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BWR Vessel and Internals Project

Lower Plenum Repair Design Criteria (BWRVIP-55NP)

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 components which are located in the lower plenum region of a BWR.

Background:
A number of components are located in the lower plenum region of a BWR. The components addressed in this document include the CRD housing and stub tubes and the incore housings. In the event that significant degradation is observed in these components, 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 possibily 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.

TR-108719NP

Key Words
Boiling Water Reactor
Repair
Stress Corrosion Cracking
Vessel and Internals
Lower Plenum
CRD Housing
Incore Housing

BWR Vessel and Internals Project

Lower Plenum Repair Design Criteria (BWRVIP-55NP)

TR-108719NP
Research Project B501

Final Report, March 2000

Prepared by:

GE Nuclear Energy

BWRVIP Repair Committee

Prepared for

BOILING WATER REACTOR VESSEL & INTERNALS PROJECT and

EPRI

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Organization(s) that prepared this report:

GE Nuclear Energy

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ORDERING INFORMATION

Requests for copies of this report should be directed to the BWRVIP Program Manager, 3412 Ave., Palo Alto, Ca. 94304, (650) 855-2340.

ACKNOWLEDGMENTS

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

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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 components located in the lower plenum of the reactor. It is provided to assist BWR owners in designing repairs which maintain the structural integrity of the lower plenum components 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.

Issuance of this document is not intended to imply that repair of the lower plenum components is the only viable method for resolving cracking in the components. Due to variation in the material, fabrication, environment and as-found condition of the individual lower plenum components, 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 [1] as a follow-on to the activities completed on shroud cracking. As documented in this safety assessment, there are several BWR reactor internal components, located in the lower plenum, where extensive degradation can be tolerated. The BWRVIP have also prepared generic inspection and evaluation guidelines for the internal components located in the bottom head, below the core support or lower plenum [2] to assure the continued safety function integrity of the lower plenum internals. There have been several reports of cracking in BWR lower plenum components, principally the control rod drive and incore instrument penetrations, and some plants have implemented repairs to these components. To prepare for potential repairs, the BWRVIP have prepared this repair criteria for the lower plenum reactor internal components.

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 internal components in the reactor vessel lower plenum area.

The issuance of this document is not intended to imply that a repair of lower plenum reactor internal components is the only viable disposition of such cracking/degradation.

1.3 Scope

This document is applicable to General Electric BWR/2 through BWR/6 plants which plan to implement repairs to lower plenum items. The following lower plenum components are addressed in this document: Control Rod Drive Housing, Control Rod Drive Stub Tube, In-core Housing, In-core Guide Tube, In-core Stabilizer and BWR/2 Flow Baffle. The aligner pin for the CRGT and OFS and the peripheral fuel support assembly are also included in this repair criteria, even though they are located on the upper surface of the core support plate. The Shroud Support legs, and Standby Liquid Control & Core Delta Pressure nozzles and internal lines are addressed in separate repair criteria [3, 4] and are not included in the scope of this report. The Control Rod Guide Tube, Orificed Fuel Support, and In-core Dry Tube assemblies are also discussed in this document; however, as these items are by design replaceable components there is no need to apply this repair criteria to these components.

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 lower plenum internals. Reducing an indication to an acceptable size is within the definition of repair. Weld overlay, without removal of the defect, is another repair in the context of this criteria.
Lower Plenum	The BWR2-6 lower plenum is the space inside the reactor vessel which is below the core support plate and the shroud support plate. Note: not all of the internal components in the lower plenum are considered in this report.
CRD Penetration	The CRD vessel penetration includes the portion of the CRD housing which penetrates the vessel head and the stub tube (where applicable). The weld of the CRD housing to the stub tube, the weld of the stub tube to the bottom head and, where applicable, the CRD housing to the bottom head are included with the CRD penetration. The CRD penetration also includes several inches of adjacent low alloy steel vessel material.

3. LOWER PLENUM INTERNAL COMPONENT CONFIGURATIONS AND SAFETY FUNCTIONS

3.1 General Physical Description

This section describes the various BWR internal components which are located in the lower plenum and their functions. The guidelines of this report are generic in nature. Efforts have been taken to identify the various configurations, differences in materials, etc. between different plant types. However, it is the responsibility of the BWRVIP member utilities to verify their specific plant configurations for applicability with respect to the descriptions, materials, figures and tables given in this document.

3.1.1 Control Rod Drive Housing, Stub Tube, Control Rod Guide Tube, and Orificed Fuel Support

The control rod guide tubes (CRGT), control rod drive (CRD) housings (CRDH) and stub tubes (CRDST) are an assembly of components (Figures 1 and 2) at symmetrical locations below the core which support the weight of the fuel (except the peripheral bundles which are supported by the core support plate) and allow the movement of control rods into the reactor core to achieve reactivity control. Control rods provide the primary means of achieving shutdown conditions.

The CRD housing contains the CRD mechanism for controlling the position of the control rods. The generic CRD housing and penetration configurations are depicted in Figure 3. On pre-BWR/6 and one BWR/6 plant, the CRD housing is welded to a stub tube. The stub tube in turn is welded to the vessel bottom head at the CRD penetration. Figures 4, 5, and 6 depict the specific configurations for the different BWR types. The stub tube transmits the loads, caused by vessel internal pressure, the weight of the fuel and CRD reaction loads, from the CRD housing to the vessel bottom head. Most BWR/6 plants do not have stub tubes. In these plants, the CRD housing is welded directly to the vessel bottom head at the penetration (Figure 7). The loads from the CRD housing are transferred directly to the bottom head.

The CRD housings extend about 14 feet outside the vessel bottom head, becoming part of the primary pressure boundary. The CRD mechanisms are mounted at the end of the housing by a bolted flange connection. Materials for the CRD Housing are summarized in Table 1.

The control rod guide tube houses the control rod when it is withdrawn from the core. The control rod guide tube (Figures 2 and 8) extends from the core plate to the CRD housing. The guide tube is mechanically connected to the housing by a bayonet mechanism which engages the thermal sleeve inside the housing. The thermal sleeve serves to protect the CRD housing to RPV stub tube weld from thermal over-stress, and also as a locking mechanism for the guide tube. The guide tube is constrained from axial rotation by an anti-rotation pin embedded in the core plate. This pin engages a slotted alignment lug welded to the top of the guide tube (Figure 9). Four holes are provided in the guide tube just below the core plate to provide a flow path for water from the vessel bottom head to enter the core. The orificed fuel support (OFS) assembly is inserted into the top of the guide tube and has holes aligned with the guide tube holes to direct core flow to the individual fuel bundles.

The orificed fuel support assembly supports the weight of the fuel assemblies and distributes core flow into the fuel bundles. The OFS assembly is a casting with four wrought welded orifices; there are three types of OFS assemblies used in the BWR2-6 product lines.

The four-lobed OFS assembly is a cylindrical structure with four internal compartments and a central opening for the positioning of the control rod blade. A fuel bundle is inserted into each of the four internal compartments. The OFS assembly provides vertical and lateral support, and alignment to the bottom of the fuel bundles. The weight of the fuel bundle is transferred through the OFS assembly to the control rod guide tubes which in turn is transferred to the CRD housings. The coolant flow into the fuel assemblies is regulated by an orifice located on the side of the lower portion of the OFS casting. Orifice sizing varies on the different product lines.

The peripheral fuel support consists of a single opening cylindrical structure that provides support to one peripheral fuel assembly. The peripheral fuel support assemblies are welded into openings in the core support plate (see Figure 17). The flow regulating orifice on the peripheral fuel support is located directly below the top opening.

Table 1 - Material Summary for CRD Housing, CRGT and Stub Tubes

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3.1.2 In-core Housing, Incore Guide Tube and In-core Stabilizer Hardware

The Neutron Monitoring System (NMS) measures neutron flux in the reactor core. The neutron flux data is used to control operation of the reactor and, in some cases, induce a scram signal that would terminate reactor operation. The in-core housings and guide tubes provide a pathway for the NMS detectors to have access inside the reactor core. The detectors are inserted through tubes inside of the in-core housings and in-core guide tubes. The tops of the detectors are spring fitted into the top guide to prevent lateral movement. Figures 10, 11, 12, and 13 depict the in-core housings and guide tube configurations.

The in-core housing extends from below the lower reactor vessel head (RPV) thru the lower RPV head to a point approximately four feet above the low point of the head. The tops of the in-core guide tubes are laterally supported by the core plate. The in-core housing is welded at the inside surface of the RPV bottom head penetration. The in-core housings from the vessel penetration to the flange outside the vessel are part of the reactor vessel primary pressure boundary. The section of the in-core housing inside the vessel and the entire in-core guide tube are not part of the RPV primary pressure boundary.

There are no welds in the section of the in-core housing which is inside the reactor vessel. The upper end of the in-core housing has an integral socket; the in-core guide tube inserts into this socket and is attached to the in-core housing with a fillet weld. There are no welds in the in-core guide tube itself, and its upper end makes a slip fit with a mating hole in the core plate (not welded). The top of the guide tube is not sealed. The in-core housing (section inside the vessel) and the in-core guide tube have a function to laterally support and position instrumentation tubes; this is not a safety related function. The in-core housings and in-core guide tubes are not the pressure boundaries for the instrumentation tubes themselves. The inside surface of the in-core housings and the in-core guide tubes are exposed to reactor water.

The in-core stabilizer hardware is a latticework of clamps, tie bars and spacers which gives lateral support and rigidity to the incore guide tubes (Figure 14). Interconnecting the guide tubes creates an assembly that is laterally stiffer than the individual tubes. This minimizes the potential effects of flow induced vibration of the in-core guide tube and the in-core housing. This hardware is located between the core plate and the bottom RPV head. The support hardware is all type 304 stainless steel and is assembled by bolting and tack welds. Table 2 contains a summary of the materials used in the aforementioned components.

Table 2 - Material Summary for In-core Housing and Guide Tube

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3.1.3 In-core Flux Monitor Dry Tube Assembly

The Neutron Monitoring System (NMS) measures neutron flux, which is used to control operation of the reactor and, in some cases, induce a scram signal that would terminate reactor operation. The source range monitor (SRM) and intermediate range monitor (IRM) instruments operated in a dry ambient pressure air environment inside the reactor core which is provided by "dry tubes". The dry tubes are installed within the in-core housing/guide tube assembly. The top of the dry tube assembly is spring fitted (Figures 15 and 16) into the top guide to prevent lateral movement.

Dry tubes are installed in the SRM and IRM in-core housings (e.g. in a BWR-4 with 764 fuel bundles 12 of the 55 in-core housings are for SRMs and IRMs), but dry tubes are not used with the power range detectors. Procedures are available for routine replacement of SRM/IRM dry tubes. There is no welding required to replace dry tubes. The tooling to replace cracked SRM/IRM dry tubes is designed to capture the cracked upper two feet of the dry tube.

3.1.4 BWR/2 Flow Baffle

The BWR/2 lower plenum includes a flow baffle which prevents direct impingement of flow from the recirculation inlet nozzles on the outer most radially located CRGT's and In-core guide tubes. The baffle is supported from the shroud support, as shown in Figure 18, The 91 inch high cylindrical baffle is made from one inch thick stainless steel. Portions of the cylindrical surface are perforated to minimize the differential pressure across the plate and cause a more uniform flow inside the baffle, but most of the flow is channeled through a large gap between the bottom of the baffle and the RPV bottom head.

3.2 Safety Design Bases

3.2.1 CRD Housing and Stub Tube

The safety design bases for the CRD housing; are to: (1) provide a portion of the primary coolant pressure boundary during normal operation,(2) form part of the refloodable coolant volume for the reactor core following a loss of coolant accident, (3) provide vertical support for the bulk of the fuel assemblies (four per CRD housing) and thus maintain core geometry, (3) provide support for the CRD, including scram forces (reactivity control safety function).

3.2.2 CRGT

The CRGT safety functions are: (1) to provide vertical support to the core, (2) to aid in the proper alignment and thus insertion time for the control rods (reactivity control safety function), and (3) provide the lateral load path for horizontal dynamic loading from the non-peripheral fuel bundles to the core support plate.

3.2.3 In-core Housing and In-core Guide Tube

The portion of the in-core housing which is below the weld attaching the housing to the RPV bottom head has a safety function as a portion of the primary pressure boundary. The remainder of the in-core housing and the in-core guide tube have no safety function.

3.2.4 In-core Stabilizer

The in-core stabilizer hardware has no safety function.

3.2.5 BWR/2 Flow Baffle

The BWR/2 Flow baffle has no safety function.

3.2.6 Loose Parts

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3.3 Event Analyses

The purpose of this document is to provide general design criteria for repairs of lower plenum internal components. Accordingly, various events and operational conditions must be considered to ensure that the repair does not inhibit the ability of the lower plenum components 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 Design Basis Accidents (Emergency/Faulted Conditions)

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3.3.4 Loading Combinations

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4. SCOPE OF REPAIRS

The lower plenum repairs primarily address cracking and or leaking in IGSCC susceptible stainless steel and nickel-chrome-iron alloy components. Susceptible lower plenum welds and materials are discussed in Reference 2. This repair criteria applies to the following lower plenum components: Control Rod Drive Housing and Stub Tube, In-core Housing, In-core Guide Tube, and BWR/2 flow baffle. Justification for continued operation as-is of failed components is covered in Reference 2. Repair options considered are, abandonment in-place, replacement of whole components, weld repair of defects, structural weld overlay, mechanical repairs. The Control Rod Guide Tube, Orificed Fuel Support, and In-core Dry Tube assemblies are by design replaceable components; therefore, replacement of these items is a routine maintenance activity and not a repair as defined in this repair design 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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5.5 Retained Flaw(s)

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6.2 BWR/6 Core Support Structural Components

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Table 3 - Typical CRD Reaction 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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7.7 Flow Induced Vibration

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7.9 Radiation Effects on Repair Design

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7.10 Analysis Codes

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7.11 Thermal Cycles

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7.12 Corrosion Allowance

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Table 4: Load Combinations for Mark I Plants

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Table 5: Load Combinations for Mark II and Mark III Plants

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Table 6: Load Term Definitions for Tables 4 and 5

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8.2 Power Uprate

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9.1 Materials

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9.3 Welding and Fabrication

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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 Scram Tests

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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-108727, "BWR Vessel and Internals Project, Lower Plenum Inspection and Flaw Evaluation Guidelines," (BWRVIP-47), December 1997

[3] EPRI Report TR-108720, "BWR Vessel and Internals Project, Shroud Support and Vessel Bracket Repair Design Criteria," (BWRVIP-52), June 1998

[4] EPRI Report TR-108716, "BWR Vessel and Internals Project, Standby Liquid Control Repair Design Criteria," (BWRVIP-53), July 1998

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

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

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

[8] 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

14. FIGURES

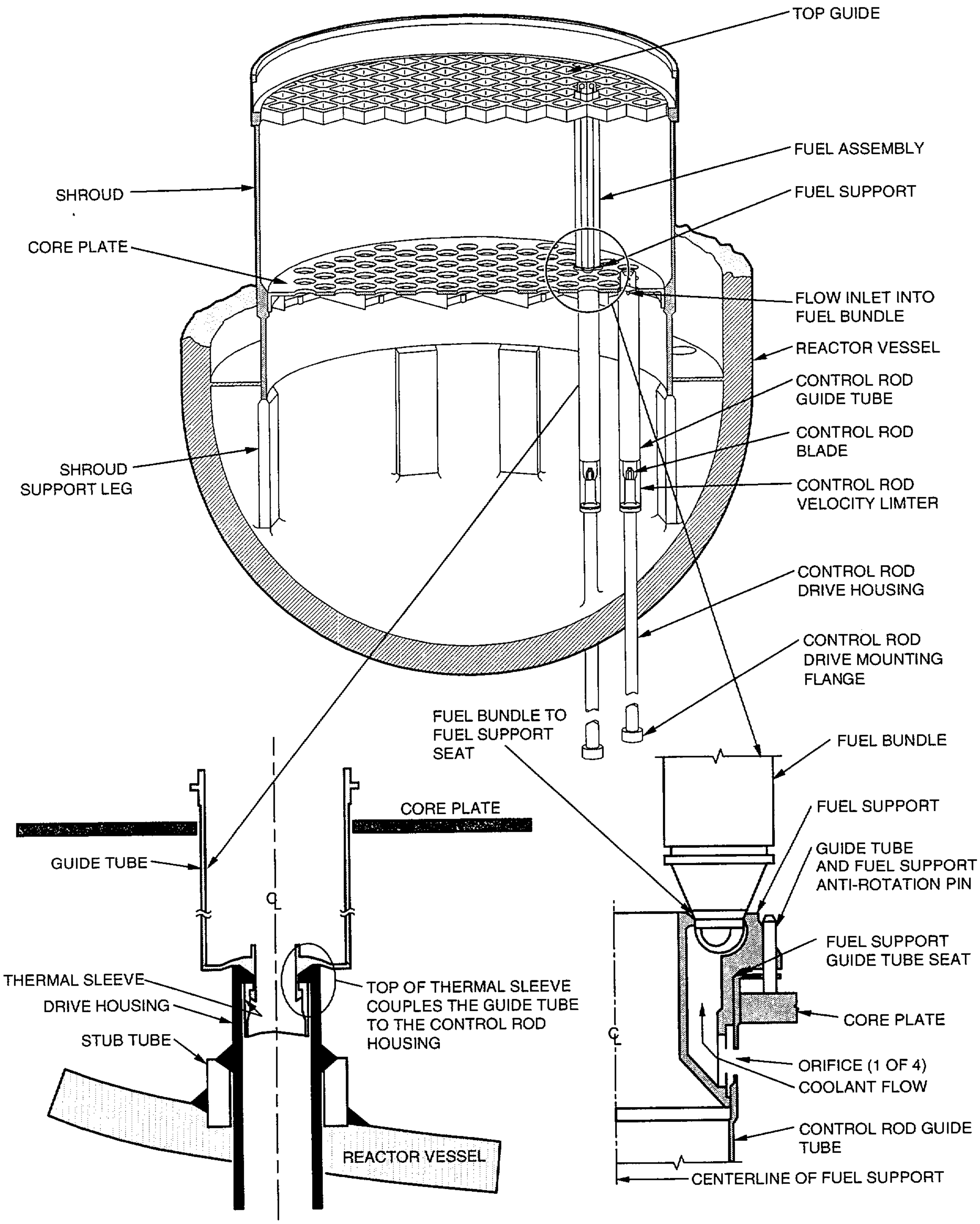

Figure 1: Control Rod Guide Tube, Housing and Stub Tube Arrangement (BWR 2-6)
(Most BWR/6 do not have stub tubes)

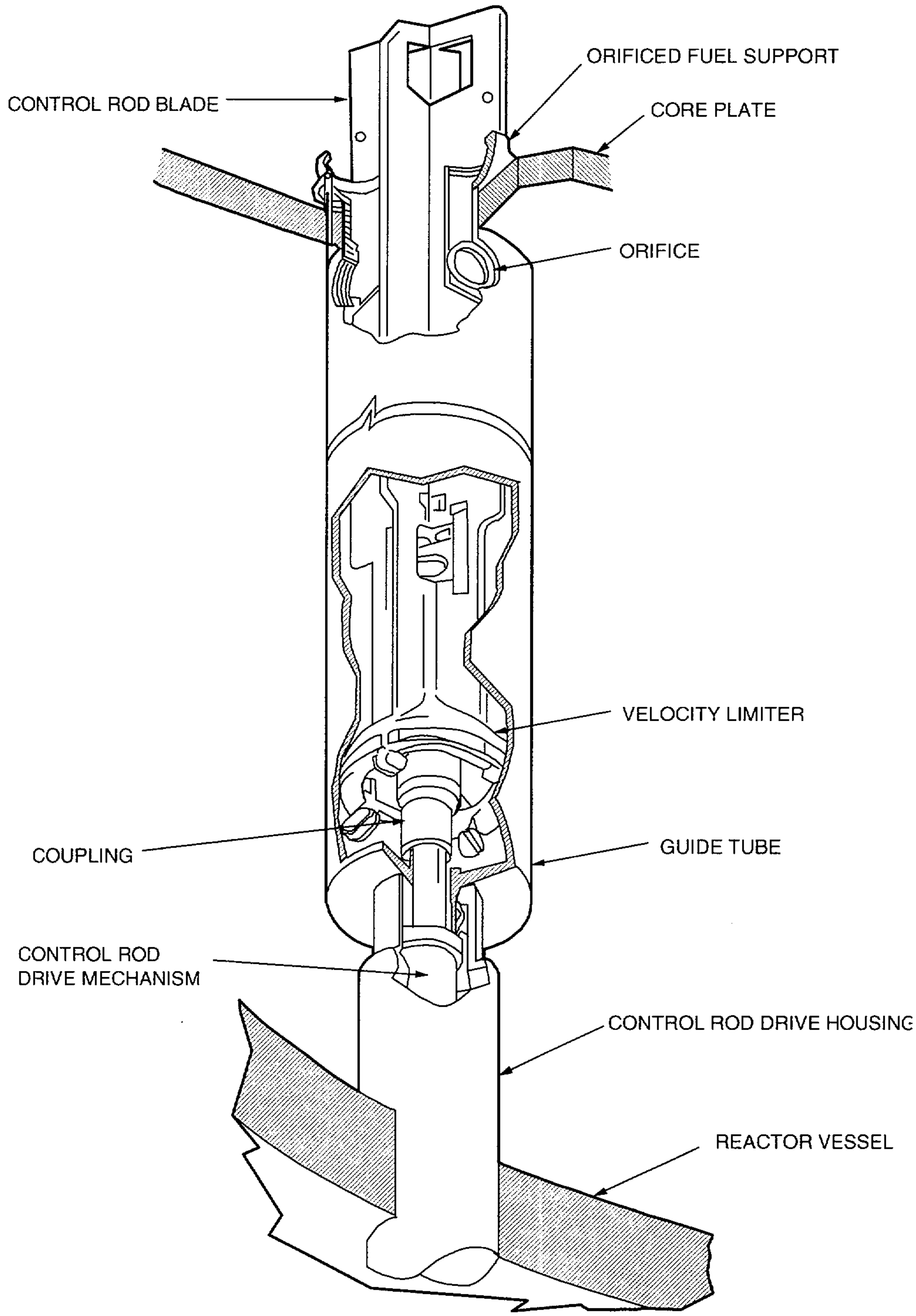

Figure 2: Control Rod Drive (BWR/2-6)
(Stub tube omitted for clarity)

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Figure 3: CRD Penetration Configurations

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Figure 4: BWR/2 CRD Housing and Penetration Configuration

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Figure 5: BWR/3/4/5 & Non-US BWR/6 CRD Housing and Socket Stub Tube Penetration Configuration

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Figure 6: BWR/3/4 CRD Housing and Set-on Stub Tube Configuration

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Figure 7: US BWR/6 CRD Housing and Straight-thru Penetration Configuration

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Figure 8: Control Rod Guide Tube BWR/2-6

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Figure 9: Orificed Fuel Support Assembly

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Figure 10: In-core Guide Tube, In-core Housing & In-core Penetration, BWR/2-5 except La Salle 1, Monticello, Fermi 2, Nine Mile 1 and Hope Creek

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Figure 11: In-core Guide Tube, In-core Housing & In-core Penetration
La Salle 1, Monticello, Fermi 2, Nine Mile 2

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Figure 12: In-core Guide Tube, In-core Housing & In-core Penetration, BWR/6

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Figure 13: In-core Guide Tube, In-core Housing & In-core Penetration, Hope Creek

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Figure 14: In-core Stabilzer Hardware

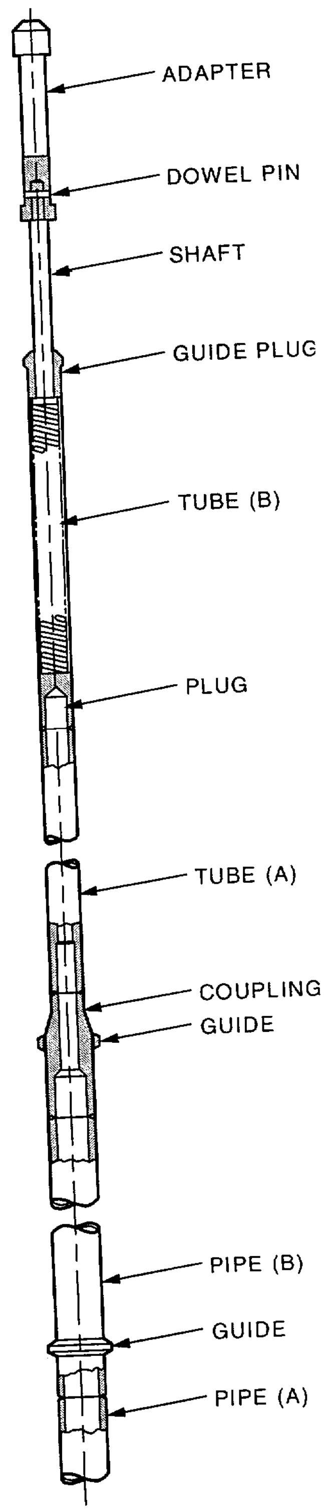

Figure 15: In-core Dry Tube Assembly

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Figure 16: In-core Dry Tube, Detail of Upper End

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Figure 17: Peripheral Fuel Support

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Figure 18: BWR/2 Flow Baffle

APPENDIX A REPAIR CONCEPTS

A.1 Scope

Table A-1 provides a summary of possible repair concepts for the lower plenum components within the scope of this repair design criteria. Some of these concepts are discussed further in the following section. The information in this appendix is for information only and is not considered part of the preceding repair design criteria. The repair concepts are not necessarily complete and some of these concepts have not been implemented or even developed.

Table A-1 - Summary of Repair Concepts for Lower Plenum Components

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A.2 CRD Housing and Stub Tube Repairs

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A.3 Incore Housing and Penetration Repairs

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Figure A1: CRD Stub Tube Repair

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Figure A.2: Mechanical Sleeve CRD Repair

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Figure A.3: Welded Sleeve CRD Stub Tube Repair

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Figure A.4: Local CRD Stub Tube Weld Repair Concept

Target:
Nuclear Power

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