BWR Vessel and Internals Project Standby Liquid Control Line Repair Design Criteria (BWRVIP-53NP)

REPORT SUMMARY

The Boiling Water Reactor Vessel and Internals Project (BWRVIP), formed in June, 1994, is an association of utilities focused exclusively on BWR vessel and internals issues. This BWRVIP report documents criteria which can be used to design a repair for the standby liquid control (SLC) line in a BWR.

Background

In the event that significant degradation is observed in BWR SLC piping, repair may be required. Utilities need criteria which can be used in the development of designs for those repairs.

Objectives

To compile the appropriate repair design criteria into a document which can be used by utility personnel performing the design and which could be submitted to appropriate regulatory agencies for approval of the generic design process.

Approach

The contractor assembled a draft document which discussed all elements which need to be considered in designing a repair. Items discussed include: design objectives; structural evaluation; system evaluation; materials, fabrication and installation consideration; and, required inspection and testing. The resulting draft was reviewed in depth by BWRVIP utility representatives as well as third party contractors. The final report incorporates comments received during those reviews.

Results

The document provides general design acceptance criteria for the repair of SLC piping. Repairs designed to meet these criteria will maintain the structural integrity of the component under normal operation as well as under postulated transient and design basis accident conditions.

EPRI Perspective

The criteria listed in the report define a standard set of considerations which are important in designing a repair. It is intended that these criteria will be submitted to the USNRC, and possibly non-US regulators, for their approval. Regulatory acceptance of these generic criteria will significantly reduce the utility effort required to obtain approval for plant-specific repairs.

PROJECT

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Nuclear Power Group
Contractor: General Electric Nuclear Energy

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TR-108716NP

Interest Categories
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Licensing and safety assessment

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Vessel and internals
Standby liquid control

BWR Vessel and Internals Project

Standby Liquid Control Line Repair Design Criteria (BWRVIP-53NP)

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Research Project B501

Final Report, February 2000

Prepared by:

GE Nuclear Energy

BWRVIP Repair Committee

Prepared for

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BWRVIP Repair Committee

ORDERING INFORMATION

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ACKNOWLEDGMENTS

The members of the BWRVIP SLC Repair Team, listed below, are gratefully acknowledged for their efforts which led to the successful completion of this document.

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Framatome Technologies, Inc. is gratefully acknowledged for their significant contribution to the discussion of potential repair techniques. Principal FTI contributors:

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Executive Summary

The Boiling Water Reactor Vessel and Internals Project (BWRVIP) was formed in June 1994 as a utility-directed initiative to address BWR vessel and internals issues. This criteria document was developed by the Repair Technical Subcommittee of the BWRVIP.

This document provides the general design acceptance criteria for temporary and permanent repair of BWR standby liquid control and core differential pressure (SLC&CDP) nozzles and internal lines. It is provided to assist BWR owners in designing repairs which maintain the structural integrity of the SLC&CDP nozzles and internal lines during normal operation and under postulated transient and design basis accident conditions for the remaining plant life or other service life as specified by the plant owner. Discussion of SLC&CDP nozzle and internal lines repair concepts are included in the appendices to this document (separate from the design criteria).

Issuance of this document is not intended to imply that repair of the SLC&CDP nozzles and internal lines is the only viable method for resolving cracking in the SLC&CDP nozzles and internal lines. Due to variation in the material, fabrication, environment and as-found condition of the individual SLC&CDP nozzles and internal lines, repair is only one of several options that are available. The action to be taken for individual plants will be determined by the plant licensee.

1. INTRODUCTION

1.1 Background

Recently, the BWRVIP prepared a safety assessment of BWR internals as a follow-on to the activities completed on shroud cracking. As documented in this safety assessment [1], there are several BWR reactor internal components where extensive degradation can be tolerated because of the redundancy provided by the Standby Liquid Control (SLC) System. Therefore, the boron injection function of the SLC system is important to achieve reactor shutdown.

The BWRVIP have prepared generic inspection and evaluation guidelines for the Standby Liquid Control and Core Differential Pressure (SLC&CDP) internals [2] to assure the continued safety function integrity of the SLC&CDP internals. There has been only one report of cracking in any BWR SLC&CDP nozzles or internals (a 1965 failure of the standby liquid control sparger in an overseas BWR/1) however, there is reason to anticipate that such cracking is possible within the reactor service life. If the SLC&CDP nozzle or internals are found to be cracked or leaking it will be necessary to repair the nozzle or internal lines before restarting the plant, or to justify continued operation as-is. Therefore, to prepare for potential repairs, the BWRVIP have prepared this repair criteria for the SLC&CDP nozzle and internals.

1.2 Purpose

The purpose of this document is to provide general design guidance and acceptance criteria for permanent and temporary repair of: cracked or leaking SLC&CDP nozzles, and cracked or broken SLC&CDP lines inside the vessel. Appendices provide additional guidance on potential repair concepts as well as discussion of the steps that would have to be taken to qualify an alternate core dP source.

The issuance of this document is not intended to imply that a repair of SLC&CDP nozzles and internal lines is the only viable approach to resolution of the cracking/degradation issue.

1.3 Scope

This document is applicable to General Electric BWR/2, BWR3-5, and BWR/6 plants which plan to implement repairs of SLC&CDP nozzles and internal lines.

2. DEFINITIONS

Repair	Repair as used in the context of this document is a broad term that applies to actions taken to design, analyze, fabricate and install hardware that restores the structural and functional integrity of all or a portion of the SLC&CDP nozzle and internals. Procedural changes to accomplish necessary functions and allow the abandonment of SLC&CDP internal lines is considered within the definition of repair. Weld overlay, without removal of the defect, is also a repair in the context of this criteria.
SLC&CDP Nozzle	The standby liquid control and core differential pressure nozzle penetrates the reactor vessel wall. SLC&CDP nozzles are of two types: full penetration welded low alloy steel nozzles, and nickel-chrome-iron alloy (Inconel) partial penetration welded nozzles. The nozzle includes an internal stainless steel socket for attachment of the internal CDP internal line.
SLC&CDP Nozzle Safe End	A stainless steel safe end is a short cylindrical section which was welded to the exterior end of the SLC&CDP nozzle during vessel construction to provide a material transition to the external tee.
SLC&CDP Internal Lines	The core differential pressure (CDP) line provides a means to sense the static pressure above the core support plate. The standby liquid control line provides a means of delivery and distribution of the sodium penta-borate solution in the area below the core support plate and a means to sense reactor static pressure below the core support plate (see Figure 1; all figures located at the end of this document). Differential pressure (dP) across the core support is then determined as the difference in these two static pressure readings.
SLC&CDP External Tee	The BWR/2-5 standby liquid control and core differential pressure external tee assembly is a stainless steel piping assembly which is attached to the SLC&CDP nozzle safe end. It provides a means of making separate piping connections outside the RPV with the internal standby

liquid control line and the internal core differential pressure line (see Figure 2).

SLC Sparger

A sparger for distribution of the sodium penta-borate solution is part of the SLC&CDP internals. BWR/2's included a horizontal ring sparger (1-inch schedule 40 pipe) with 1/4 inch holes. This sparger is just below the shroud core support flange. BWR/3-6's use a 1-inch capped vertical pipe sparger with typically seven 1/4 inch diameter holes.

3. SLC&CDP NOZZLE AND INTERNALS CONFIGURATION AND SAFETY FUNCTION

3.1 General Physical Description

The Standby Liquid Control System is designed to shut down the reactor from full power by injecting a neutron absorber (sodium penta-borate) into the reactor core when the normal method of controlling core reactivity with control rods cannot be accomplished. In most plants, a line from the SLC&CDP nozzle in the vessel bottom head supplies liquid sodium penta-borate solution to a standpipe or sparger inside the RPV, which, in turn, distributes the liquid through holes to the coolant entering the core. In some plants, the boron solution is injected through a core spray line; however, those plants still have the SLC&CDP nozzle and internal SLC&CDP line hardware in the lower plenum. This repair design criteria is not applicable to the repair of SLC hardware used for injection through the core spray line; however, it is applicable to the repair of the SLC&CDP nozzle and internal SLC&CDP line hardware which is located in the lower plenum of these plants. The SLC line also provides the below core plate pressure reading used to determine the differential pressure across the core support.

A line around the boron injection line, or a separate line in the bottom head (BWR/6), is used in measuring the pressure above the core plate. The CDP line instrumentation provides information on core flow performance for diagnostic purposes, on Control Rod Drive (CRD) system water differential pressure indication and on core spray piping break detection.

3.1.1 SLC&CDP Nozzle Configurations

The SLC&CDP nozzle provides a penetration in the reactor vessel for delivering sodium penta-borate solution, sensing reactor static pressure above the core support plate, and sensing pressure in the lower plenum. BWR/2-5s use a single nozzle for these functions: an inner pipe running through the nozzle carries the sodium penta-borate solution and senses reactor pressure in the lower plenum. The inner pipe also functions as a thermal sleeve to minimize thermal shock on the nozzle in the event of a cold liquid control injection. BWR/6 use two separate nozzles for these functions. BWR/2-4 typically locate the SLC&CDP nozzle as a radial nozzle in the lower vessel head at 14 degrees below the horizontal tangent line of the lower head. This puts the SLC&CDP nozzle outside the vessel support skirt. BWR/5/6s typically use a vertical orientation for the SLC&CDP nozzle(s), locating the nozzle just outside the pattern of CRD penetrations. This location is inside the vessel support skirt, above the vessel bottom head insulation panels.

All SLC&CDP nozzles use either a full penetration nozzle design or a partial penetration nozzle design. In the full penetration design a low alloy steel nozzle forging was welded into the lower head plate material, through the full thickness. In the partial penetration nozzle design an Inconel Alloy 600 nozzle forging was welded at the inside of the lower head by a partial penetration weld (typically the Ni-Cr-Fe J-groove weld is made to a Ni-Cr-Fe weld overlay). It is unlikely that cracks or leaks will develop in the low alloy steel material or the full penetration nozzle to lower head weld. On the other hand, it is reasonable to suspect that a BWR may develop a crack or leak in the Alloy 600 partial penetration SLC&CDP nozzle weld during its life time. Either design can develop cracks or leaks in the stainless steel safe end or the external SLC&CDP tee, which is attached to the nozzle safe end.

There are nine basic penetration designs among the BWRs evaluated. The designs depend upon the vessel fabricator and the vintage of BWR, because GE and the vessel fabricators changed design criteria with time. The applicable vessel fabricators are Combustion Engineering (CE), Chicago Bridge and Iron (CB&I) which later formed CBI Nuclear (CBIN), Babcock and Wilcox (B&W), Hitachi, and Rotterdam Drydock (RDM).

3.1.2 Configuration of SLC&CDP Internals

The typical configuration of the SLC&CDP internal lines for BWR/2s is shown in Figure 1 and 2. A 2-inch line attaches to a socket at the inside of the vessel nozzle.

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Specific plant configurations are indicated in Table 1.

Table 1: BWR/2-6 SLC&CDP Configurations

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3.2 Safety Design Bases

3.2.1 SLC&CDP Nozzle Safety Design Bases

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3.2.1.1 Bottom Head Leakage

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3.2.1.2 Alternative SLC&CDP Nozzle Safety Basis

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3.2.2 SLC&CDP Internal Lines Safety Design Bases

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3.2.2.1 Boron Mixing

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3.2.2.2 Potential Pinching of the SLC Internal Line

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3.3 Event Analyses

As previously stated, the purpose of this document is to provide general design criteria for repairs of degraded SLC&CDP nozzles and internal components. Accordingly, various events and operational conditions must be considered to ensure that the repair does not inhibit the ability of the SLC&CDP nozzles to perform their basic safety functions. The following general load cases shall be considered in design of the proposed repair.

3.3.1 Normal Operation

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3.3.2 Anticipated Operational Occurrences (Upset Conditions)

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3.3.3 Alternative Anticipated Operational Occurrences (Upset Conditions)

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3.3.4 Design Basis Accidents (Emergency/Faulted Conditions)

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3.3.5 Loading Combinations

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4. SCOPE OF REPAIRS

4.1 IGSCC Susceptible Materials

The SLC&CDP nozzle and internal repairs may address cracking in IGSCC susceptible stainless steel and nickel-chrome-iron alloy components by a number of options. This repair criteria applies to the following SLC&CDP nozzle and internal components: the partial penetration nozzle weld, the nickel-chrome-iron alloy partial penetration nozzle body, the stainless steel nozzle safe end, the stainless steel external tee, the internal stainless steel SLC&CDP lines, and supports for the internals lines.

4.1.1 SLC&CDP Internal Lines

The scope of the internal SLC&CDP internals repair is to address repairs of the SLC lines and sparger, the above core plate pressure line and the double wall section of piping from the nozzle to the internal tee. The "repair" may in fact be a use as-is justification or removal of these items. Concepts for repair of the SLC&CDP internals are discussed in Appendix A. Modifications to provide alternative sources for the above core plate pressure reading are discussed in Appendix B.

4.1.2 Partial Penetration SLC&CDP Nozzle

The scope of the SLC&CDP partial penetration nozzle repair is to address repairs of a crack or leaks in the partial penetration nozzle weld, the nozzle safe end and the external tee. Concepts for these repairs are discussed in Appendix C.

4.2 Low Alloy Steel Nozzle

The repair of low alloy steel SLC&CDP nozzle body and full penetration attachment weld to the reactor vessel head is adequately covered by ASME Code Section XI and will not be discussed further in this repair criteria.

5. DESIGN OBJECTIVES

5.1 Design Life

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5.2 Safety Design Bases

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5.3 Safety Analysis Events

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5.4 Structural Integrity

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5.5 Retained Flaw(s)

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5.6 Loose Parts Considerations

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5.7 Physical Interfaces with Other Reactor Internals

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5.8 Installation Considerations

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5.8.1 Vessel Drain Down

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5.8.2 Access For SLC&CDP Nozzle and Internals Repair

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6. DESIGN CRITERIA

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6.1 SLC&CDP Nozzle

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6.2 SLC&CDP Internal Component

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7. STRUCTURAL AND DESIGN EVALUATION

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7.1 Load Definitions - Applied Loads

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7.2 Service Level Conditions

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7.3 Load Combinations

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7.3.1 Mark I Plants

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7.3.2 Mark II and III Plants

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7.4 Functional Evaluation Criteria

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7.5 Allowable Stresses

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7.6 Flow Induced Vibration

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7.7 Repair Impact on Existing Internal Components

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7.8 Radiation Effects on Repair Design

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7.9 Analysis Codes

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7.10 Thermal Cycles

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7.11 Corrosion Allowance

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Table 2: Load Combinations for Mark I Plants

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Table 3: Load Combinations for Mark II and Mark III Plants

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Table 4: Load Term Definitions for Tables 2 and 3

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8.1 Systems Evaluations

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8.2 SLC Solution Distribution

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8.3 Loss of the Above Core Plate Pressure Reading

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8.4 Power Uprate

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9.1 Materials

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9.2 Crevices

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9.3 Welding and Fabrication

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9.4 Pre-Installation As-Built Inspection

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9.5 Installation Cleanliness

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9.6 ALARA

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9.7 Qualification of Critical Design Parameters

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10.1 Inspection Access

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10.2 Pre and Post Installation Inspection

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10.3 System Hydrostatic Test

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10.4 Flow Test

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10.5 Instrumentation Checks

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11. QUALITY ASSURANCE PROGRAM

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12. Documentation

The following documentation shall be prepared and maintained as permanent records:

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13. REFERENCES

[1] EPRI Report TR-105707, "BWR Vessel and Internals Project, Safety Assessment of BWR Reactor Internals," (BWRVIP-06), October 1995.

[2] EPRI Report TR-107286, "Standby Liquid Control and Core Plate dP Internals Inspection and Evaluation Guidelines, (BWRVIP-27), April 1997

[3] EPRI Document 84-MG-18, "Nuclear Grade Stainless Steel Procurement, Manufacturing and Fabrication Guidelines", Rev. 2, January 1986

[4] EPRI Document NP-7032, Material Specification for Alloy X-750 for Use in LWR Internal Components, Revision 1

[5] Code Case N-516, "Underwater Welding Section XI, Division", Approved August 9, 1993

[6] EPRI Report TR-106712, "BWR Vessel and Internals Project- Roll/Expansion Repair of Control Rod Drive and In-Core Instrument Penetrations in BWR Vessels (BWRVIP-17)", November, 1996

[7] GENE Document NEDC-32436, Qualification of Inconel 82 Overlay Repair Welding Using Machine Gas Tungsten-arc Welding Temperbead Techniques Without Preheat or Post Weld Heating, January 1995

APPENDIX A REPAIR CONCEPTS FOR SLC&CDP INTERNAL LINES

This appendix includes discussion of concepts for the repair of the SLC&CDP internal lines.

A.1 Abandoning In Place

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A.2 Physical Repair of the SLC&CDP Internal Lines

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APPENDIX B ALTERNATE CORE PLATE dP SIGNAL SOURCES

In the event that a crack occurs in the above core plate instrumentation line or in the outer wall of the coaxial section of the SLC&CDP lines, the core plate Dp signal will be impaired. An alternate source for this signal will be required. This appendix discusses alternate operational approaches which could be used in this situation.

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B.1 dP Signal Source Modifications

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B.2 Core Plate dP Alternate Operational Approach

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B.2.1 Core Plate dP

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B.2.2 CRD Drive Pressure

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B.2.3 Core Spray Break Detection (BWR/2,3,4)

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APPENDIX C REPAIR CONCEPTS FOR SLC&CDP NOZZLES

This appendix includes discussion of various concepts for the repair of the SLC&CDP nozzles. It is intended to provide the designer with an overview of potential repair approaches.

C.1 Known Repair Techniques

Four basic repair techniques have been performed on leaking small nozzles at operating nuclear power plants. Three of the techniques are weld repairs, and the fourth is roll expansion of the leaking nozzle out against the nozzle penetration.

C.1.1 Weld Repairing

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C.1.2 Safe End and External Tee Weld Repairs

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C.1.3 Roll Expanding

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C.2 New Repair Techniques

C.2.1 Full Nozzle Penetration Temperbead Welding

C.2.1.1 EPRI CRD Repair

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C.2.1.2 Japanese Owner's Group In-core Repair

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C.2.2 Nozzle OD Structural/Seal Weld

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C.2.3 Non-Structural Thermal Spray Leakage Barrier

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C.2.4 Full Penetration (Through Nozzle Wall) Temperbead Repair

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C.2.5 Mechanical Seals

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C.3 Additional Repair Considerations

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C.4 Code/Design Considerations

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FIGURES

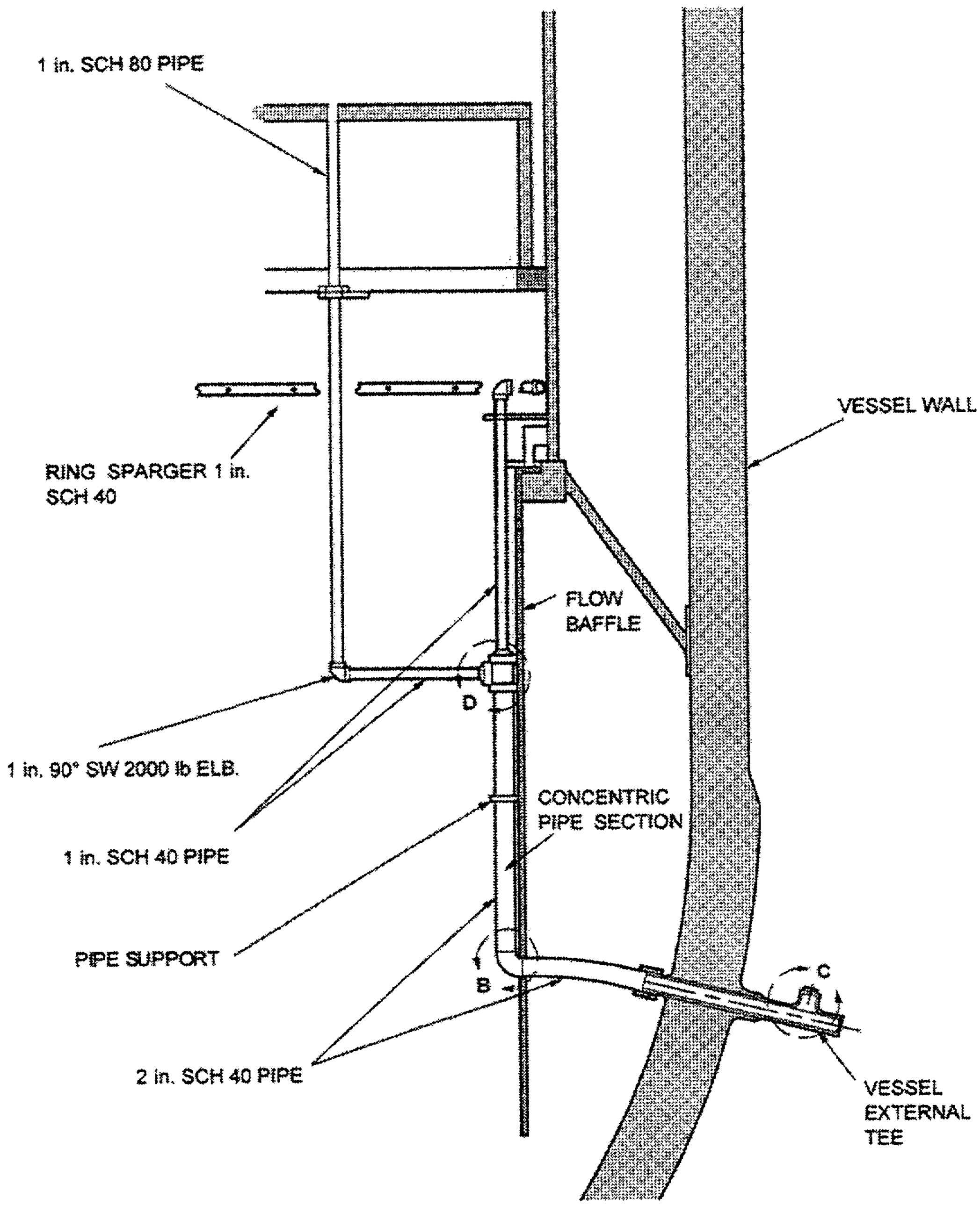

Figure 1: BWR/2 SLC&CDP Internals

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Figure 2: BWR/2 SLC&CDP Internals Details

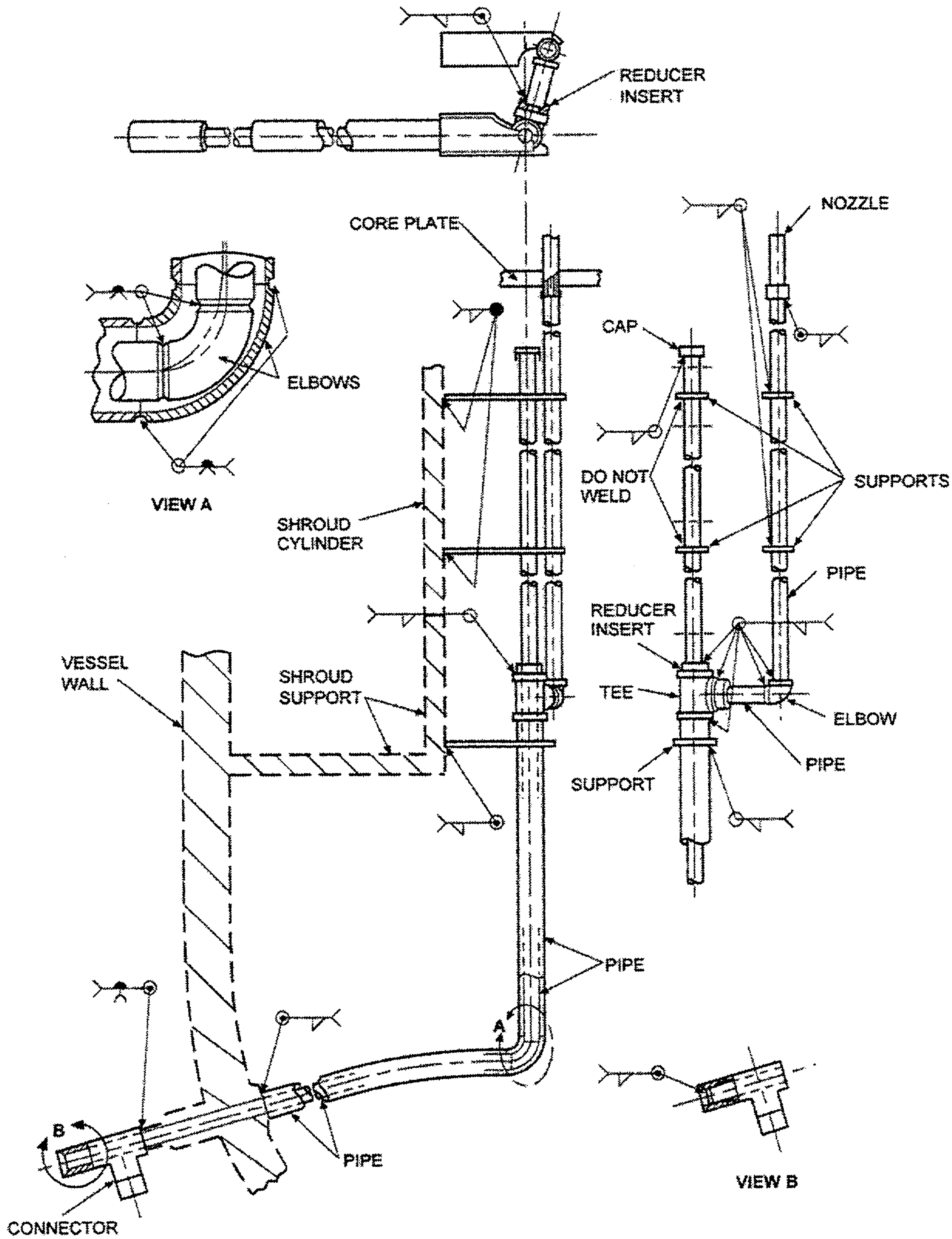

Figure 3: Typical SLC&CDP Internal Lines (BWR/3/4)

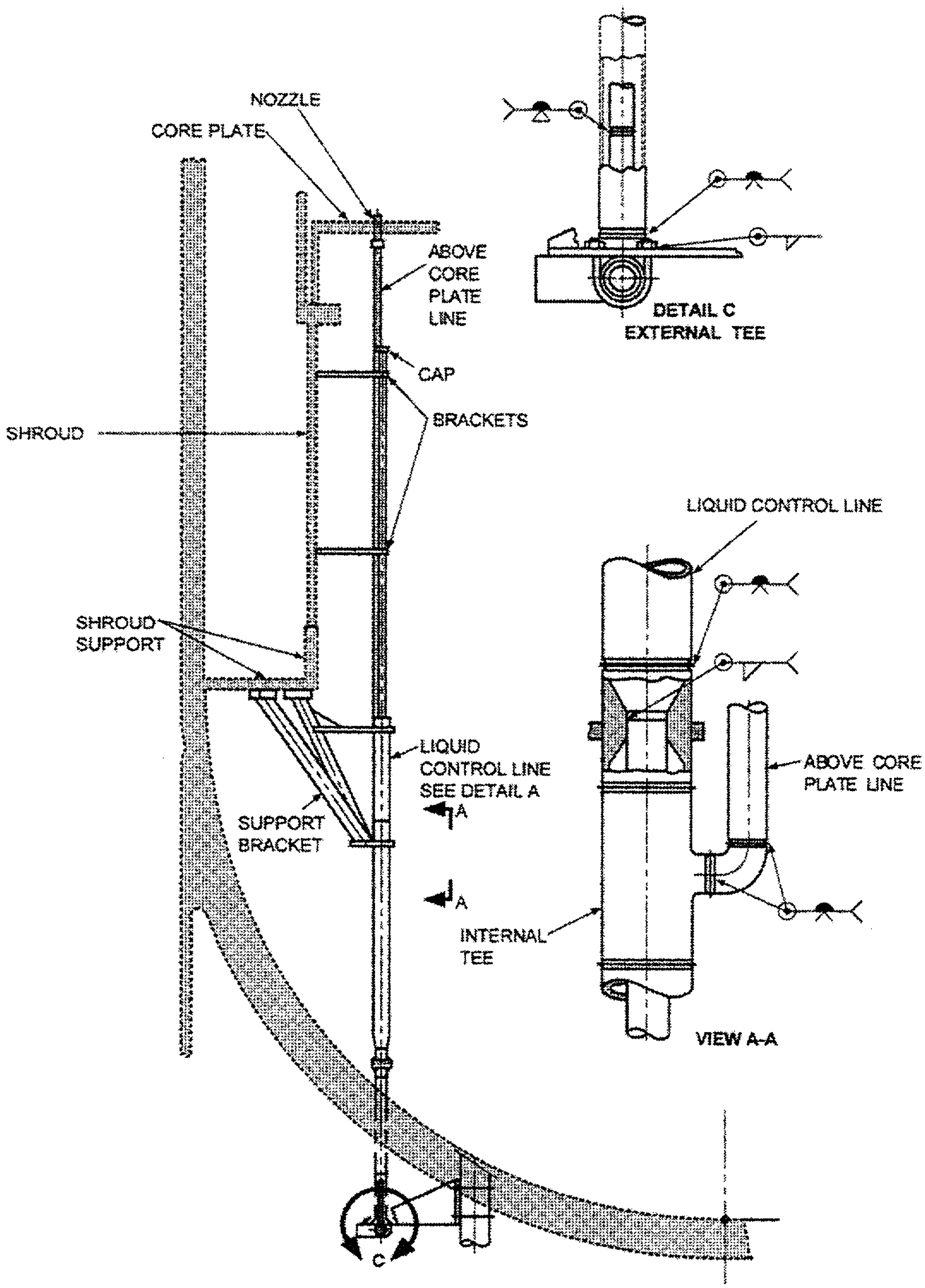

Figure 4: BWR/4/5 SLC&CDP Arrangement

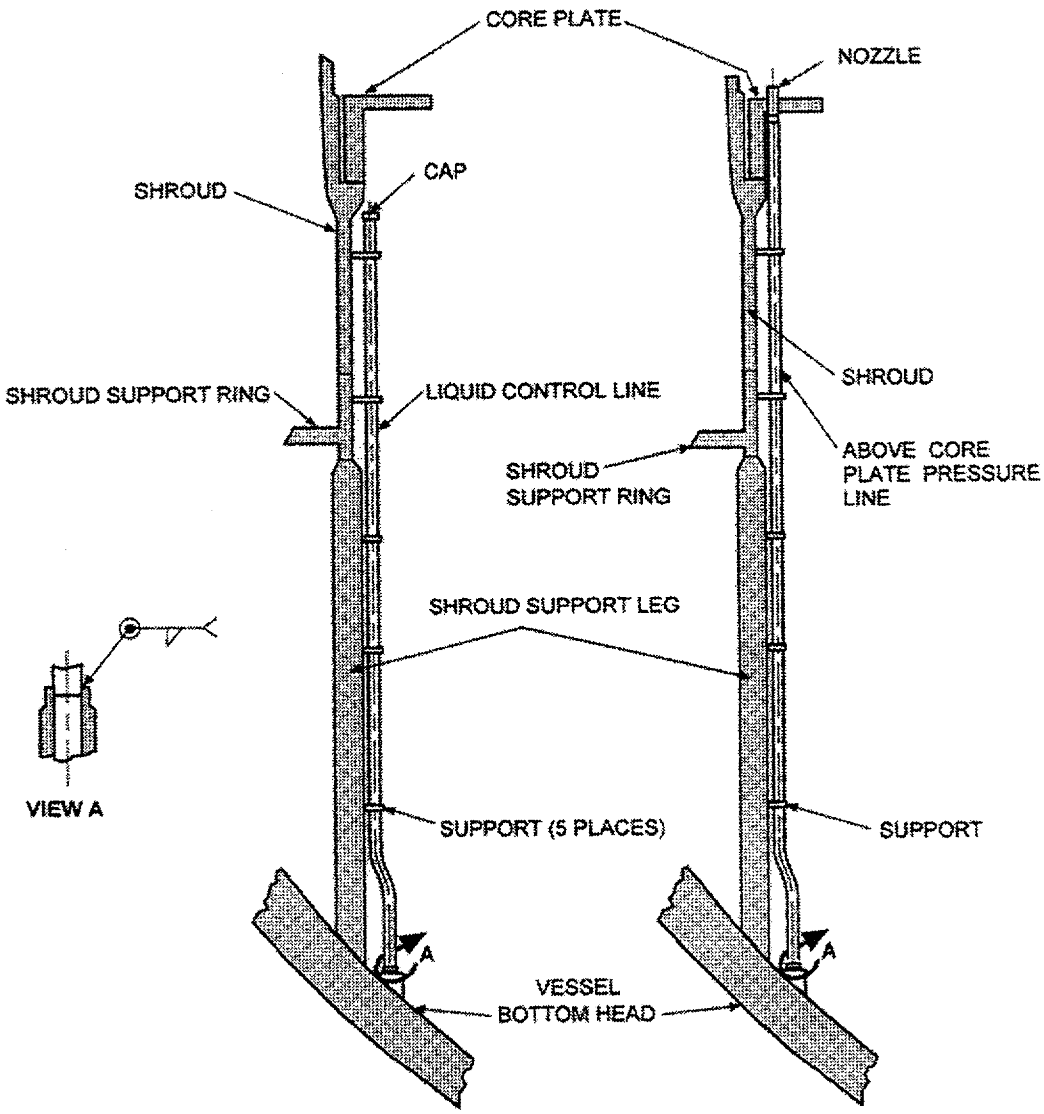

Figure 5: BWR/6 SLC&CDP Internals

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Figure 6: Typical BWR Power-Flow Map

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Figure 7: SLC&CDP Nozzle Typical for BWR/2 and Early BWR/4 CE Vessels

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Figure 8: SLC&CDP Nozzle for BWR/4 Vessels

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Figure 9: SLC&CDP Nozzle For BWR/3/4 B&W Vessels

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Figure 10: SLC&CDP Nozzle For BWR/3/4 CB&I Vessels and BWR/3 RDM Vessels

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Figure 11: SLC&CDP Nozzle For BWR/4 Hitachi Vessel

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Figure 12: SLC&CDP Nozzle For BWR/4/5 CB&I Vessels

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Figure 13: SLC&CDP Nozzle For BWR/4/5 CE Vessels

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Figure 14: SLC&CDP Nozzle For BWR/6 CB&I Vessels

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Figure 15: SLC&CDP Nozzle For BWR/6 RDM Vessels

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Figure 16: dP Sensing Arrangement (Above Core Plate Functions)

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Figure 17: Concept for Replacement dP Line

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Figure 18: Temperbead Weld Nozzle Replacement

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Figure 19: Structural/Seal Nozzle Repair

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Figure 20: CRD Stub Tube Repair

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Figure 21: Thermal Spray Repair

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Figure 22: Another Temper Bead Nozzle Repair

Target:
Nuclear Power

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