specimens. Tables 5-4, 5-5, and 5-6 illustrate this comparison for Capsule D, G, and H materials, respectively. Measured shifts that are greater than predicted shifts including margin are shown in bold.

Tables 5-7, 5-8 and 5-9 present a comparison of the predicted upper shelf energy (USE) percent decrease using the USNRC Regulatory Guide 1.99, Rev. 2 figure [1] with the measured percent decrease calculated from the values presented in Tables 5-1 through 5-3. Measured percent decreases that are greater than those predicted are shown in bold.

Table 5-4
Comparison of Actual Versus Predicted Embrittlement of SSP (Oyster Creek) Capsule D Materials

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Table 5-5
Comparison of Actual Versus Predicted Embrittlement of SSP (Oyster Creek) Capsule G Materials

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Table 5-6
Comparison of Actual Versus Predicted Embrittlement of SSP (Oyster Creek) Capsule H Materials

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Table 5-7
Comparison of Actual Versus Predicted Percent Decrease in Upper Shelf Energy (USE) of SSP (Oyster Creek) Capsule D Materials

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Table 5-8
Comparison of Actual Versus Predicted Percent Decrease in Upper Shelf Energy (USE) of SSP (Oyster Creek) Capsule G Materials

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Table 5-9
Comparison of Actual Versus Predicted Percent Decrease in Upper Shelf Energy (USE) of SSP (Oyster Creek) Capsule H Materials

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19. *BWRVIP-128: BWR Vessel and Internals Project, Updated Fluence Calculations for Supplemental Surveillance Capsules D, G, and H Using RAMA Fluence Methodology,* EPRI, Palo Alto, CA, 2004. 101997.
20. *BWRVIP-135: BWR Vessel and Internals Project, Integrated Surveillance Program (ISP) Data Source Book and Plant Evaluations*, EPRI, Palo Alto, CA: 2004. 1011019.
21. Framatome ANP Engineering Information Record 51-5023275-00, "Charpy Impact Testing of Oconee 1 Plate Material," December 20, 2002.

A
SUMMARY OF CHARPY V-NOTCH TEST DATA

Entire Appendix
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B
TANH CURVE FIT PLOTS OF CVN TEST DATA

Ten (10) Charpy V-Notch specimens of each irradiated plate and weld material were tested at temperatures selected to define the toughness transition and upper shelf portions of the fracture toughness curves. The absorbed energy and lateral expansion data were fit with the hyperbolic tangent function of CVGRAPH [6]. The absorbed energy data and fit plots are presented in this Appendix. Unirradiated data for the same materials were also fit and are presented for comparison. The curves have been sequenced by material in order of unirradiated, followed by irradiated.

Note: Fluences shown on CVGRAPH figures for A0421 and BMF have been superseded. See Section 4 for the correct specimen fluences.

Note: Subsequent to the original issue of this capsule report, the Charpy V-notch data for most capsule materials were re-analyzed for other reports using a newer version of CVGRAPH and to show the updated fluences from BWRVIP-128. In some cases, the newer version of CVGRAPH resulted in a small (e.g., <0.3°F) change in reference temperature due to the more advanced tanh fitting routine. In addition, for a few materials (e.g., P2130-2) additional baseline data was found in addition to the original SSP baseline data, and the curve fit was regenerated with all appropriate data. As a result, many of the original CVGRAPH figures have been replaced in this appendix, to ensure consistency between this report and the values reported and used in other BWRVIP ISP program documents and capsule reports.

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C
CVN FRACTURE APPEARANCE PHOTOGRAPHS

Photographs of each Charpy specimen fracture surface were taken per the requirements of ASTM E185-82 [5]. Figures C-1 through C-30 show both fracture surfaces of each specimen presented in order of test temperature, which is identified below each photograph. Exceptions to this are Figures C-1 and C-11, representing the EP2 materials, which show only one fracture surface. Specific details of the Charpy test results including percent shear values are presented in Tables A-1 through A-30.

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D
RECORD OF REVISIONS

BWRVIP-87, Revision 1	Information from the following documents was used in preparing the changes included in this revision of the report: 1. *BWRVIP-135: BWR Vessel and Internals Project, Integrated Surveillance Program (ISP) Data Source Book and Plant Evaluations*, EPRI, Palo Alto, CA: 2004. 1011019. 2. *BWRVIP-128: BWR Vessel and Internals Project, Updated Fluence Calculations for Supplemental Surveillance Capsules D, G, and H Using RAMA Fluence Methodology,* EPRI, Palo Alto, CA 2004. 101997. 3. Framatome ANP, Engineering Information Record 51-5023275-00, "Charpy Impact Testing of Oconee 1 Plate Material," December 20, 2002. 4. GE-NE-523-101-1290, "Progress Report on Phase 2 of the BWR Owners' Group Supplemental Surveillance Program," GE Nuclear Energy, January 1992. 5. Letter, W.L. Server (ATI Consulting) to R.G. Carter (EPRI), Reassessment of EPRI-CRIEPI Joint Program Materials Heat Identities and Chemistries, October 25, 2002. Details of the revisions can be found in Table D-1.

Table D-1
Revision Details

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
SECTION 1, INTRODUCTION		
	NEI 03-08	Implementation Requirements added.
SECTION 2, MATERIALS		
Update the best estimate chemistry values for plate heats C2331-2, P2130-2, C3985-2, and C3278-2 and weld heat 5P6756.	Reference 1.	The chemistry values originally reported were based on the chemistry measurements made by GE at the time the SSP capsules were assembled [4]. Subsequent to the publication of the original issue of this report, the BWRVIP found additional chemistry measurements for these surveillance materials from the source plant records. Reference 1 calculated a revised best estimate based on all valid data. Tables 2-1 through 2-5 were updated to show the latest best estimate chemistry values for these surveillance materials.
Correct the best estimate Cu chemistry value for weld heat CE-1(WM).	Reference 1.	The Cu value for CE-1(WM) was incorrectly reported as 0.21 wt.%. Tables 2-1 and 2-5 were revised to show the correct value of 0.22 wt.%.
Correct the Si chemistry value for plate heat A0610-1.	Reference 4.	The Si value for A0610-1 was incorrectly reported as 0.019 wt.%. This value was corrected to 0.19 wt.% in Table 2-3.
Correct the material description of Heat BMF; it is a forging, not a plate.	Reference 5.	The material description of BMF in Table 2-3 was changed from "plate" to "forging."
Update the baseline Charpy properties of heats EP2, A1224-1, C2331-2, C3278-2, CE-1(WM), CE-2(WM), C3985-2, C1079-1, A0610-1, A1195-1, B&W Linde 80 SAW, Humboldt Bay 3 SAW, 34B009, Quad Cities 2 ESW, 5P6214B, 5P6756, and 406L44.	Make the reported baseline Charpy properties of these materials consistent with other BWRVIP ISP capsule reports.	The tanh curve fits to the baseline data originally reported for these materials were generated with CVGRAPH Version 4.1. Subsequent analyses for all materials utilized in the BWRVIP ISP have used an updated version of CVGRAPH, Version 5.0.2. Depending on the data set analyzed, small differences in reference temperature may be obtained due to the improved tanh fitting routine in CVGRAPH 5.0.2. Therefore, to ensure consistent results for all materials analyzed by the BWRVIP ISP, the baseline data were reanalyzed using Version 5.0.2, and the baseline values reported in Tables 2-6, 2-7, and 2-8 were updated. The updated curve fits are provided in Appendix B.

Table D-1
Revision Details (Continued)

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
Update the baseline Charpy properties of plate heat P2130-2 in Tables 2-6 and 2-7.	Reference 1	This material is used in the BWRVIP ISP. Subsequent to the original issue of this capsule report, additional analyses of the CVN properties were conducted using an updated version of CVGRAPH, Version 5.0.2, and documented in Reference 1. Additional, valid baseline data for the material was found and included in the analysis. The baseline values reported in Tables 2-6 and 2-7 were updated to be consistent with the values used in the BWRVIP ISP *BWRVIP-135 Data Source Book* for ISP implementation. The updated curve fits are provided in Appendix B.
Correct the baseline Charpy properties of plate heat B&W-1(BM) in Table 2-8.	Reference 3.	The baseline Charpy values originally reported in Table 2-8 for B&W-1(BM) were incorrect; the fabricator had provided the HAZ Charpy data as being the base plate data. Archive material for this heat was retested, and in addition the correct original baseline data were identified. The combined baseline data were fit by CVGRAPH and are reported in Table 2-8. The updated curve fit is provided in Appendix B.
Correct the material description of Heat BMF; it is a forging, not a plate.	Reference 5.	The material description of BMF in Table 2-8 was changed from "plate" to "forging."
SECTION 3, TEST SPECIMEN DESCRIPTION		
Correct the material description of Heat BMF; it is a forging, not a plate.	Reference 5.	The material description of BMF in Table 3-1 was changed from "plate" to "forging."
SECTION 4, MATERIAL IRRADIATION		
Revise subsection "Capsule Neutron Exposure Determination".	Reference 2.	This subsection, as originally published, has been superseded in its entirety by the revised fluence analysis reported by BWRVIP-128 [2]. The original subsection was deleted and the results tables from BWRVIP-128 were added to provide immediate reference to the revised fluence results. Readers are referred to BWRVIP-128 for a detailed discussion on the revised capsule fluence analysis.

Table D-1
Revision Details (Continued)

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
SECTION 5, RESULTS		
Update the paragraph under *Irradiated versus Unirradiated CVN Properties.*	Editorial.	Deleted mention of References 7 and 18 as the sources of the CVGRAPH curve fits; those references are no longer the source of most fits in Appendix B; identification of the internal ATI documents which are the sources is not necessary. Deleted description of Tables 5-4 through 5-12, which have been deleted in this Revision because they were unnecessary repetition of the data in Tables 5-1 through 5-3.
Table 5-1: Update the notch toughness properties for EP2, A1224-1, C2331-2, P2130-2, C3278-2, CE-1(WM), 5P6214B, 34B009, Quad Cities 1 ESW, and 406L44.	Table 2-6	The values shown in this table were updated to reflect the values from updated tanh curve fits for these materials. The updated Charpy energy curve fits are presented in Appendix B.
Table 5-1: Update the fluence values for the specimens given in the footnote to the table.	Reference 2.	Fluences were updated per BWRVIP-128.
Table 5-2: Update the notch toughness properties for EP-2, A1224-1, C2331-2, P2130-2, C3278-2, CE-2(WM), 5P6214B, 34B009, Quad Cities 2 ESW, and 406L44.	Table 2-7	The values shown in this table were updated to reflect the values from updated tanh curve fits for these materials. The updated Charpy energy curve fits are presented in Appendix B.
Table 5-2: Update the fluence values for the specimens given in the footnote to the table.	Reference 2.	Fluences were updated per BWRVIP-128.
Table 5-3: Update the notch toughness properties for B&W-1(BM).	Reference 3.	The baseline (unirradiated) values shown in this table were updated to reflect the values from updated tanh curve fit for B&W-1(BM), based on new test data. The updated baseline Charpy energy curve fit is presented in Appendix B.
Table 5-3: Update the notch toughness properties for C3985-2, C1079-1, A0610-1, A1195-1, B&W Linde 80 SAW, Humboldt Bay 3 SAW, and 5P6756.	Table 2-8	The values shown in this table were updated to reflect the values from updated tanh curve fits for these materials. The updated Charpy energy curve fits are presented in Appendix B.

Table D-1
Revision Details (Continued)

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
Table 5-3: Update the fluence values for the specimens given in the footnote to the table.	Reference 2.	Fluences were updated per BWRVIP-128.
Delete Tables 5-4 through 5-12.	Editorial.	These tables unnecessarily duplicated the data in Tables 5-1 through 5-3.
Update the *Discussion* section to specify the revised number of materials which exceeded predicted embrittlement; to reflect deletion of Tables 5-4 through 5-12; and to delete discussion of the extent to which USE decrease was exceeded in some materials..	Editorial.	The discussion of the number of materials exceeding a 1.15 x predicted decrease in USE was out of date as a result of the revised analyses and is not required to be reported in the capsule report.
Update the three tables (formerly Tables 5-13, 5-14, and 5-15, now 5-4, 5-5, and 5-6, for Capsules D, G, and H, respectively) which compare the actual versus predicted embrittlement of the capsule specimens.	Reference 2.	As a result of the revised fluences from BWRVIP-128, all materials have a revised predicted shift. Some materials also have revised measured shifts, based on updated baseline data or updated tanh curve fits. Also, Footnote 3 to each table was modified to more precisely define the margin term.
Correct the material description of Heat BMF; it is a forging, not a plate.	Reference 5.	The material description of BMF in Table 5-6 was changed from "plate" to "forging."
Update the three tables (formerly Tables 5-16, 5-17, and 5-18, now 5-7, 5-8, and 5-9, for Capsules D, G, and H, respectively) which present the percent decrease in USE of the capsule specimens.	Reference 2.	All materials were updated for new fluence values from BWRVIP-128. Some materials were updated for % USE decrease based on revised CVN curve fits. The RG 1.99 Rev. 2 – predicted decrease in USE was updated due to all materials having a new fluence and some materials having an updated best estimate Cu.
SECTION 6, REFERENCES		
Add references as required.	Editorial.	CVGRAPH Version 5.0.2, used for all tanh curve fitting for the revised Charpy analyses for this revision, was added as Reference 18, replacing the previous Reference 18, which is superseded and no longer required as a reference. BWRVIP-128 revised fluence analysis was added as Reference 19. BWRVIP-135 ISP Data Source Book was added as Reference 20. Framatome testing report for B&W-1(BM) was added as Reference 21.

Table D-1
Revision Details (Continued)

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
APPENDIX A, SUMMARY OF CHARPY V-NOTCH TEST DATA		
Update the caption for Table A-26 to show BMF is a forging, not a plate.	Reference 5.	Replaced "plate" with "forging."
APPENDIX B, Tanh Curve Fit Plots of CVN Test Data		
Add a note at the introduction of the appendix to explain that some fluences on the CVGRAPH printouts for A0421 and BMF have been superseded by BWRVIP-128.	Editorial.	An explanatory note was added. Readers are directed to Section 4 for the updated specimen fluences.
Add a note at the introduction of the appendix to explain that the original baseline and irradiated curve fits for many capsule materials have been replaced by updated CVGRAPH curve fits.	Reference 1.	In order to ensure consistency between the data in this report and other BWRVIP ISP documents and capsule reports, most CVGRAPH Version 4.1 figures have been replaced with the more recent tanh fit analyses generated using CVGRAPH Version 5.0.2. Replacement of the tanh fits for A0421 and BMF was not required because those heats are unique to SSP Capsule H.
Replace Figures B-1, B-2, and B-3 with updated curve fits for heat EP-2.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-4, B-5, and B-6 with updated curve fits for heat A1224-1.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-7, B-8 and B-9 with updated curve fits for heat C2331-2.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-10, B-11, and B-12 with updated curve fits for heat P2130-2.	Reference 1.	The updated tanh curve fit(s) for this material generated for Reference 1 (BWRVIP-135) using CVGRAPH 5.0.2 included additional baseline data which became available after the original curve(s) in this report were generated. The updated curves are used to ensure consistency of ISP data in all BWRVIP reports.

Table D-1
Revision Details (Continued)

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
Replace Figures B-13, B-14, and B-15 with updated curve fits for heat C3278-2.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-16 and B-17 with updated curve fits for heat CE-1(WM).	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-18 and B-19 with updated curve fits for heat CE-2(WM).	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-20, B-21, and B-22 with updated curve fits for heat 5P6214B.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-23, B-24, and B-25 with updated curve fits for heat 34B009.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-26, B-27, and B-28 with updated curve fits for heat Quad Cities 2 ESW.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-29, B-30, and B-31 with updated curve fits for heat 406L44.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figure B-32 with updated curve fit for heat B&W-1(BM) baseline data.	Reference 3.	The baseline data originally reported for B&W-1(BM) was incorrect. Additional baseline Charpy testing was conducted and the updated curve fit is provided.
Replace Figure B-33 with updated curve fit for heat B&W-1(BM) in SSP H.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-34 and B-35 with updated curve fits for heat C3985-2.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-36 and B-37 with updated curve fits for heat C1079-1.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-38 and B-39 with updated curve fits for heat A0610-1.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-40 and B-41 with updated curve fits for heat A1195-1.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.

Table D-1
Revision Details (Continued)

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
Update the captions for Figures B-42 and B-43 to show BMF is a forging, not a plate.	Reference 5.	In the captions for Figures B-42 and B-43, replaced "plate" with "forging".
Replace Figures B-46 and B-47 with updated curve fits for heat B&W Linde 80 SAW.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-48 and B-49 with updated curve fits for heat Humboldt Bay 3 SAW (unknown heat).	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
Replace Figures B-50 and B-51 with updated curve fits for heat 5P6756.	Data consistency within all BWRVIP ISP reports.	Tanh curve fit(s) for this material were generated using CVGRAPH Version 5.0.2 to replace previous fits using Version 4.1.
APPENDIX C, CVN FRACTURE APPEARANCE PHOTOGRAPHS		
Update the caption for Figure C-26 to show BMF is a forging, not a plate.	Reference 5.	In the caption for Figure C-26, replaced "plate" with "forging".

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