EPRI

BWR Vessel and Internals Project
BWR Core Shroud Repair Design Criteria, Rev. 2
(BWRVIP-02NP)

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 Core Shroud in a BWR.

Background

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

Objective

To revise the Core Shroud Repair Design Criteria to include provisions for repair of vertical shroud welds. The revised document can be used by utility personnel performing the design and will be submitted to appropriate regulatory agencies for approval of the generic design process.

Approach

The contractor began with Revision 1 of the Repair Design Criteria and modified it as required to incorporate considerations unique to vertical welds. 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 vertical and circumferential welds in core shrouds. 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.

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Interest Categories
Piping, Reactor, Vessel and Internals
Licensing and Safety Assessment

Key Words
Boiling Water Reactor
Repair
Stress Corrosion Cracking
Vessel and Internals
Core Shroud

BWR Vessel and Internals Project

BWR Core Shroud Repair Design Criteria, Rev. 2 (BWRVIP-02NP)

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Prepared by:

Sargent & Lundy

BWRVIP Repair Committee

Prepared for

BOILING WATER REACTOR VESSEL & INTERNALS PROJECT and EPRI

3412 Hillview Ave.
Palo Alto, California 94304

Organization(s) that prepared this report:

Sargent and Lundy

BWRVIP Repair Committee

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.

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Jai Brihmadesam	Entergy
John Johnson	Alliant Energy
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L.E. Willertz	PP&L
Tom Crippes	NSP
Charles Garrow	BECO
John Langdon	CP&L
Dave Schmidt	PECO Energy
Ted Seiver	NMPC
Ed Hartwig	TVA
Bruce McLeod	SNC
Priit Okas	NYPA
Bob Geier	CECO

S&L Principal Investigators:

Tom Behringer
Steve Lange

BWR CORE SHROUD REPAIR
DESIGN CRITERIA, Rev. 2

Table of Contents

LIST OF FIGURES

ABSTRACT

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 permanent mechanical repair that ensures that the shroud will meet its design basis safety functions in the event of cracking in circumferential or vertical shroud welds. It is provided to assist BWR owners in designing a permanent mechanical repair which maintains the structural integrity of the core shroud during normal operation and under postulated transient and design basis accident conditions for the remaining plant life.

The issuance of this document is not intended to imply that a repair that replaces circumferential or vertical shroud welds is the only viable method of resolving the core shroud cracking issue. Due to variation in the materials, fabrication, environment and as-found conditions of individual units' shrouds, 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.

BACKGROUND

In 1990, crack indications were reported at core shroud welds located in the beltline region of an overseas reactor (BWR-4). This reactor had completed approximately 190 months of power operation before the cracks were discovered. As a result of this discovery, General Electric (GE) issued a Rapid Information Communication Services Information Letter (RICSIL) 054, "Core Support Shroud Crack Indications", on October 3, 1990, to all owners of GE BWRs. This RICSIL summarized cracking found in the overseas reactor and recommended that at the next scheduled refueling outage plants with high-carbon-type 304 stainless steel (SS) shroud perform a visual examination of the accessible areas of the seam welds and associated heat affected zone on the inside and outside surfaces of the shroud.

During the 1993 refueling outage of Brunswick Unit 1 (BWR-4), In-Vessel Visual Inspection (IVVI) revealed cracks at weld regions of the core shroud. Brunswick found both circumferential and axial cracks in the shroud, although cracking was predominately circumferential. These circumferential cracks were located on the shroud inside surface in the heat-affected zone (HAZ) of weld H-3 and extended 360° around the circumference of the shroud. Weld H-3 is a horizontal weld that attaches the bottom of the Top Guide Support Ring (TGSR) to the top of the shroud cylinder below the ring. The H-2 weld that joins the upper shroud cylinder to the top of the other side of the TGSR was also cracked extensively although the cracking was more shallow. The first axial crack discovered was located on the outer shroud surface at weld H-4 (Lower Shroud Cylinder). Brunswick performed additional visual testing (VT) and ultrasonic testing (UT) of the shroud and removed boat samples at welds H-2, H-3, and H-4 to evaluate the length and size of the cracks, as well as validate their ultrasonic inspection sizing test procedures.

General Electric issued Revision 1 to RICSIL 054 on July 22, 1993, to update the information on the core support shroud cracks and to provide revised interim recommendations to perform visual examination of accessible areas of the shroud at all GE BWR plants during their next scheduled outage. Since the issuance of RICSIL 054, Revision 1, cracking has been identified in several domestic BWR core shrouds.

Subsequently, on October 4, 1993, GE issued Services Inspection Letter (SIL) 572, Revision 1. This document superseded RICSIL 054, Revision 1 and provided updated guidance on inspection and cracking susceptibility.

On June 10, 1994, the BWR Vessel Internals Project (VIP) was established to focus industry resources and senior management attention on the resolution of vessel internals cracking issues, with shroud cracking identified as the highest priority. As part of the BWRVIP initiative to address this issue a "Core Shroud Repair Design Criteria" (Reference 1) and a "Guide for Format and Content of Core Shroud Repair Design Submittals (Reference 2) were developed to provide general design criteria and acceptance criteria for permanent core shroud repairs. This current revision incorporates the most recent lessons learned from the core shroud inspections and repairs performed since the fall of 1994. It also incorporates criteria related to the repair and assessment of cracking in the vertical welds. The general repair design criteria contained in this document are the products of the Repair Committee of the BWRVIP.

1.0 INTRODUCTION

1.1 Purpose

The purpose of this document is to provide general design acceptance criteria for a permanent repair of the 304 SS circumferential and vertical welds in BWR Reactor Pressure Vessel (RPV) shrouds. These criteria are based on the premise that a repair for the circumferential welds would be implemented either prior to, or at the same time as a vertical weld repair. The document does not include criteria for the repair of vertical welds alone. These criteria are being submitted for approval by the United States Nuclear Regulatory Committee (USNRC) staff. Following USNRC staff approval, it is expected that individual licensees and repair vendors will adhere to these criteria in the development of plant-specific repair designs.

The issuance and NRC approval of this document is not intended to imply that a repair is the only viable approach to resolution of the BWR core shroud cracking issue. When a utility elects to repair one or more of the circumferential and vertical shroud welds it is expected that the designs will meet the requirements of this document. For shroud welds that are not encompassed by the repair, it is expected that the BWRVIP requirements for continued inspection and assessment would be utilized.

1.2 Scope

This document is applicable to GE BWR/2, BWR3-5 and BWR/6 plants that implement a permanent repair of the 304 SS shroud welds that may be sensitized and, therefore, subject to cracking. Other RPV internal welds and temporary weld repairs are not within the scope of this document. The criteria specified apply to both circumferential and vertical welds unless specifically noted otherwise.

2.0 DEFINITIONS

Permanent Repair	A plant modification that structurally replaces specific cracked or uncracked circumferential and/or vertical shroud welds.
Repair	The word "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 ensures that the structural integrity of specific shroud circumferential and/or vertical welds is maintained.

3.0 SHROUD CHARACTERISTICS AND SAFETY FUNCTION

3.1 Generic Physical Description

The typical arrangement of the Boiler Water Reactor vessel internals is shown in Figure 3-1. The core structure surrounds the active core of the reactor and consists of the core shroud, shroud head and steam separator assembly, core support plate, and top guide. This structure is used to form partitions within the reactor vessel, sustain pressure differentials across the partitions, direct the flow of the coolant water, and laterally locate and support the fuel assemblies, control rod guide tubes, and steam separators. Figure 3-2 shows the typical reactor vessel internal flowpaths.

The core shroud is a stainless steel cylindrical assembly which provides a partition to separate the upward flow of coolant through the core from the downward recirculation flow. This partition separates the core region from the downcomer annulus, thus providing a floodable region following a postulated recirculation line break, except for BWR 2's. The floodable inner volume as shown in Figure 3-2 is the volume inside the core shroud up to the level of the jet pump suction inlet. BWR 2's do not have jet pumps and consequently do not have a floodable inner volume.

The boundary of the inner volume consists of the following:

- The jet pumps suction inlet down to the shroud support ring.
- The shroud support ring which forms a barrier between the outside of the shroud and the downcomer annulus inside of the reactor vessel.
- The reactor vessel wall below the shroud support ring.
- The core shroud up to the level of the jet pump suction inlet.

The volume enclosed by the core shroud is characterized by three regions, each with a different shroud diameter. The upper shroud has the largest diameter and surrounds the core discharge plenum which is bounded by the shroud head on top and the top guide support ring below. The central portion of the shroud surrounds the active fuel and forms the longest section of the shroud. This section has an intermediate diameter and is bounded at the bottom by the core plate support ring. The lower shroud, surrounding part of the lower plenum, has the smallest diameter and at the bottom is welded to the reactor vessel shroud support ring. The various core shroud regions are made of 304 or 304L SS. Figures 3-3A through 3-3G depict typical core shroud arrangements and show typical configuration and designation of welds that may have a sensitized 304 SS area.

While all BWR core shrouds serve basically the same function and are very similar in design, there are some significant differences between individual reactors which must be considered in designing a permanent repair for circumferential as well as vertical weld cracking. Some of these differences include but are not limited to:

- Diameter of shroud (varies among plants)
- Thickness of shroud wall (in some cases varying thickness along shroud height)
- Number of horizontal welds and different heights of cylindrical sections
- Number of vertical welds connecting the cylindrical shells
- Vessel internal components design (i.e., gussets vs. no gussets)
- Conical vs. flat shroud support plate
- Configurations and location of Emergency Core Cooling Systems (ECCS) piping, brackets, etc.
- Differential pressure and seismic loading
- With/without jet pumps
- Tapered lower cylindrical shell vs. straight lower cylindrical shell

Although many differences exist between plants, the important factors unique to BWR/2 plants are as follows: (a) recirculation flow enters the reactor vessel from the bottom, (b) ECCS for large breaks are two redundant, double capacity, core sprays, (c) short and long term cooling responses for large recirculation line breaks rely on core spray, as the vessel will not flood, (d) failure of the bimetallic weld (shroud support ring to shroud support plate weld) could possibly result in the shroud having no vertical support, (e) the reactor vessel has two, instead of four steamlines, (f) no jet pumps or floodable inner volume in vessel design.

3.2 Safety Design Bases

The reactor internals, of which the core shroud is a part, have three basic safety functions.

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3.3 Event Analysis

As previously stated, the purpose of this document is to provide general design criteria for permanent repairs for 304 SS circumferential, and vertical shroud welds that may be sensitized and thus subject to cracking. Accordingly, various events and operational conditions must be considered to ensure that the repair does not inhibit the ability of the core shroud to perform its basic safety functions and meet its power generation objectives. The following load cases shall be considered in the design of the proposed repair.

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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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4.0 SCOPE OF REPAIRS

The shroud repair addresses potential cracking in the circumferential, or vertical welds of 304 SS shrouds that may be sensitized (see Figures 3-3A through 3-3G). The scope and extent of the repair shall be clearly defined and will include all of the circumference of a horizontal weld. These criteria were developed to address a repair of any one or all of the circumferential welds. The incorporation of a repair of the vertical welds can be implemented subsequent to the circumferential weld repair or in combination with a circumferential weld repair. This criteria does not address a vertical weld repair independent of a circumferential weld repair. The design concept shall either structurally replace or provide for verification of adequate structural integrity of all design reliant features and hardware. The design concept shall be integrated with the pre-installation and periodic reinspection requirements to ensure that the assumptions used in the analysis are consistent with or bounding for the actual conditions.

Design concepts that rely on selected welds are acceptable, provided that the assumed weld configurations are either verified by inspection as prescribed in this and other applicable BWRVIP Guidelines or represent a bounded condition. This design criteria is applicable for the repair of circumferential and vertical welds H-1 down through the bimetallic weld where the shroud was welded to the shroud support.

5.0 DESIGN CRITERIA

The following design criteria must be addressed in the development of any core shroud repair.

5.1 General Design Requirements

5.1.1 Repair Design Life

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5.1.2 Safety Design Bases

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5.1.3 Safety Analysis Events

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5.1.4 Load Combinations

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5.1.5 Flow Partition

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5.1.6 Flow Induced Vibration

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5.1.7 Loading on Existing Internal Components

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5.1.8 Annulus Flow Distribution

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5.1.9 Core Bypass Flow Distribution

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5.1.10 Emergency Operating Procedure (EOP) Calculations

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5.1.11 Power Uprate

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5.1.12 Radiation Effects on Repair Design

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5.2 Design Basis

5.2.1 Structural

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5.2.1.1 Load Combinations

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5.2.1.2 Allowable Stresses

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5.2.1.3 Seismic Loads

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5.2.2 Shroud Differential Pressure

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5.2.3 Design Analysis

The following design analysis requirements apply to all shroud repairs:

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The following design analysis requirements apply to circumferential weld repairs only.

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The following design analysis requirements apply to vertical weld repairs only:

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5.3 Functional Requirements

5.3.1 Circumferential Weld Repairs

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5.3.1.1 Allowable Displacement of Shroud

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5.3.1.2 Plant Specific Requirements

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5.3.1.3 Leakage Evaluation

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5.3.2 Vertical Weld Repairs

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5.4 Qualification of Critical Design Parameters

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5.5 Thermal Cycles

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5.6 Chemistry/Flux

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5.7 Loose Parts Considerations

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5.8 Inspection Access

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5.9 Crevices

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5.10 Materials

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5.11 Welding and Fabrication

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5.12 Pre-Installation As-Built Inspection

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5.13 Installation Cleanliness

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5.14 Pre and Post Installation Inspection

5.14.1 General Requirements

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5.14.2 Circumferential Welds

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5.14.3 Vertical Welds that are not Structurally Replaced by the Repair

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5.14.4 Ring Segment (Radial) Welds that are not Structurally Replaced by the Repair

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5.14.5 Post Installation Repair Hardware Inspections

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5.15 ALARA

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6.0 CODES AND STANDARDS

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7.0 FUNCTIONAL TESTING

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8.0 QUALITY ASSURANCE PROGRAM

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9.0 DOCUMENTATION

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

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10. REFERENCES

1. Core Shroud Repair Design Criteria, Revision 2 (BWRVIP-02), Sept. 1994

2. Guide for Format and Content of Core Shroud Repair Design Submittal (BWRVIP-04), October 1995

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5. Nuclear Grade Stainless Steel Procurement, Manufacturing and Fabrication Guidelines, EPRI Document 84-MG-18

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

7. Control of Ferrite Content in Stainless Steel Weld Metal, Regulatory Guide 1.31

8. BWR Core Shroud Inspection and Flaw Evaluation Guideline, Revision 2 (BWRVIP-01), October, 1996

9. Guidelines for Reinspection of BWR Core Shroud (BWRVIP-07), February, 1996

10. Core Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63), In preparation.

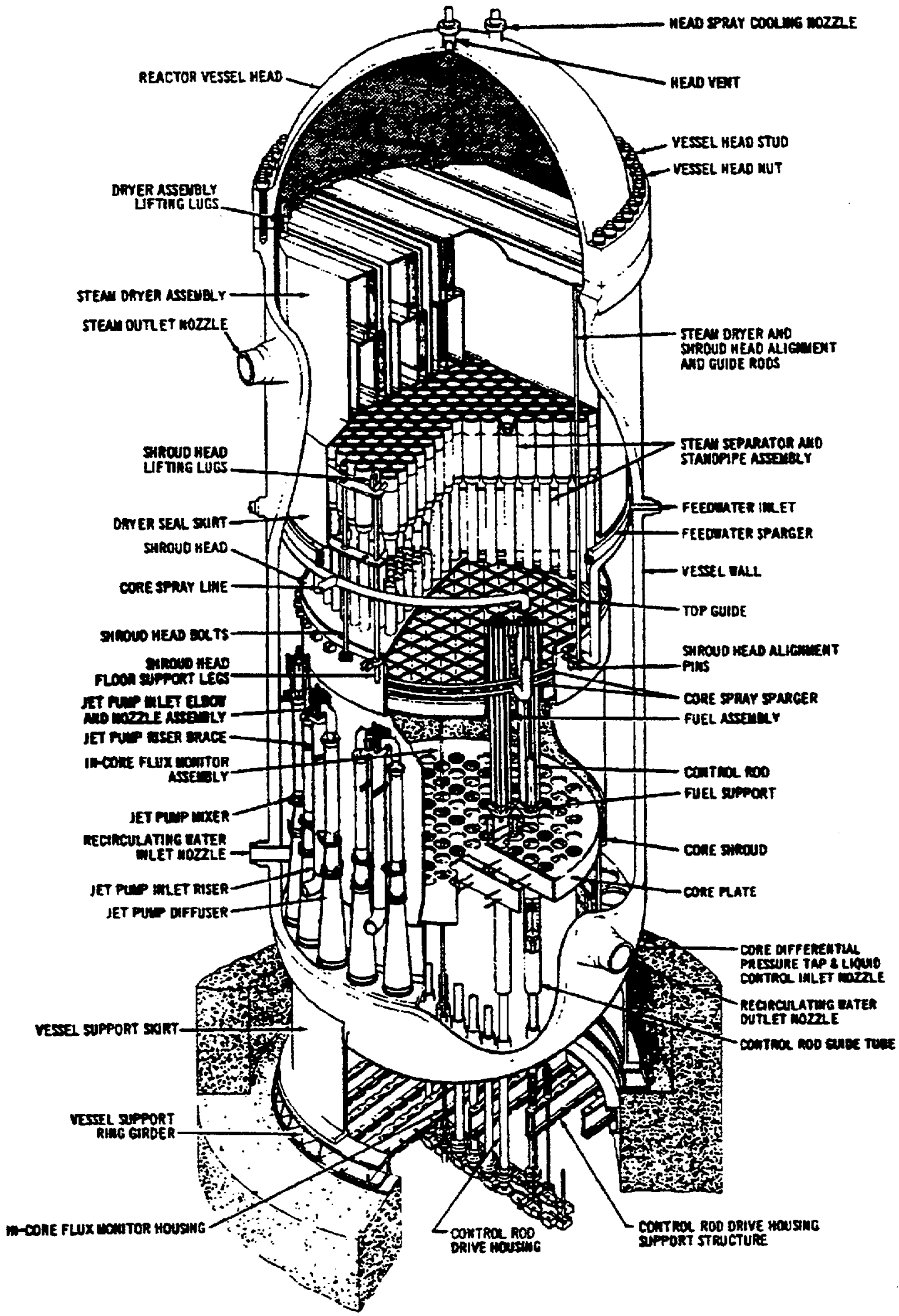

Figure 3-1
Typical Reactor Internals Arrangement

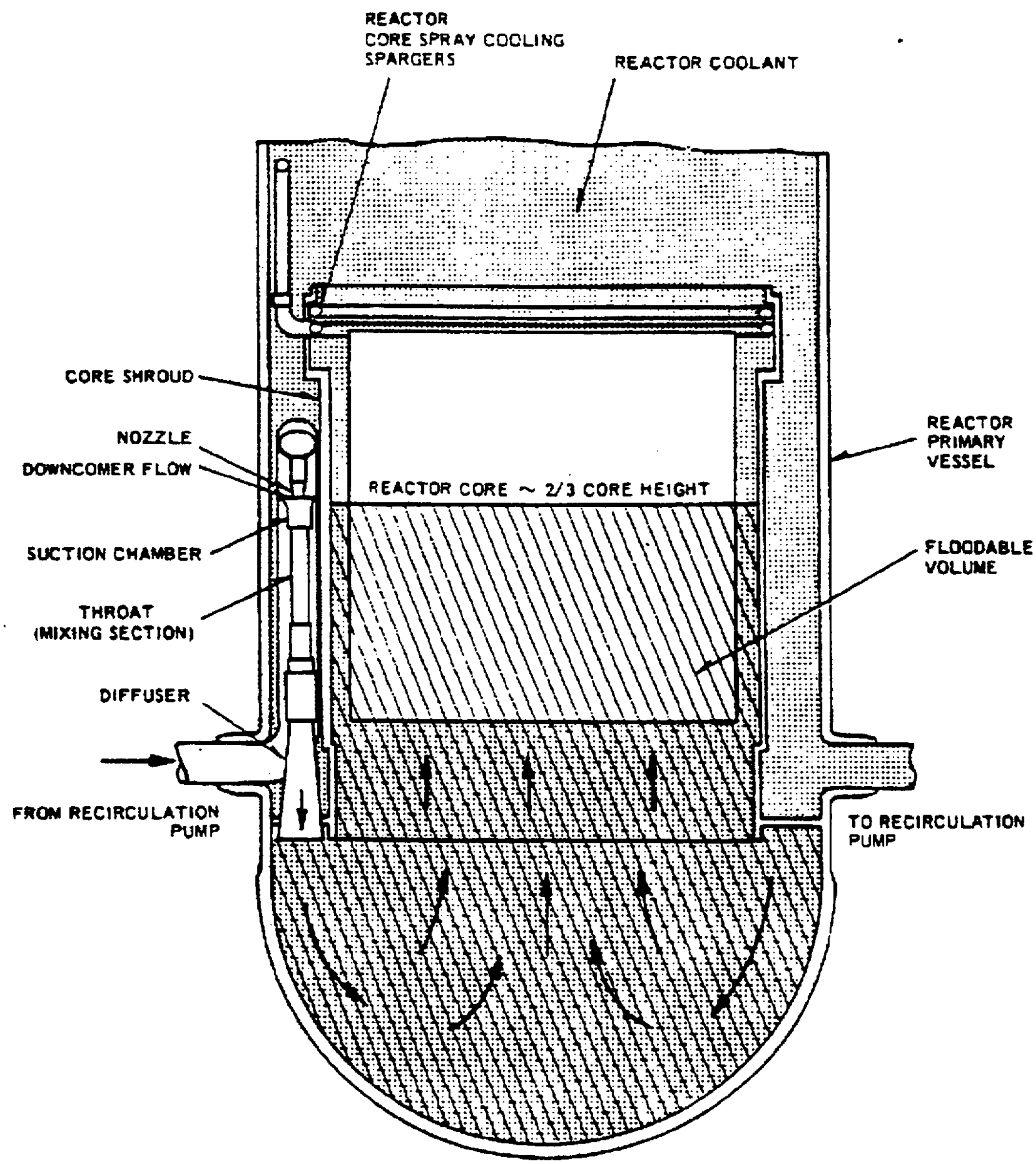

Figure 3-2
Reactor Internal Flowpaths

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Figure 3-3A
Shroud Horizontal Welds

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Figure 3-3B
Shroud Horizontal Welds

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Figure 3-3C
Shroud Horizontal Welds

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Figure 3-3D
Shroud Horizontal Welds

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Figure 3-3E
Shroud Horizontal Welds

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Figure 3-3F
Shroud Horizontal Welds

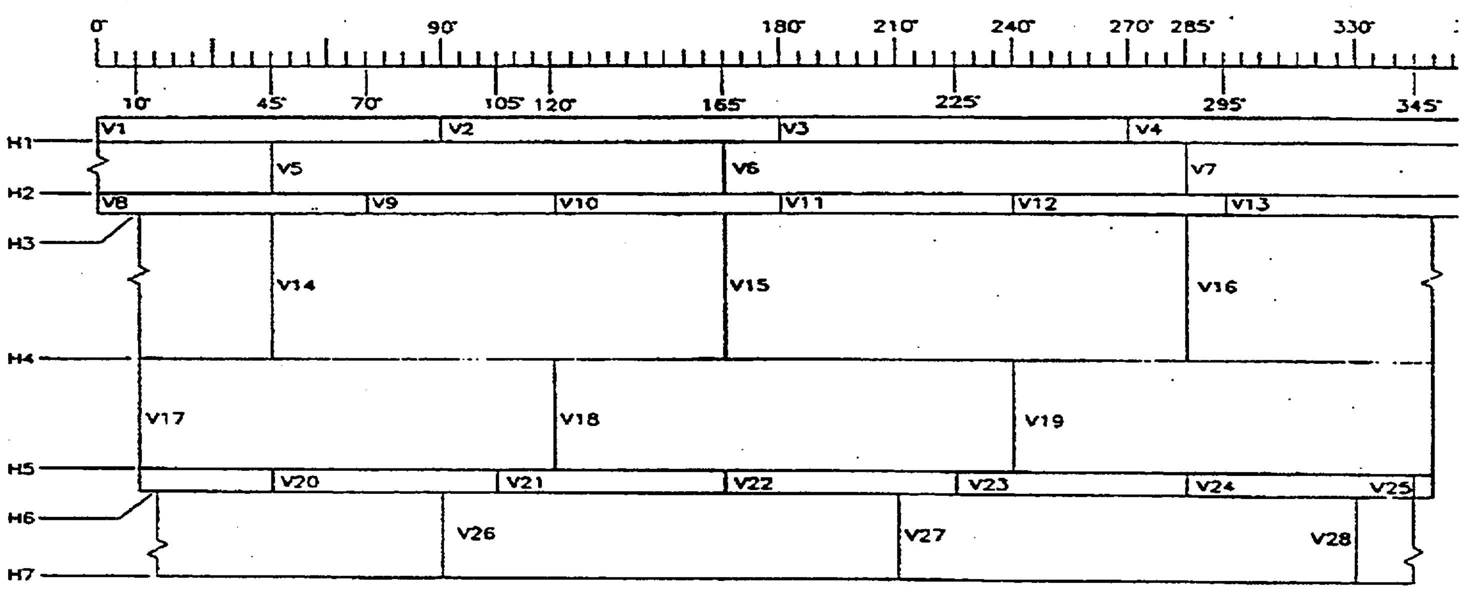

Figure 3 - 3G
Shroud Vertical Welds
(Representative Example Configuration)

Targets:
Nuclear Power

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EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.1212 • askepri@epri.com • www.epri.com