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Attention: C. E. Carpenter

Subject: Project 704 - Transmittal of "BWR Vessel and Internals Project, BWR Integrated Surveillance Program Plan (BWRVIP-78NP), EPRI Report TR-114228NP, April 2000.

Reference: Letter from C. Terry to C. E. Carpenter, December 22, 1999: Transmittal of "BWR Vessel and Internals Project, BWR Integrated Surveillance Program Plan (BWRVIP-78), EPRI Report TR-114228, December 1999.

Enclosed are two (2) copies of the subject report. This is the non-proprietary version of the document submitted to the NRC by the letter referenced above.

If you have any questions on this subject please call Steve Lewis of Entergy, BWRVIP Assessment Committee Chairman, at (601) 368-5444.

Sincerely,

CTerry

Carl Terry
Niagara Mohawk Power Company
Chairman, BWR Vessel and Internals Project

Enclosure

D058

BWR Vessel and Internals Project BWR Integrated Surveillance Program Plan (BWRVIP-78NP)

BWR Vessel and Internals Project BWR Integrated Surveillance Program Plan (BWRVIP-78NP)

TR-114228NP

Final Report, April 2000

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REPORT SUMMARY

Each BWR has a surveillance program for monitoring changes in reactor pressure vessel (RPV) material properties due to neutron irradiation. Substantial cost savings and improvements in data quality are possible by integrating these individual surveillance programs. This report describes development of the BWR Integrated Surveillance Program (ISP) plan and identifies capsules to be tested throughout the life of the BWR fleet.

Background

Each BWR has its own surveillance program and the specimen selection, testing, analysis, and monitoring is conducted on a plant-specific basis. These programs consist of surveillance capsules installed inside the RPV that include specimens from RPV plate, weld, and heat affected zone materials. However, since BWRs were licensed over a period of years, the requirements and content of individual surveillance programs vary. For example, as a result of changes to industry standards and NRC regulatory guidance, some plants do not have surveillance specimens for the limiting RPV plate or weld material. Additionally, the same or similar heats of materials are sometimes included in surveillance programs of more than one BWR. For these and other reasons, BWR Vessel and Internals Project (BWRVIP) utilities concluded that it would be beneficial to combine all the separate BWR surveillance programs into a single integrated program. In such an integrated program, representative materials chosen for a specific RPV could be materials from another plant surveillance program or other source that better represents the limiting materials.

Objectives

- To optimize the quality of data and number of materials that will be used to monitor embrittlement of BWR reactor vessel materials.
- To ensure that the ISP will comply with the requirements for an integrated surveillance program in 10CFR50, Appendix H.
- To demonstrate a significant cost savings to the BWR fleet by implementing an ISP.

Approach

Researchers collected all available BWR reactor vessel fabrication records and surveillance program results. The ISP design included evaluating existing surveillance specimens, along with other available specimens, to develop an integrated plan for monitoring BWR RPV embrittlement, which would be an improvement compared to individual programs. A test matrix was developed to identify those specimens that best meet the needs of each BWR. Materials for the ISP were

specifically chosen to best represent the limiting plate and weld materials for each plant using specimens from the entire BWR fleet. Specimens that were not chosen as a best representative were not included for testing because other materials in the integrated program provided better quality and more representative data.

Results

In the current U. S. BWR surveillance program, 40 capsules remain to be tested by the end of plant license. Evaluations performed as part of the ISP demonstrate that 18 capsules were not chosen as a best representative of the fleet. Therefore, 22 capsules remain to satisfy the needs of the BWR fleet and maintain compliance with 10CFR 50 Appendix H requirements through the end of current licenses. In the license renewal period, a greater reduction in capsules to be tested may be realized. Of 69 capsules available, only 13 are needed, resulting in a potential net reduction of 56 capsules.

EPRI Perspective

Neutron irradiation exposure reduces the toughness of reactor vessel steel plates, welds, and forgings. Accurate methods for monitoring radiation embrittlement are important for evaluating the remaining life of RPV materials. The ISP will result in significant cost savings to the BWR fleet and provide more accurate monitoring of embrittlement in BWRs.

TR-114228NP

Keywords

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

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ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

10CFR50 Appendix H	Appendix H to Part 50 of Title 10 of the Code of Federal Regulations, "Reactor Vessel Material Surveillance Program Requirements"
ASME Code	American Society of Mechanical Engineers Boiler and Pressure Vessel Code
ASTM E-185	American Society for Testing and Materials E-185, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels"
BWR	Boiling Water Reactor
BWROG	BWR Owners' Group
BWRVIP	BWR Vessel and Internals Project
Capsule Set	A capsule set includes three or more capsules installed in a plant
EFPY	Effective full power year
EOL	End-of-license
Existing Surveillance Program	The set of surveillance capsules that were installed when each BWR was licensed. The surveillance capsules typically include specimens for plate, weld, and heat affected zone (HAZ) materials. The test results from the specimens are to be used for monitoring radiation embrittlement for the plant.
Full Charpy Curve	A Charpy curve based on Charpy tests of 8 or more specimens that are tested over a broad range of temperatures so that the shape of the curve can be clearly defined.
HAZ	Heat Affected Zone
Reg. Guide 1.99	USNRC Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials"
Representative Material	A plate or weld material that is selected from among existing surveillance programs or the SSP to represent the corresponding limiting plate or weld material in a plant.
Representative Data Set	The data set from the Charpy Impact test of the representative material that consists of three Charpy curves: 1) unirradiated, 2) 1st irradiated, and 3) 2nd irradiated.
RPV	Reactor Pressure Vessel
ISP	BWR Integrated Surveillance Program
IVE	Individual Vessel Evaluation

MLE	mils Lateral Expansion
SRM	Standard Reference Material is a material used to provide an independent check on the measurement of irradiation conditions for the surveillance materials.
SSP	BWR Supplemental Surveillance Program
USE	Upper Shelf Energy

ABSTRACT

This report describes an Integrated Surveillance Program (ISP) plan for monitoring radiation embrittlement of BWR reactor pressure vessels (RPVs). Each BWR has a surveillance program for monitoring the changes in RPV material properties due to neutron irradiation. These programs consist of surveillance capsules installed inside the RPV that include specimens from RPV plate, weld and heat affected zone materials. These specimens are removed at periodic intervals, tested and analyzed to monitor the radiation embrittlement of the RPV. Each BWR has their own surveillance program and the specimen selection, testing, analysis and monitoring is conducted on a plant-specific basis.

Since BWRs were licensed over a period of years, the requirements and content of the individual surveillance programs vary. For example, as a result of changes to industry standards and NRC regulatory guidance, some plants do not have surveillance specimens for the limiting RPV plate or weld material. Additionally, the same or similar heats of materials are sometimes included in the surveillance programs of more than one BWR. For these and other reasons, the utilities of the BWR Vessel and Internals Project (BWRVIP) concluded that it would be beneficial to combine all the separate BWR surveillance programs into a single integrated program. In such an integrated program, representative materials chosen for a specific RPV could be materials from another plant surveillance program or other source that better represents the limiting materials. The BWRVIP began this effort in 1998, and this report documents the ISP plan resulting from this work.

The design of this ISP included evaluating the existing surveillance specimens, along with other available specimens, to develop an integrated plan for monitoring BWR RPV embrittlement that would be an improvement compared to the individual programs. A test matrix was developed to identify those specimens that best meet the needs of each BWR. The materials for the ISP were specifically chosen to best represent the limiting plate and weld materials for each plant using specimens from the entire BWR fleet. Specimens that were not chosen as a best representative are not included and need not be tested, because other materials in the integrated program provide better quality and more representative data. This ISP will also result in significant cost savings to the BWR fleet.

This report describes the development of the BWR ISP plan and identifies the capsules to be tested throughout the life of the BWR fleet. The report also describes how the ISP will comply with the requirements for an integrated surveillance program in 10CFR50, Appendix H.

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1 INTRODUCTION

Each plant in the BWR fleet has an existing vessel surveillance program that consists of a set of surveillance capsules that were installed when the plant was licensed. The surveillance capsules typically include specimens for plate, weld, and heat affected zone (HAZ) materials. The test results from the specimens are used for monitoring radiation embrittlement of the beltline materials for that plant. However, many plants do not have a surveillance material that represents the limiting plate and/or weld material of the plant vessel. Instead of using the plant-specific surveillance data from a given plant, the data from across the fleet could be used. Material data from another plant surveillance program or other source could be used to better represent the limiting material for the target plant. Integrating the existing surveillance programs together is called the Integrated Surveillance Program (ISP).

The ISP will have several advantages over the existing plant-specific surveillance programs:

1. The capsule materials for the ISP are specifically chosen to provide an equal or better match for limiting plate and weld materials for each plant.

2. As a whole, the unirradiated material data for the ISP are of better quality than that of the existing surveillance programs.

3. The ISP includes the BWR Supplemental Surveillance Program (SSP) capsules. The SSP capsules contain important BWR-specific materials with well-characterized unirradiated properties. The SSP capsules are being irradiated to fluences characteristic of a BWR at the end-of-license and will provide a significant amount of BWR data over the next few years – much sooner than the current surveillance programs can provide.

4. The ISP will reduce the cost of surveillance testing and analysis to the entire BWR fleet.

5. The ISP will establish a plan for appropriate data sharing.

A review of the BWR fleet historical background is helpful to understand the advantages of the ISP. Each plant in the BWR fleet has an existing vessel surveillance program meeting the requirements of 10CFR50 Appendix H. However, there are three areas in which the existing programs can be improved. First, the surveillance materials in many plant-specific programs are not representative of the limiting vessel beltline materials. Many surveillance programs were established before 10CFR50 Appendix H, so there were no specific requirements to select the limiting beltline materials. For some plants licensed after 10CFR50 Appendix H was promulgated, the correlation for determining the limiting beltline materials changed after their programs were established. Consequently surveillance materials selected to represent the previous limiting materials may not now represent the new limiting materials. A second area for improvement relates to missing or inadequate unirradiated data for some surveillance materials. Third, most BWR surveillance programs are slow to yield surveillance data for fluences typical of BWR end-of-license (EOL) conditions, and it is desirable to improve the quantity and quality of EOL data sooner than current programs can provide.

1.1 Historical Background

A reactor pressure vessel (RPV) surveillance program is intended to monitor the changes in vessel material properties due to neutron irradiation. In July 1973, the Code of Federal Regulations, 10CFR50, Appendix H, established the first legal requirements for comprehensive surveillance programs in nuclear plants. Plants already licensed prior to that time had installed irradiation test samples using the guidance of the 1961 (tentative), 1962, 1966, 1970 or the then-emerging 1973 version of ASTM E-185. Today, reactor pressure vessels that exceed a peak neutron fluence of 10^{17} n/cm^2 at the end-of-license are required to have an RPV material surveillance program that monitors radiation embrittlement in accordance with 10CFR50 Appendix H [1].

10CFR50 Appendix H [1] specifies that the design of the surveillance program and the withdrawal schedule must meet the requirements of the edition of ASTM E-185 that is current on the issue date of the ASME Code to which the reactor vessel was purchased. Table 1-1 is a list of the editions of ASTM E-185 that establishes the requirements for each U. S. BWR plant at the time that the reactor vessel was purchased. (Note that this table may not necessarily reflect the current licensing basis for the plant.)

ASTM E-185 has undergone several enhancements since its introduction in 1961. The latest NRC approved version is ASTM E-185-82 [2]. Similarly, 10CFR50 Appendix H has been revised to more explicitly establish requirements for scheduling capsule withdrawal, testing capsule specimens, reporting test/analysis results, and integrating surveillance programs.

Currently, each BWR plant has an existing surveillance program that includes weld and plate materials. However, many plants do not have a surveillance material that represents the limiting plate and/or weld material of the RPV. Following are two reasons that this has occurred.

> First, many of the surveillance programs were implemented prior to the establishment of 10CFR50 Appendix H. As can be seen from Table 1-1, most plants pre-date the 1973 edition of ASTM E-185. There were no specific requirements to choose materials that represent the limiting beltline material for plants built prior to 1973. Therefore, some plants never had a plate and/or weld surveillance material to represent the limiting beltline material in their surveillance program. This is more true for weld material than for plate material.
>
> Second, for some plants, a revision to Reg. Guide 1.99 [3] resulted in a change in the limiting beltline material for that vessel.

In addition, some plants have limited or no unirradiated surveillance specimen data. For some plants, the unirradiated specimens were misplaced. The unirradiated data is needed to measure the irradiation shift of the tested surveillance materials.

Given the limitations in the existing plant surveillance programs, a program was introduced in the late 1980s to obtain additional BWR surveillance data on well-characterized BWR vessel materials. That program is called the Supplemental Surveillance Program (SSP). The SSP was designed to supplement the available vessel embrittlement database and to examine BWR specific irradiation trends. Selecting materials that are suitable for a fleet-wide correlation also results in a selection of materials representing a broad range of BWR fleet RPV materials chemistry. The SSP fills in gaps in the existing plant surveillance programs to match the BWR fleet limiting beltline materials. The scope of the SSP includes 84 sets of BWR Charpy specimens that represent both BWR plate and weld materials. In fact, most of the materials in the SSP are actual BWR vessel archive materials. Each of the 84 sets also has an excellent set of unirradiated data.

The combination of surveillance materials from the existing programs and materials from the SSP will make sufficient materials available to improve compliance with 10CFR50 Appendix H. Instead of using the plant-specific surveillance data from a given plant, the data from across the fleet could be evaluated to select the "best" representative material to monitor radiation embrittlement for that plant. The environments within the BWR fleet are very similar and use of material across the fleet should not result in any substantial variance of the radiation embrittlement results. This is supported by the correlation presented in Reg. Guide 1.99 and is discussed in more detail in Section 3.2.

Therefore, existing plant surveillance programs could realize significant improvement to embrittlement monitoring if surveillance materials were available to better represent the limiting materials and the quality of the unirradiated data were improved. The addition of the SSP materials to the existing surveillance program materials could further improve the ability of each plant in the BWR fleet to monitor radiation embrittlement of the limiting beltline materials.

1.2 Objectives of the Integrated Surveillance Program

There are two objectives for this BWR ISP:

1. Select the "best" representative material to monitor radiation embrittlement for each plant.
2. Reduce the cost of surveillance monitoring to the BWR fleet.

The BWR ISP will consider all the BWR fleet surveillance capsules and SSP capsules to choose the best representative for each of the plant limiting materials (plate and weld). These capsules will be matched to the limiting materials for each plant to determine the best representative materials for that plant. In determining the best match for limiting welds, consideration will be given to welds with the same heat number, similar chemistries, and common fabricator with the same welding procedure and flux type. Since most vessel plates were made from SA533, Grade B material, the primary factors for matching of plates will be the similarity in chemistries and availability of unirradiated data. Relative weighting will be given to the closeness of the chemistry match and the quality of the unirradiated data to compare the possible representative materials for each limiting weld and plate. The final ISP test matrix will take into account the fact that different fabricators made vessels and a special effort will be made to include enough materials from each fabricator to adequately reflect the overall fleet. In matching the available surveillance plates and welds, some capsule materials are good representatives for the limiting material for multiple plants. For example, the materials in the SSP capsules are well suited to be representative surveillance materials for many BWR vessels. This is a good demonstration of the value of the SSP, and it makes up for those existing capsules with materials that are poor matches for any limiting vessel material. The withdrawal schedule for the capsules with low value to the ISP will be deferred indefinitely. By optimizing the matches for capsule materials, the integrated surveillance program will result in better representation of the limiting beltline materials for each plant, while reducing the number of capsules to be tested. Therefore, the cost of the ISP will be reduced compared to the existing surveillance programs for the BWR fleet.

The work documented in this report was performed in accordance with 10CFR50, Appendix B.

1.3 Benefits of the ISP

An integrated BWR surveillance capsule testing program offers many advantages compared to the existing BWR capsule programs. The integrated program will be based on those capsules that best meet the needs of the BWR fleet. The benefits of the ISP to the BWR fleet are as follows:

- Improve compliance for each plant with the current version of 10CFR50 Appendix H [1] and ASTM E-185 [2].
- Better matching capsule data to the limiting materials for each plant
- Sharing BWR data within the BWR fleet
- Provide additional data for BWR vessels with missing or incomplete data from their plant-specific surveillance programs
- Improve the knowledge of embrittlement effects in BWR vessels
- Support license renewal by identifying appropriate surveillance capsules
- Reduce cost, exposure and outage time for the BWR fleet by eliminating testing of surveillance capsule materials that have no direct bearing on the irradiation behavior of plant-specific limiting beltline materials
- Obtain SSP data that will improve the quality of materials used to assess embrittlement. Consequently, the ISP will not only provide data that is considerably more representative of limiting materials, but the database will be larger and will be available well before actual end-of-license for the plants in the fleet. The quality of the

data will be consistent because of the standard methods that will be used for subsequent testing and also improved because of the high quality of the unirradiated and irradiated specimens.

Therefore, there are substantial benefits to integrating the existing surveillance programs and the SSP for monitoring radiation embrittlement of BWR RPVs.

Table 1-1
ASTM E-185 Revision Required for Each U. S. BWR Plant

U. S. BWR Plant	*ASME (Code Edition/Addenda)*	ASME Code Issue Date	ASTM E-185 Issue Date
Browns Ferry 2	1965/Summer 1965	7/1/65	1962
Browns Ferry 3	1965/Summer 1966	7/1/66	1962
Brunswick 1	1965/Summer 1967	7/1/67	11/16/66
Brunswick 2	1965/Summer 1967	7/1/67	11/16/66
Clinton	1971/Summer 1973	7/1/73	3/1/73
Cooper	1965/Winter 1966	12/1/66	11/16/66
Dresden 2	1963/Summer 1964	7/1/64	1962
Dresden 3	1965/Summer 1965	7/1/65	1962
Duane Arnold	1965/Summer 1967	7/1/67	11/16/66
Fermi 2	1968/Summer 1969	7/1/69	11/16/66
FitzPatrick	1965/Winter 1966	12/1/66	11/16/66
Grand Gulf	1971/Winter 1972	12/1/72	7/15/70
Hatch 1	1965/Winter 1966	12/1/66	11/16/66
Hatch 2	1968/Summer 1970	7/1/70	11/16/66
Hope Creek	1968/Winter 1969	12/1/69	11/16/66
LaSalle 1	1968/Winter 1969	12/1/69	11/16/66
LaSalle 2	1968/Winter 1970	12/1/70	7/15/70
Limerick 1	1968/Summer 1969	7/1/69	11/16/66
Limerick 2	1968/Summer 1969	7/1/69	11/16/66
Monticello	1965/Summer 1966	7/1/66	1962
Nine Mile Point 1	1962 Section I/Dec11, 1963 Nuclear Code Case	12/1/63	1962
Nine Mile Point 2	1971/Winter 1972	12/1/72	7/15/70
Oyster Creek	1962 Section I/Dec11, 1963 Nuclear Code Case	12/1/63	1962
Peach Bottom 2	1965/Winter 1965	12/1/65	1962
Peach Bottom 3	1965/Winter 1965	12/1/65	1962
Perry	1971/Winter 1972	12/1/72	7/15/70
Pilgrim	1965/Winter 1966	7/1/65	1962
Quad Cities 1	1965/Summer 1965	12/1/65	1962
Quad Cities 2	1965/Summer 1965	7/1/66	1962
River Bend	1971/Summer 1973	7/1/73	3/1/73
Susquehanna 1	1968/Summer 1970	7/1/70	11/16/66
Susquehanna 2	1968/Summer 1970	7/1/70	11/16/66
Vermont Yankee	1965/Summer 1966	7/1/66	1962
WNP-2	1971/Summer 1971	7/1/71	7/15/70

2
DEVELOPMENT OF THE BWR INTEGRATED SURVEILLANCE PROGRAM

2.1 Requirements for an ISP (from 10CFR50 Appendix H)

The NRC has established specific criteria in 10CFR50 Appendix H for an integrated surveillance program. The requirements for an integrated surveillance program, as specified in 10CFR50 Appendix H, are as follows [1]:

1. In an integrated surveillance program, the representative materials chosen for surveillance for a reactor are irradiated in one or more reactors that have similar design and operating features. The Director, Office of Nuclear Reactor Regulation, on a case-by-case basis, must approve integrated surveillance programs. Criteria for approval include the following:

   a) The reactor in which the materials will be irradiated and the reactor for which the materials are being irradiated must have sufficiently similar design and operating features to permit accurate comparisons of the predicted amount of radiation damage.

   b) Each reactor must have an adequate dosimetry program.

   c) There must be adequate arrangement for data sharing between plants.

   d) There must be a contingency plan to assure that the surveillance program for each reactor will not be jeopardized by operation at reduced power level or by an extended outage of another reactor from which data are expected.

   e) There must be substantial advantages to be gained, such as reduced power outages or reduced personnel exposure to radiation, as a direct result of not requiring surveillance capsules in all reactors in the set.

2. No reduction in the requirements for number of materials to be irradiated, specimen types, or number of specimens per reactor is permitted.

3. No reduction in the amount of testing is permitted unless previously authorized by the Director, Office of Nuclear Reactor Regulation.

The following global criteria were established for the ISP to meet the 10CFR50 Appendix H requirements above:

a) In response to 1a), assure that the irradiation environments of the BWR fleet are sufficiently similar. This is discussed in Section 3.2.

b) In response to 1b), provide fluence data for each plant (i.e., a dosimetry program or equivalent). This is discussed in Section 3.3.

c) In response to 1c), develop a plan for data sharing. This is discussed in Section 3.4.

d) In response to 1d), develop a contingency plan. This is discussed in Section 3.5.

e) In response to 1e), provide substantial advantages, such as reduced personnel exposure and reduced outage schedule. This is discussed in Section 1.3.

f) In response to 2) and 3), assure that each plant has a representative data set. This is discussed in Section 3.1. See Section 2.2.1 for a definition of representative data for the limiting plate and weld material.

2.2 Definitions Used in the Development Process

As discussed in Section 1.1, many plants lack materials that represent their limiting beltline materials. Other plants lack quality unirradiated data to determine irradiation shift of the surveillance materials. Therefore, an objective of the ISP is to improve the quality of materials that represent the limiting materials for each plant in the BWR fleet.

One improvement is to choose the best representative material from the materials in the entire BWR fleet for the limiting material in each plant. This is the key component for identifying radiation embrittlement influences on the limiting material. Section 2.2.1 provides a definition of what is considered a representative material. A second improvement is to choose the best representative material with consideration given to the amount and quality of unirradiated and irradiated data that is needed to determine the irradiation shift of the surveillance material. This data is called a representative data set and is described in Section 2.2.2.

2.2.1 Representative Materials

A representative material is a plate or weld material that is selected from among all the existing surveillance programs or the SSP to represent the corresponding limiting plate or weld material in a plant. The choice of a representative material considers chemistry (%Cu and %Ni), heat number, fabricator, and welding process as it represents the plants' limiting materials. The "best" representative material is a material that has the following three qualities: 1) a good or excellent chemistry match, 2) the same welding process (if a weld) and fabricator, and 3) results in optimal consolidation of the test matrix (i.e., a candidate is better if it is capable of representing a number of plants rather than just one plant). In choosing a representative material, the availability of a plant capsule for license renewal is also considered.

2.2.2 A Representative Data Set for the Limiting Plate or Weld Material

A representative data set for the limiting plate or weld material consists of three Charpy curves: 1) unirradiated, 2) 1st irradiated and 3) 2nd irradiated. The Charpy specimens used to develop the curves are of the same heat with the same orientation (either transverse or longitudinal) and irradiated in the same plant. The source of the unirradiated data set can be from a BWR, SSP, or other source. The source of the irradiated data set can only be from existing BWR capsules or SSP capsules. Each curve should be based on Charpy tests of 8 or more specimens that are tested over a broad range of temperatures so that the shape of the curve can be clearly defined (this is called a full Charpy curve). At a minimum, these temperatures should be chosen to define the 30 ft-lb and 50 ft-lb Charpy impact energy, 35 mils Lateral Expansion (MLE) and the Upper Shelf Energy (USE). Unirradiated and irradiated data that can be used to develop a full Charpy curve and has a defined chemistry is considered "good quality data." An illustration of a representative data set (full Charpy curve) is shown in Figure 2-1 below.

2.3 Overview of BWR Surveillance Data

2.3.1 BWR Capsules and Vessel Materials

For existing surveillance programs, each plant has established a withdrawal schedule for the capsules consistent with 10CFR50 Appendix H. Therefore, the design of the surveillance program and the withdrawal schedule must meet the requirements of the edition of the ASTM E-185 that was current on the issue date of the ASME Code to which the reactor vessel was purchased, see Table 1-1. Later editions of ASTM E-185 could be used, but only through 1982 in accordance with the latest approved version in 10CFR50 Appendix H [1].

As discussed in Section 1.1, most plants pre-date the 1973 edition of ASTM E-185. For plants built prior to 1973, there were no specific requirements to choose materials that represent the limiting beltline material. Therefore, some plants never had a plate and/or weld material to represent the limiting beltline material in their existing surveillance program. For other plants, a change in Reg. Guide 1.99 [3], used to establish the limiting beltline material, resulted in a change in the limiting beltline material for that vessel. The ISP will choose surveillance materials from the existing surveillance program, Table 2-1 for plate and 2-2 for weld, and the SSP, Table 2-3 for plate and 2-4 for weld, that represent the limiting beltline materials for each plant. A list of the limiting BWR vessel plate and weld materials that will be represented by the ISP materials is shown in Table 2-5 for plate and 2-6 for weld.

For BWR vessels, at least three capsules were provided. The first two capsules are scheduled for removal during the plant life and are used for monitoring radiation embrittlement. The third capsule is scheduled for removal at End-of-License (EOL) and may be held without testing or used for the purpose of license renewal. Planned and actual withdrawal dates (in Effective Full Power Years [EFPY]) together with the fluence of the capsule withdrawn are shown in Table 2-7.

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EPRI Proprietary Information

Sharing of data within the BWR fleet has been limited and there has been no coordinated fleet-wide effort prior to development of the ISP described in this report. By providing a systematic arrangement to share data and by expanding the embrittlement database, the BWR fleet could minimize or eliminate many of the differences and inconsistencies in the BWR surveillance data. As discussed in Section 2.3.2, the SSP supplements the data from the existing BWR surveillance programs. Developing an integrated program provides the means to coordinate the sharing of data from existing plant surveillance and SSPs.

2.3.2 Supplemental Surveillance Program Materials

The BWR Owners' Group (BWROG) initiated the Supplemental Surveillance Program (SSP) in the late 1980s to obtain additional BWR surveillance data. The purpose of the program was to supplement the available vessel embrittlement data so that an irradiation shift correlation could be developed specifically for BWR vessels as an alternative to Reg. Guide 1.99. Selecting materials that are suitable for a fleet-wide correlation also results in a selection of materials representing a broad range of BWR fleet chemistry. Although it was not the original intention of the SSP, this selection of materials is exactly what is needed to complement the existing plant surveillance programs to better match the BWR fleet limiting beltline materials. The SSP specimens are superior to the existing surveillance program specimens for several reasons:

1) Unirradiated data - Unirradiated Charpy specimens for each of the materials were fabricated from the same plate and under the same conditions as the irradiated specimens. The unirradiated specimens were tested at the initiation of the program.

2) Chemical composition - A broken unirradiated Charpy specimen half of each material was tested for carbon, manganese, phosphorus, sulfur, silicon, nickel, molybdenum, and copper.

3) Dosimetry – Neutron fluence monitors are included in each capsule so that fast flux and fast fluence of each specimen set can be individually determined. Each monitor is sensitive to a specific neutron energy range and increased accuracy in a flux-spectrum is achieved by the use of several monitors (up to eleven different types of flux wires).

4) Temperature Monitors – The inherent operating nature of the BWR, with temperature related directly to pressure according to the steam saturation relationship, makes the vessel wall temperatures quite constant, even from plant to plant. The 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 the feedwater temperature, this annulus region is between 525°F and 535°F. Therefore, five (5) temperature monitors were designed to melt at temperatures within the range of 504°F and 580°F.

5) Flux/Fluence – The capsules were irradiated to target the BWR fleet mid- to end-of-license fluence ranges (see Figure 2-2). Capsules were paired to obtain constant flux with double the fluence or double the flux with constant fluence. There were seven different capsule irradiation conditions as shown in Table 2-8. The objective is to tie the SSP test matrix to the existing surveillance program flux/fluence region and then extend flux/fluence pairings into the range of 32 EFPY fluences as far as possible while maintaining fluxes within a factor of 3 of those experienced by BWR beltline materials.

6) Standard Reference Material (SRM) – A SRM was added to the SSP to provide an independent check of the measurement of irradiation conditions for the surveillance materials. The material used in this program is HSST-02. This material could also be used to validate the assumptions regarding flux and fluence.

The test results and flux/fluence predictions are documented in the Phase 2 progress report of the SSP [4]. Targeting the mid- to end-of-license fluence is an important benefit of the SSP, since existing surveillance programs will take 20 to 40 years to achieve these fluences. Although this results in somewhat higher fluxes, the benefit of having mid- to end-of-license irradiated data far outweighs any disadvantages that the higher flux may impose.

The SSP developed a test plan and fabricated supplemental capsules to be inserted into two host BWR reactors [4]: Cooper and Oyster Creek. With the cooperation of EPRI, plate and weld materials were selected from the GE archive to represent a range of the BWR vessel beltline materials. EPRI also supplied specimens of plate and weld materials from other irradiation programs. The variables which were ultimately determined to be significant for this study were flux, fluence, and material chemistry (i.e., copper, nickel and phosphorous).

There were three capsules inserted into Cooper and six capsules inserted into the Oyster Creek vessel. The scope included 84 sets of Charpy specimens. Existing BWR surveillance program materials were used as often as possible to meet the needs of the SSP material matrix. Tables 2-3 and 2-4 show the materials selected for the SSP specimens, along with their Cu, Ni, and P contents. Note that the chemistry values reported in Tables 2-3 and 2-4 were based on actual chemistry measurements from the specimens fabricated for the SSP and may differ from the preliminary data that was used to select specimens for this program as shown in Figures 2-3 and 2-4. The plate and weld materials contributed by EPRI to the SSP capsules are also identified in Tables 2-3 and 2-4. The matrix of SSP capsule materials and the listing of specimens in each capsule are given in Table 2-9. The range of selected copper and nickel contents for the plate and weld metals in the SSP capsules are shown in Figures 2-3 and 2-4, respectively. The data plotted in Figures 2-3 and 2-4 is data that was available at the time that the SSP was established in 1990. Although other data is currently available, these plots demonstrate the rationale for choosing specimens for the SSP at that time. These figures show Ni content plotted versus copper content, with each data point annotated with its specific P content. The circles on the plots indicate materials selected for the SSP specimens. The criteria used in selecting these materials (in order of priority) were as follows:

- Select materials to span the range of Cu, Ni, and P values in the surveillance program (and in the vessel beltline materials).
- Select pairs of materials such that, to the extent possible, variations in only one of the key elements can be established.
- Select materials with intermediate levels of the key elements, especially Cu.

2.4 The Development Process

The process to develop the integrated surveillance program consists of five steps as shown in Figure 2-5.

Since embrittlement has been found to be a function of both environmental and metallurgical variables [5], fluence (flux) and material chemistry (copper and nickel content) are the primary contributors to embrittlement. The figures in Appendix A show descriptive statistics of the flux range of the BWR fleet RPV wall, SSP capsule and existing surveillance capsule flux. The statistics show that the existing capsule flux is representative of the BWR RPV wall flux. With the number of data points (only seven estimated flux values as shown in Table 2-8) used for the SSP, there is no conclusive evidence that the SSP is or is not representative of the BWR fleet RPV wall flux. However, when the measured SSP flux becomes available, there will be sufficient data to make that determination. As discussed previously, targeting the mid- to end-of-license fluence is an important benefit of the SSP, since existing surveillance programs will take 20 to 40 years to achieve these fluences. Although this results in somewhat higher fluxes, the benefit of having mid- to end-of-license irradiated data far outweighs any disadvantages that the higher flux may impose. Consequently, flux is not considered to be a factor in choosing a representative material for each plant.

The embrittlement correlation in Reg. Guide 1.99, acknowledges %Cu and %Ni as primary factors in determining radiation shift. Vessel fabricator, material supplier, material heat treatment, rolling of the material, and material heat are not considered in the correlation. Therefore, chemistry is the primary consideration in choosing the appropriate representative data set and ultimately the best representative for each limiting material.

Step 1 selects a set of candidate surveillance capsule materials to represent the limiting beltline materials for each plant. (All of the existing surveillance materials and SSP materials are included in this selection). The candidate surveillance materials are evaluated based on the following criteria:

1. How well the copper (%wt) of the surveillance material (plate or weld) matches the copper of the target vessel limiting beltline material (plate or weld, respectively).

2. How well the nickel (%wt) of the surveillance material (plate or weld) matches the nickel of the target vessel limiting beltline material (plate or weld, respectively).

3. Whether or not the heat of the surveillance material matches the heat of the limiting beltline material.

4. Whether or not the fabricator for the surveillance material was the same fabricator as the vessel fabricator for the limiting beltline material. This was only important for surveillance weld material.

5. Whether or not the unirradiated data for the surveillance material was available and qualifies as an unirradiated curve for a representative data set. (See section 2.2.2 for a description of a representative data set.)

6. Finally, if the surveillance material was a candidate for multiple target plants, that material was given some additional weight in the consideration of choosing a representative material.

The candidate surveillance capsule materials are listed in the Individual Vessel Evaluation (IVE) sheets in Appendix B with the following sort hierarchy. First by %Cu, second by %Ni, and third by fabricator. The most valuable candidates (up to six) are shown on the IVE in addition to the plant capsule that is always included in the selection regardless of the match to the plant limiting material.

Step 2 chooses the best representative for the target limiting beltline material. The best representative is defined first by the difference between the copper and nickel of the candidate material and the target plant limiting beltline material. In this step the material fabricator and use of the material as a best representative for other plants are considered. Note that to be consistent with Reg. Guide 1.99, the value of a copper chemistry match is of much higher value than of the other criteria. Among candidates which all have a close chemistry match to the target, factors such as representing a higher number of targets (resulting in more optimum consolidation of the test matrix) could result in selection of a best representative that is not the closest chemistry match.

Step 3 reviews the entire matrix to determine if any improvements to the currently available data would produce a significantly better test matrix. When each limiting beltline material has the best representative match, the process skips to Step 5, otherwise the process moves to Step 4. The final ISP test matrix is described in Section 3.1.

Step 4 takes into consideration additional actions that would improve the selection of the best representative. To accomplish this, modifications to the existing surveillance capsule database are recommended. Some examples are testing additional unirradiated specimens or utilizing new information from other sources. If any of these revisions are determined necessary, the process returns to Step 1 to re-evaluate the test matrix. Otherwise, the process proceeds to Step 5. The final selection of the best representative is presented on the IVEs. Recommended actions are also provided in the IVE notes.

Step 5 is performed to assure that the remaining requirements of 10CFR50 Appendix H are considered. Consideration of dosimetry is addressed in Section 3.3, data sharing is addressed in Section 3.4 and the contingency plan is described in Section 3.5.

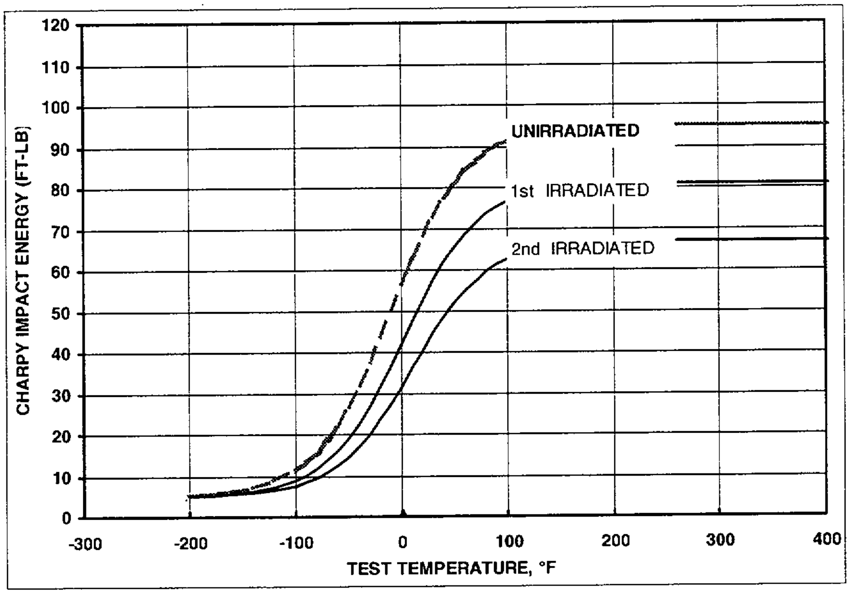

Figure 2-1
Representative Data Set

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Figure 2-2
SSP-Targets Relative to Vessel Design and Existing Surveillance Data

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Figure 2-3
Chemistry Matrix of SSP Surveillance and Archive Plates

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**Figure 2-4
Chemistry Matrix of SSP Surveillance and Archive Welds**

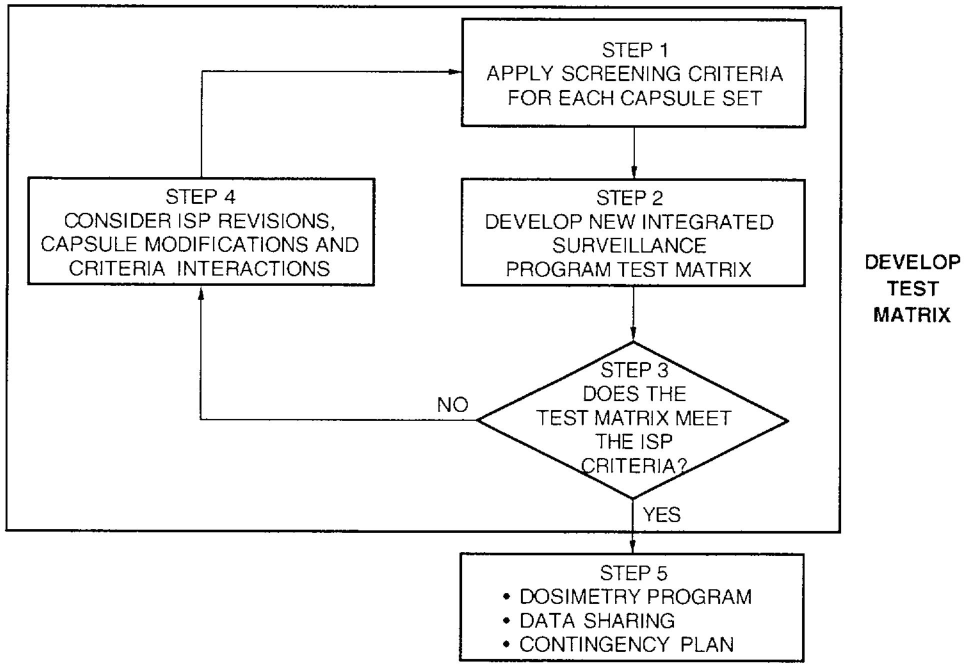

Figure 2-5
ISP Development Process

Table 2-1
BWR Plate Surveillance Capsule Data

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Table 2-2
BWR Weld Surveillance Capsule Data

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Table 2-3
SSP Plate Material Data

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Table 2-4
SSP Weld Material Data

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Table 2-5
Limiting BWR Vessel Plate Materials

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Table 2-6
Limiting BWR Vessel Weld Materials

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Table 2-7
Schedule of Existing BWR Surveillance Capsules

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Table 2-8
Flux/Fluence Combinations for the SSP Test Matrix

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Table 2-9
Supplemental Surveillance Program (SSP) Specimen Matrix

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Table 2-9
Supplemental Surveillance Program (SSP) Specimen Matrix (Continued)

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Table 2-9
Supplemental Surveillance Program (SSP) Specimen Matrix (Continued)

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3
BWR INTEGRATED SURVEILLANCE PROGRAM TEST PLAN

3.1 ISP Test Matrix

The process used to develop the ISP test matrix is described in Section 2.4. The ISP test matrix (shown in Table 3-1) identifies the surveillance capsule that will provide the representative material for each plant's limiting plate and weld material. The rows are the surveillance capsule sets (a capsule set includes three or more capsules installed in that plant) that include plate and weld material that are available to represent the vessel limiting plate or weld. The columns are the vessel limiting plate and weld materials that are to be matched with a representative capsule material.

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The near-core-capsules and the nine remaining reconstitution capsules are not included in the ISP for the following reasons:

1. These capsules are not part of the required surveillance program and were installed in the plants at the discretion of the utilities to provide additional data.
2. The capsules are not intended to be in full compliance with the current version of ASTM E-185.

The withdrawal schedule for individual capsules in a capsule set are the same as the withdrawal schedule in the existing program except that when a capsule is not used in the program, it will be indefinitely deferred. The capsule schedule is also shown on Table 3-2 in terms of EFPY and can be compared to the estimated EFPY that the plant has accumulated as of May 1999.

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This improvement is demonstrated by a comparison of the limiting BWR vessel plate chemistries and available capsule material plate chemistries, as shown in Figure 3-1. The ISP/SSP materials were selected to represent the full range of materials in the BWR fleet. These graphs demonstrate that the limiting BWR vessel plates and welds can be matched by a smaller subset of the available capsules with the addition of suitable SSP materials. The consolidation of representative materials allows a reduction in the total number of capsules to be tested. A comparison of the limiting BWR vessel plate chemistries and the representative ISP/SSP capsule specimen material plate chemistries is shown in Figure 3-2. For BWR welds, a comparison of the limiting BWR vessel weld chemistries and available capsule material weld chemistries is shown in Figure 3-3. Similarly, a comparison of the limiting BWR vessel weld chemistries and the representative ISP/SSP capsule specimen material weld chemistries is shown in Figure 3-4.

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The advantages of using the ISP test matrix to match the limiting BWR vessel welds are demonstrated in Figures 3-3 and 3-4.

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3.2 Similarity of Plant Environment

It must be demonstrated that the shift measured for the materials irradiated in one reactor is representative of the shift that will be experienced for the plant that the material represents. This requires demonstrating a similarity of environment. Two factors are important when considering the similarity of plant environment: 1) temperature and 2) neutron energy spectrum and flux of the capsule.

3.2.1 Temperature

The temperatures in the downcomer region of the BWR fleet range from 525°F to 535°F, a variation of ±5°F. This temperature variation is not significant and would be a minor contribution to a change in measured shift. For these temperature variations, Reg. Guide 1.99 requires no adjustment for temperature.

3.2.2 Neutron Energy Spectrum and Flux

There have been numerous BWR neutron transport evaluations performed since the late 1970s. GE performed most of these evaluations. Therefore, GE has extensive experience in BWR fluence determinations. Both neutron transport calculations and flux wire measurements have been routinely employed for the determination of fast neutron flux at the reactor pressure vessel. A detailed description of the GE methods for performing neutron transport calculations and dosimetry evaluations is being prepared in a GE topical report. The GE topical report will also address how the methods comply with Draft Regulatory Guide DG-1053 [6].

BWRs are usually grouped according to their power levels, RPV size, core loading pattern, etc. BWRs in the same class normally have similar designs and operating features. When the surveillance capsule flux wire data are used to determine neutron flux level, it is typically assumed that the neutron energy spectrum at or near the capsule is independent of the specific plant features. This assumption can be validated easily with calculated results.

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3.3 Fluence Issues and Dosimetry Issues Relevant to the ISP

There are a number of fluence issues that are relevant to the ISP. They are:

1. The basis of fluences associated with past BWR surveillance capsule data,
2. The equivalence of radiation environments between BWRs,
3. The need for separate dosimetry in BWRs that will not withdraw future capsules as part of the ISP.

The second item is covered in Section 3.2. The first and third are discussed in this section.

3.3.1 Past BWR Surveillance Fluence Basis

There have been more than 36 BWR surveillance capsules tested since the late 1970s. GE tested most of these, and the approach used by GE to establish surveillance capsule fluence has been relatively consistent for all tests. The approach is described in GE surveillance reports and is summarized here.

Surveillance capsules contain 2 or 3 sets of flux wires, typically iron, nickel, and copper. Each wire is removed from the capsule, cleaned with dilute acid, measured for weight, mounted on a counting card, and analyzed for its radioactivity content by gamma spectrometry.

To properly predict the flux and fluence at the surveillance capsule from the activity of the flux wires, the periods of full and partial power irradiation and the zero power decay periods are considered. Operating days for each fuel cycle and the reactor average power fraction are derived from fuel records.

From the flux wire activity measurements and power history, reaction rates for Fe-54 (n,p) Mn-54, Ni-58 (n,p) Co-58, and Cu-63 (n,) Co-60 are calculated. The E >1 MeV fast flux reaction cross sections for the iron, nickel, and copper wires are empirically derived from GE test data, and are about 4% conservative relative to library cross section values. The calculated fluence results for the Fe, Ni, and Cu wires are generally within 10%, but, depending on results, the fluence used might be an average or a bounding value from the wire results.

The E > 1 MeV flux values are calculated by dividing the wire reaction rate measurements by the corresponding cross sections, factoring in the core average power history for each fuel cycle. The fluence result for the copper wire is obtained by using the following equation:

$$\Phi_{Cu} = \Phi_{fp} \sum_{i} t_i p_i \qquad \text{eq. 3-1}$$

where:

Φ_{Cu} = fluence measured by the Cu dosimeters

Φ_{fp} = full power flux value for Cu

t_i = operating time

p_i = full power fraction

The 2σ accuracy of the fluence values are influenced by the following sources of error:

+ 2%	counting rates
+ 15%	power history
+ 10%	cross sections

The uncertainty in the E > 1 MeV fluence is approximately ±20% (2σ).

In a few past cases, the iron and copper flux wires showed larger than expected differences in fluence prediction. In those cases, the power histories of the peripheral bundles closest to the capsule were processed to provide a more representative power history at the flux wires. This refinement consistently brought the iron and copper wire results into expected agreement.

One variation in fluence approach over the years, mentioned briefly in the approach above, has been in the handling of the iron, copper and nickel flux wire results. In general, the nickel wire results were not included in the evaluation. If a capsule was not received for testing for about 6 months after shutdown, the nickel wire counts could be quite low given the 70.8 day half-life of the Co-58 isotope formed by irradiation of the nickel wire. Between the iron and copper wires, the copper was generally considered the better result. The 5.27 year half-life of the copper wire isotope (vs. 312.5 days for the iron wire isotope half-life) gives the copper wire a "better memory" of the irradiation history of the first capsule, typically pulled around the tenth year of operation. Thus, in many cases the capsule fluence was based on the average of three copper wire results. However, in some cases, the capsule fluence was based on the average of the results of three copper wires and three iron wires. It is estimated that the difference between iron and copper wire fluences in these cases was not more than 10%.

The fluence determined from the dosimetry was reported in the surveillance report as the fluence for the surveillance capsule. Neutron transport calculations of fluence were performed for some, but not all, BWRs in conjunction with the surveillance capsule tests. In nearly all cases, the neutron transport calculation was used to establish the lead factor from the capsule location to the vessel peak location. The vessel fluence was then determined by taking the dosimeter flux result, adjusting it with the lead factor to the peak location and attenuating it to the 1/4T depth.

Dosimetry results for similar BWR types and sizes have shown good consistency. Table 3-3 shows that first capsule dosimeter flux values for the 251-inch BWR/4 vessels agree with a standard deviation of 8%. The variation of the results between these plants should be larger than the variation for a single plant, so σ=10% is a conservative estimate of the uncertainty of the dosimetry flux and fluence results for a given surveillance capsule.

3.3.2 Dosimetry Needs for ISP Plants

Beltline fluence values have been established for BWRs from one of three sources: 1) first capsule (10 year) dosimetry combined with lead factor calculations, 2) first cycle (1 year) dosimetry combined with lead factor calculations, or 3) neutron transport calculations alone. The vast majority of plants have fluences based on the first two sources. Under the ISP, some plants will test future capsules and some will not. For a plant that tests one or more future capsules, dosimetry will be available from the capsule as an updated basis for the projected vessel fluence. For a plant that does not test a future capsule, there are several potential scenarios:

1. If a plant has tested a previous capsule, the dosimetry from that capsule is generally the basis for its current fluence projection. This plant's fluence projection will continue to be based on its capsule dosimetry unless a major change to the core design or management is undertaken in the future.

2. If a plant has not tested a previous capsule, but has tested a first cycle dosimeter, the first cycle dosimetry is generally the basis for its current fluence projection. Comparisons of first cycle and first capsule dosimetry results have consistently shown that first cycle dosimetry results are conservative. Therefore, this plant's fluence projection will continue to be based on its first cycle dosimetry unless a major change to the core design or management is undertaken in the future. Alternatively, at the plant's discretion, it could install and subsequently test supplemental dosimetry to establish a less conservative basis for its fluence projection.

3. If a plant's fluence projection is based on neutron transport calculations alone, its fluence projection will continue to be based on the transport calculations. GE transport calculations with their associated safety factors have consistently been conservative relative to the fluences based on dosimetry. Therefore, fluence projections based on the

neutron transport calculations are conservative unless a major change to the core design or management is undertaken in the future. Alternatively, at the plant's discretion, it could install and subsequently test supplemental dosimetry to establish a less conservative basis for its fluence projection.

3.4 Data Sharing and Data Utilization

For each plant's limiting beltline plate and weld, the best representative surveillance plate or weld data will be designated. The results of the surveillance specimen testing are to be presented in a report as required by 10CFR50 Appendices G and H. A plan to manage data sharing will be developed in the implementation phase of the ISP. The BWRVIP has a good record of data sharing and availability that will be continued in the implementation phase of the ISP.

The test report will include the irradiated material properties (Charpy test results) as compared to available unirradiated properties, and the resulting measured irradiation shift. The shift is a measure of the effect of irradiation on material toughness for the plate and weld materials through Charpy testing. The fluence for the tested capsule will be used to compare the measured shift to the predicted shift in Reg. Guide 1.99. It is expected that measured shift will be within the range of predicted shift when including the margin term to establish the range.

There are two options for how the measured data can be used:

1) For option 1, the representative material specifically matches the heat of the limiting beltline material for the plant. In this case, the requirements of Reg. Guide 1.99 Position C.2 can be used for the limiting beltline material that matches that heat of material. Any chemistry, chemistry factor, and/or margin term adjustments will be made consistent with Position C.2. For all other beltline materials, Position C.1 will be used.

2) For option 2, the heat of material does not specifically match the limiting heat of beltline material for that plant. In this case the requirements of Reg. Guide 1.99 Position C.1 applies to all materials in the beltline.

This data is only used for evaluating the adjusted reference temperature (ART) for the limiting beltline materials in the plant that is being represented. The ART for all other materials in the beltline are evaluated according to the requirements of Reg. Guide 1.99 Position C.1. Pressure-Temperature curves are to be developed using the plant specific fluence in accordance with the requirement of 10CFR50 Appendix G.

3.5 Contingency Plan

A contingency plan is needed in the event that a best representative for a limiting beltline material should cease to be available. For example, a plan would be needed if a plant were to indefinitely shut down and the remaining surveillance capsule(s) is not withdrawn and tested. First, efforts would be made to retrieve the remaining capsule(s) prior to the indefinite shutdown. This is feasible, since for most plants the current estimated EFPY is close to the withdrawal schedule. If removal of the capsule cannot be accomplished, a new best representative will be chosen from the remaining candidates.

As shown in the IVEs (Appendix B), each plant has up to six candidates identified as alternatives for identifying the best representative. The candidate surveillance materials are shown in the IVE in order of %Cu, as discussed in Section 2.4. Many of the candidates are close matches to the best representative and can be used as a contingency for the best representative.

In addition, the ISP has a built-in contingency plan, since capsules that are designated as "postponed indefinitely" will remain in their respective plants. Therefore, all plants will continue to have access to the capsules in their current surveillance program.

3.6 License Renewal

The primary focus of the ISP is to satisfy the requirements of 10CFR50 Appendix H for the BWR 40-year operating period. However, the ISP must consider aging management issues in the license renewal term. The only significant license renewal concern for the beltline materials is embrittlement. Therefore, it is necessary to maintain an active surveillance program for the BWR fleet. The ISP has identified 13 of 34 plants that will provide the necessary data to monitor embrittlement in the current operating term. The exact number of surveillance capsules that need to be included in the ISP for license renewal will depend on which plants intend to seek license renewal.

It is important to recognize that there may be aging effects that could be important in determining embrittlement for extended periods of reactor operation beyond 32 EFPY. A recent review of US reactor vessel surveillance data conducted by the ASTM E900 Task Group under E10.02 suggests that long exposure times may lead to higher than expected embrittlement in BWRs. This may be the result of a synergistic effect with the low flux irradiation and operating temperature that is typical of the BWR environment. Consequently, it is necessary to monitor RPV beltline materials in the license renewal term to determine if these effects do indeed increase embrittlement with extended plant operation.

To determine which surveillance capsules should be tested in the license renewal term, a summary of surveillance capsules for each plant was developed for both the current programs and the ISP. The results are provided in Table 3-4. Under the current programs, a maximum of 42 capsules are available for license renewal testing. For the ISP, a maximum of 69 capsules could be available for license renewal testing. The number of capsules available for license renewal is larger in the ISP because it includes those capsules that will be indefinitely deferred but are still available for withdrawal in the future if the need arises.

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Figure 3-1
Comparison of Limiting BWR Vessel Plate Chemistries and Available Capsule Material Plate Chemistries

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Figure 3-2
Comparison of Limiting BWR Vessel Plate Chemistries and ISP/SSP Capsule Material Plate Chemistries

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Figure 3-3
Comparison of Limiting BWR Vessel Weld Chemistries and Available Capsule Material Weld Chemistries

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Figure 3-4
Comparison of Limiting BWR Vessel Weld Chemistries and ISP/SSP Capsule Material Weld Chemistries

Table 3-1
ISP Test Matrix

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Table 3-2
ISP Test Matrix Results

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Table 3-3
Comparison of BWR/4-251 First Capsule Dosimetry Fluxes

BWR/4 - 251" Dia. Plant	Measured Flux (n/cm^2/s)
Peach Bottom 2	7.50E+08
Peach Bottom 3	6.80E+08
Browns Ferry 2	5.90E+08
Susquehanna 1	6.60E+08
Hope Creek	7.49E+08
Susquehanna 2	6.70E+08
Mean	6.83E+08
Sigma	6.03E+07
Sigma %	8.83%

Table 3-4
Capsules Available for License Renewal (LR) Testing

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4 CONCLUSIONS

The ISP meets the current requirements in 10CFR50 Appendix H and provides a significant improvement over the existing material surveillance programs. The design of the ISP is based on judicious selection of the most representative existing surveillance capsules together with the SSP capsules, resulting in an improved test matrix for monitoring vessel embrittlement in the entire BWR fleet.

The test matrix is based on those capsules that best meet the needs of the BWR fleet. The capsule materials for the ISP are specifically chosen to provide the best match for limiting plate and weld materials for each plant. Capsule data that were not chosen as a best representative will not be included and need not be tested because other materials in the ISP (including the SSP materials) will be used to replace these capsules.

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The ISP can also accommodate changes to the existing capsule withdrawal schedules to obtain target fluence values, or defer testing of capsules that were not chosen as a best representative. The ISP will provide the following substantial advantages:

1. Data that provides an equal or better match to the limiting beltline materials for each BWR.
2. More data will be available earlier in life with the addition of the SSP.
3. As a whole, the unirradiated material data for the ISP will be of better quality than that of the existing surveillance programs.
4. Continuing dosimetry for plants.

A cooperative program involving all BWR utilities will provide the means to make the Integrated Surveillance Program possible and will facilitate the sharing of data and information resulting from this program. The ISP will improve 10CFR50 Appendix H compliance of the entire BWR fleet while being more cost-effective than the existing programs. The ISP will also provide for data sharing, and an extensive high-quality database for improved monitoring of embrittlement trends.

5 REFERENCES

1. 10CFR50, Appendix H, "Reactor Vessel Material Surveillance Program Requirements," Appendix H to Part 50 of Title 10 of the Code of Federal Regulations, U.S. Nuclear Regulatory Commission, December 1995.

2. ASTM E-185, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels," American Society for Testing and Materials, July 1982.

3. "Radiation Embrittlement of Reactor Vessel Materials," USNRC Regulatory Guide 1.99, Revision 2, May 1988.

4. Caine, T.A., "Progress Report on Phase 2 of the BWR Owners' Group Supplemental Surveillance Program," GE-NE, San Jose, CA, January 1992, (GE-NE-523-99-0792).

5. NUREG/CR-6115 "PWR & BWR Pressure Vessel Fluence Calculation Benchmark Problems and Solutions," USNRC, 1999.

6. Draft Regulatory Guide 1053, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, September 1999.

A

DESCRIPTIVE STATISTICS FOR PLANT TO CAPSULE FLUX

This Appendix provides a statistical evaluation used to confirm that existing surveillance capsule data and the SSP capsule data are representative of the BWR fleet RPV wall flux data.

The measured flux values and calculated lead factors for all capsules that have been removed from BWR RPVs and the projected fluxes for the SSP were collected and evaluated. To translate the resultant flux into a value that can be meaningfully represented by statistical methods, the normalized natural log of the flux was calculated.

The following three sets of data were compiled:

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Figure A-1
Distribution of the RPV Capsule Wall Natural Log of the Normalized Flux

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Figure A-2
Distribution of the Existing Surveillance Capsule Natural Log of the Normalized Flux

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Figure A-3
Distribution of the SSP Capsule Natural Log of the Normalized Flux

One-Way Analysis of Variance

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One-Way Analysis of Variance

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Normal Probability Plot RPV Wall and SSP Capsule Data

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B

INDIVIDUAL VESSEL EVALUATIONS

Target Plant Name: Browns Ferry 2

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Target Plant Name: Browns Ferry 2

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Target Plant Name: Browns Ferry 3

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Target Plant Name: Browns Ferry 3

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Target Plant Name: Brunswick 1

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Target Plant Name: Brunswick 1

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Target Plant Name: Brunswick 2

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Target Plant Name: Brunswick 2

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Target Plant Name: **Clinton**

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Target Plant Name: Clinton

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Target Plant Name: **Cooper**

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Target Plant Name: Cooper

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Target Plant Name: **Dresden 2**

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Target Plant Name: Dresden 2

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Target Plant Name: Dresden 3

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Target Plant Name: Dresden 3

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Target Plant Name: Duane Arnold

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Target Plant Name: Duane Arnold

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Target Plant Name: Fermi 2

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Target Plant Name: Fermi 2

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Target Plant Name: FitzPatrick

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Target Plant Name: FitzPatrick

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Target Plant Name: Grand Gulf

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Target Plant Name: Grand Gulf

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Target Plant Name: Hatch 1

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Target Plant Name: Hatch 1

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Target Plant Name: Hatch 2

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Target Plant Name: Hatch 2

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Target Plant Name: Hope Creek

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Target Plant Name: Hope Creek

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Target Plant Name: LaSalle 1

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Target Plant Name: LaSalle 1

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Target Plant Name: **LaSalle 2**

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Target Plant Name: LaSalle 2

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Target Plant Name: Limerick 1

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Target Plant Name: Limerick 1

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Target Plant Name: Limerick 2

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Target Plant Name: Limerick 2

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Target Plant Name: Monticello

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Target Plant Name: Monticello

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Target Plant Name: **Nine Mile Point 1**

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Target Plant Name: Nine Mile Point 1

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Target Plant Name: Nine Mile Point 2

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Target Plant Name: Nine Mile Point 2

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Target Plant Name: **Oyster Creek**

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Target Plant Name: Oyster Creek

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Target Plant Name: Peach Bottom 2

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Target Plant Name: Peach Bottom 2

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Target Plant Name: **Peach Bottom 3**

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Target Plant Name: Peach Bottom 3

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Target Plant Name: Perry

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Target Plant Name: Perry

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Target Plant Name: Pilgrim

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Target Plant Name: Pilgrim

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Target Plant Name: Quad Cities 1

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Target Plant Name: Quad Cities 1

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Target Plant Name: Quad Cities 2

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Target Plant Name: Quad Cities 2

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Target Plant Name: River Bend

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Target Plant Name: River Bend

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Target Plant Name: **Susquehanna 1**

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Target Plant Name: Susquehanna 1

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Target Plant Name: **Susquehanna 2**

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Target Plant Name: Susquehanna 2

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Target Plant Name: Vermont Yankee

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Target Plant Name: Vermont Yankee

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Target Plant Name: WNP-2

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Target Plant Name: WNP-2

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Target:
Nuclear Power

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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