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2010-007 BWR Vessel & Internals Project (BWRVIP)

January 12, 2010

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U. S. Nuclear Regulatory Commission
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Attention: Michael McCoppin

Subject: Project No. 704 – BWRVIP-214NP: BWR Vessel and Internals Project, Technical Basis for ASME Code Case N-769, "Roll Expansion of Class 1 In-Core Housing Bottom Head Penetrations in BWRs, Section XI Division 1"

Enclosed are five (5) copies of the report "BWRVIP-214NP: BWR Vessel and Internals Project, Technical Basis for ASME Code Case N-769, Roll Expansion of Class 1 In-Core Housing Bottom Head Penetrations in BWRs, Section XI Division 1," EPRI Technical Report 1019069, May 2009. This report is provided to the NRC for information only.

ASME Code Case N-769, "Roll Expansion of Class 1 In-Core Housing Bottom Head Penetrations in BWRs, Section XI Division 1" allows the use of roll-expansion for sealing leaks in BWR in-core housings. The enclosed report provides the technical basis for that code case.

Please note that the enclosed report is non-proprietary and is available to the public.

If you have any questions on this subject please call Randy Schmidt (PSEG Nuclear, BWRVIP Assessment Committee Technical Chairman) at 856.339.3740.

Sincerely,

Rick Libra

Rick Libra
Exelon
Chairman, BWR Vessel and Internals Project

G004
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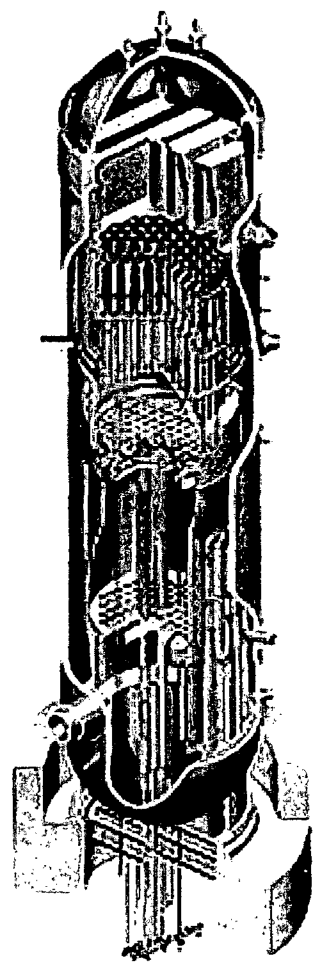
BWRVIP-214NP: BWR Vessel and Internals Project

Technical Basis for ASME Code Case N-769, "Roll-Expansion of Class 1 In-Core Housing Bottom Head Penetrations in BWRs, Section XI Division 1"



BWRVIP-214NP: BWR Vessel and Internals Project

Technical Basis for ASME Code Case N-769, "Roll-Expansion of Class 1 In-Core Housing Bottom Head Penetrations in BWRs, Section XI Division 1"

1019069

Final Report, May 2009

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This report describes research sponsored by the Electric Power Research Institute (EPRI) and its BWRVIP participating members.

The report is a corporate document that should be cited in the literature in the following manner:

BWRVIP-214NP: BWR Vessel and Internals Project, Technical Basis for ASME Code Case N-769, "Roll-Expansion of Class 1 In-Core Housing Bottom Head Penetrations in BWRs, Section XI Division 1." EPRI, Palo Alto, CA: 2009. 1019069.

PRODUCT DESCRIPTION

ASME Code Case N-769, "Roll-Expansion of Class 1 In-Core Housing Bottom Head Penetrations in BWRs," is written to allow the use of roll-expansion for sealing leaks in BWR in-core housings. This report provides the technical basis for that code case.

Results & Findings

The report demonstrates that roll-expansion is a technically sound method for repairing leaking in-core housings. Roll-expansion maintains all functional requirements of the penetration, causes no material damage to the housing or vessel, and has been shown in qualification tests and in-plant applications to be an effective means of sealing leakage. In addition, it requires considerably less outage time, development cost, and radiation exposure than alternative repair methods such as welding.

Challenges & Objectives

The fundamental objective of this project was to document the acceptability of roll-expansion as a repair technique in a report that serves as the technical basis for Code Case N-769. Approval of the code case by the ASME Committee will allow utilities to apply roll-expansion without plant-specific review and approval by the Nuclear Regulatory Commission.

Applications, Value, & Use

In-core housing penetrations are potentially susceptible to cracking. Cracking and leakage have occurred in at least one plant. Utilities need cost-effective methods to repair the leaking penetrations. Roll-expansion provides a relatively fast and economical solution to the problem.

EPRI Perspective

As reactors continue to age, material degradation will continue to be a significant issue in terms of ensuring continued safe operation and economic viability. The development of roll-expansion as a solution to one degradation issue was made possible through the Electric Power Research Institute (EPRI) BWR Vessel and Internals Project (BWRVIP). BWRVIP members contributed test data and operating experience that resulted in a robust technical basis document.

Approach

Code Case N-769 shares many technical characteristics with Code Case N-730 ("Roll-Expansion of Class 1 Control Rod Drive Bottom Head Penetrations in BWRs"). The project team was able to capture much of the technical basis for Code Case N-769 from the technical basis report for Code Case N-730 (BWRVIP-146NP, Revision 1, which is EPRI report 1016586). Additional data specific to roll-expansion of in-core housings was developed based on the information in BWRVIP-17 (*BWR Vessel and Internals Project, Roll/Expansion Repair of Control Rod Drive and In-Core Instrument Penetrations in BWR Vessels)*, which is EPRI report TR-106712. The resulting report describes a set of comprehensive requirements for roll-expansion of in-core housings as well as requirements for future inspections and tests.

Keywords
Boiling water reactor
In-core housing
Repair
Roll-expansion
Stress corrosion cracking
Vessel and Internals

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1 INTRODUCTION

This paper provides the technical basis for the ASME Section XI Code Case N-769 "Roll expansion of Class 1 In-Core Housing Bottom Head Penetrations in Boiling Water Reactors (BWRs), Section XI, Division 1". The proposed code case is similar to that approved by the ASME for roll expansion repairs on Control Rod Drive (CRD) penetrations (Code Case N-730).

Cracking and occasional leaks have been reported in some BWR CRD stub tubes and in-core housings (ICH). Typical BWR CRD configurations are shown in Figure 1-1. The CRD penetrations in BWR/2-5 plants include the stub tube which is welded to the vessel bottom head and the housing which is welded to the stub tube. The BWR/6 design (also shown in Figure 1-1) has no stub tube and the housing is directly welded to the vessel. Figure 1-2 shows the BWR in-core housing configurations. In most BWR/2-6 plants, the in-core housing is directly welded to the vessel bottom head, similar to the BWR/6 CRD housing. The Hope Creek design (shown separately in Figure 1-2) is slightly different in that there is a weld build-up (made of Alloy 82/182) on the vessel bottom head. The ICH is in-turn welded to the weld build-up. From the viewpoint of the application of roll expansion repair and the implementation of the code case, there is no difference between the Hope Creek design and the other BWR/2-6 ICH penetrations. Figure 1-3 shows the Advanced Boiling Water Reactor (ABWR) in-core housing penetration where the ICH is welded to a stub tube, which in turn, is welded to the vessel bottom head. The CRD housing is approximately 6 inches in diameter and is made of either stainless steel or Alloy 600. The in-core housing is typically 2 inches in diameter and is made of either stainless steel or Alloy 600. The CRD housing (CRDH) contains the control rod drive mechanism and housing alignment is critical for the CRD function. The ICH has no significant functional safety implication since it merely provides a pressure boundary that contains the in-core instrumentation.

Cracking has occurred in the stub tube and in the Alloy 182 attachment weld in CRD penetrations. Cracking and leakage has also been observed in the in-core housing attachment weld to the vessel in one plant. Cracking in bottom head penetrations has been evaluated and has been found to present no safety issues. Nevertheless, it is important to limit the leakage from the cracks. Roll expansion of CRD housings against the Reactor Pressure Vessel (RPV) bottom head penetration has been used successfully to provide a leak barrier. The ASME Code has approved Code Case N-730, "Roll-Expansion of Class 1 Control Rod Drive Bottom Head Penetrations in BWRs Section XI, Division 1 [1]". Code Case N-730 provides specific criteria for the application of roll expansion in CRD penetrations. Compliance with code case assures that the repair can be applied without prior approval by the NRC. The technical basis for Code Case N-730 has been documented in BWRVIP-146 [2] and in other papers [3, 4].

BWR/2-5 Designs (Set-in and Set-on Stub Tubes)

BWR/6 Design (Housing directly welded to the vessel)

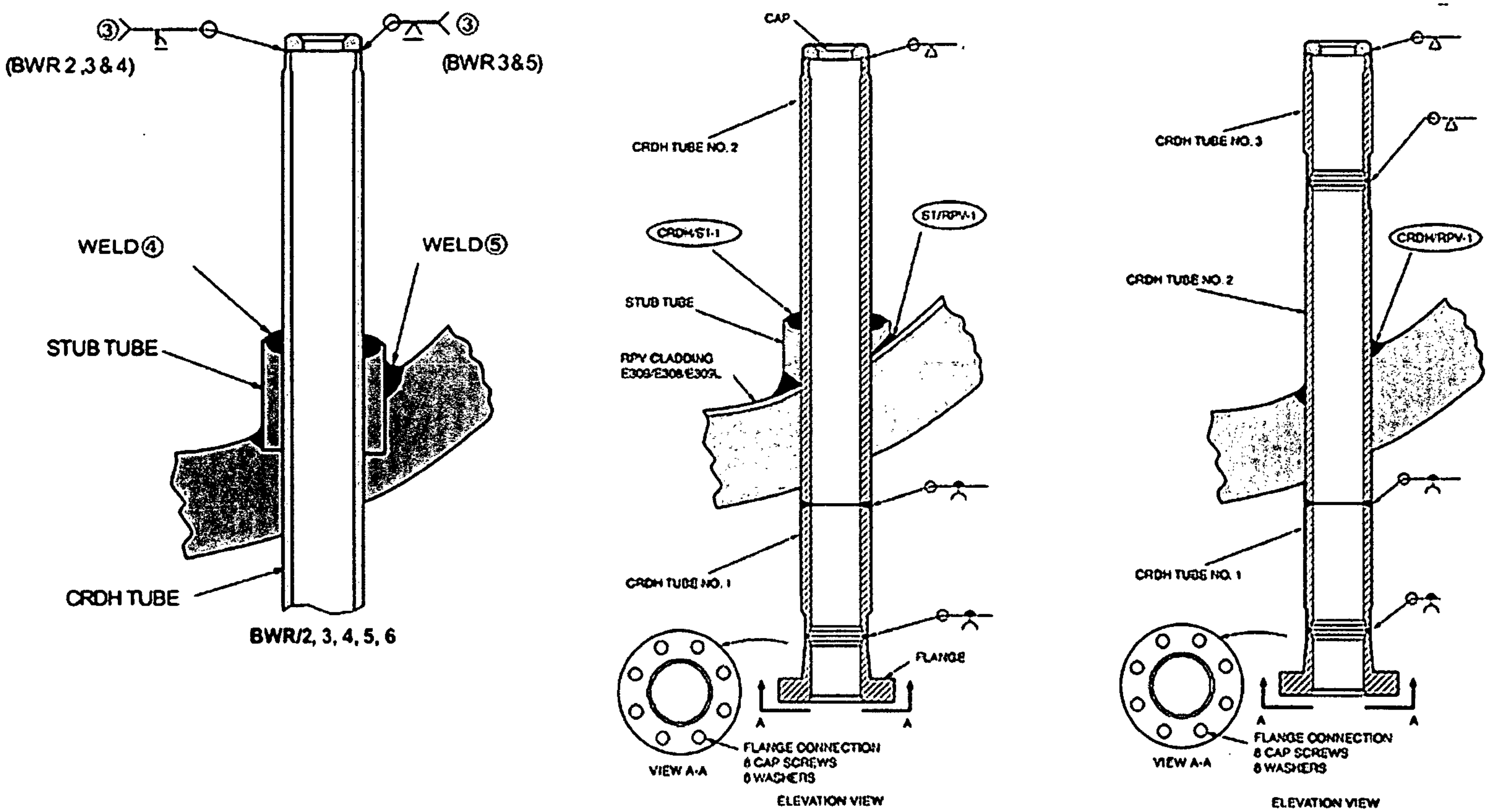

Figure 1-1
CRD penetration configurations

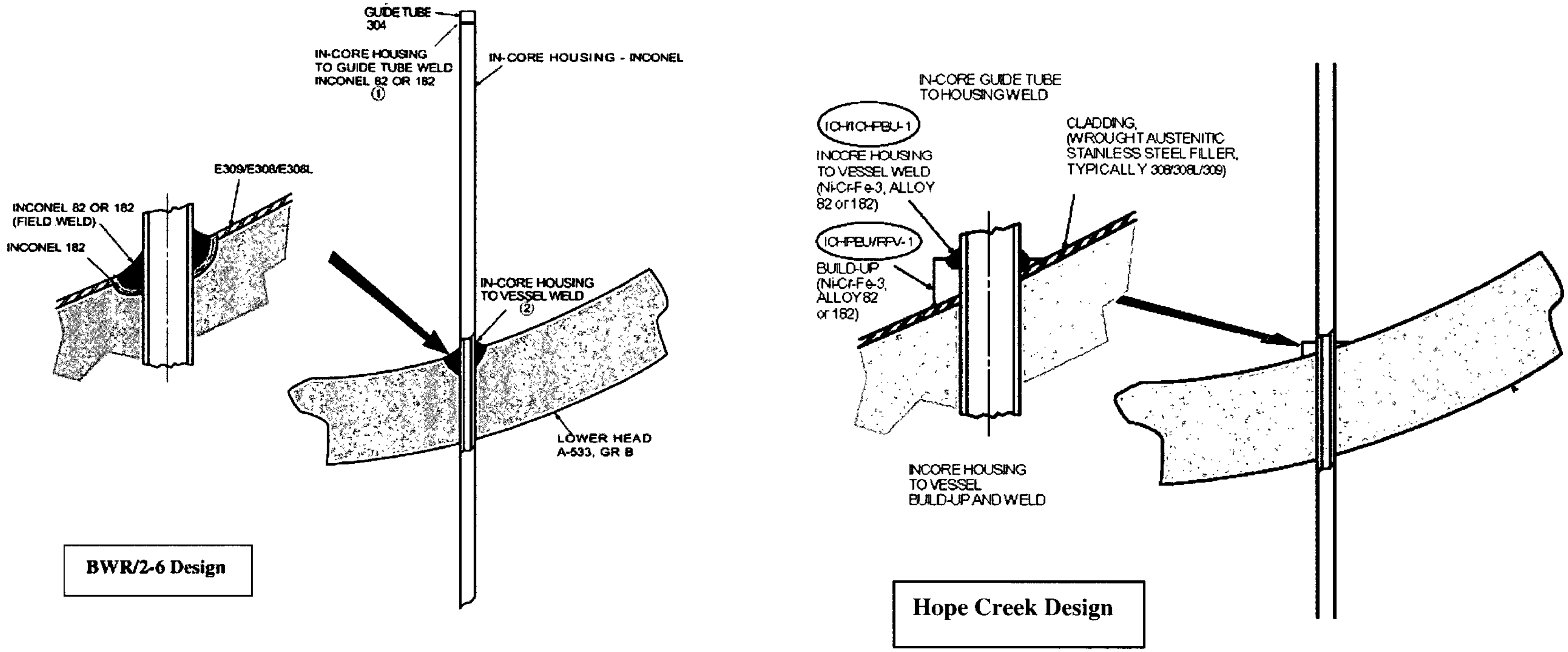

Figure 1-2
BWR In-core housing penetration designs

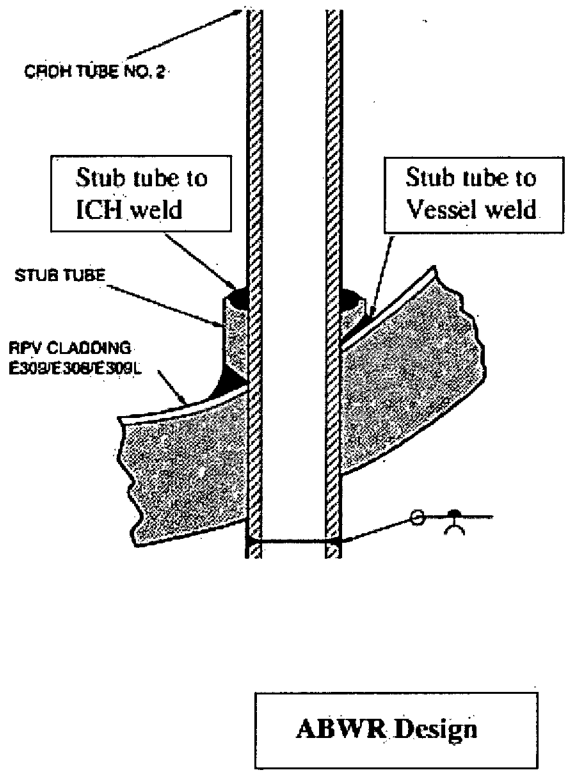

Figure 1-3
ABWR In-core housing penetration design

Cracking has also been observed in an in-core housing at the Oyster Creek plant and was attributed to a fabrication flaw in the attachment weld. The leak was found and repaired by roll expansion in 1974 (after 4 years of operation.) The plant has been operating successfully with no leakage since the repair. In fact, the longest service life for a roll repair (CRDH or ICH) is the ICH penetration at Oyster Creek (approximately 35 years). Code Case N-730 is limited to CRD penetrations; ICH penetrations are not covered. The objective of this report is to describe a similar Code Case for ICH penetrations and document the technical basis for the ICH roll expansion repair.

1.1 Implementation Requirements

This report provides the technical basis for Code Case N-769. The requirements for implementation of roll repair of in-core housings are stated in the code case. The intent of this report is to document the technical basis for the code case requirements, not to specify additional requirements. In accordance with the implementation requirements of Nuclear Energy Institute (NEI) 03-08, *Guideline for the Management of Materials Issues*, all sections of this report are provided for information only.

2
BACKGROUND

Table 2-1 compares the CRD and ICH penetrations. Both are located on the bottom head of the vessel. The comparison is useful in evaluating the applicability of much of the work done in support of Code Case N-730 for the ICH roll expansion code case.

Table 2-1
Comparison of the CRD and In-core Penetrations

CRD Penetration	In-core Penetration
Both stub tube (BWR/2-5) and directly welded (BWR/6) designs	ICH directly welded to the vessel in most BWR/2-6 plants (similar to BWR/6 CRD configuration); The Hope Creek design is slightly different in that the ICH is welded to a weld build-up pad instead of direct welding to the vessel. ABWR uses a stub tube design.
Stainless Steel housing (most BWR/2-5 plants) and Alloy 600 housing (BWR/6)	Stainless Steel housing (most BWR/2-5 plants) and Alloy 600 housing (BWR/6). The ABWR uses a modified Alloy 600 stub tube and Type 316 NG stainless steel housing.
6 inches in diameter	2 inches in diameter
Encloses the CRD mechanism	Encloses the in-core instrumentation
Higher safety significance compared to the in-core penetration, since it encloses the CRDs	Low safety significance
Larger number of CRDs	Generally one ICH for four CRDs

Leakage from the CRD stub tubes or the ICH (and the associated welds) has been minimal, well within the system leakage limits and has been a small fraction of the system make-up capability. Unlike Pressurized Water Reactors (PWRs) where the coolant uses borated water, there is no boron in the BWR water and leakage from the stub tube cracking does not lead to boron corrosion concerns.

Much of the safety assessment performed for CRD stub tube cracking is applicable to ICH cracking also. Because of the smaller diameter and the fact that the ICH carries only the instrumentation lines, ICH cracking has less safety significance than CRD stub tube cracking.

3
DESCRIPTION OF THE ROLL EXPANSION PROCESS

The roll expansion process for the CRDH is described in detail in [2]. The same steps apply for the ICH. The only difference is in the diameter and thickness of the housing. The qualification studies described in BWRVIP-17 [5] apply equally to the ICH. The procedure qualification using mockups and performance demonstrations required for the CRD in Code Case N-730 are also applied to the ICH.

4 ROLL EXPANSION REQUIREMENTS

Before describing the design requirements of the roll expansion itself, it is useful to describe the function of the ICH. Since the roll expansion is a proposed repair for ICH, it must assure that the functional requirements of the ICH are maintained.

4.1 Functional Requirements of the ICH

The operational and safety functions of the ICH penetrations in BWRs are typically as follows:

- The ICH penetration provides a portion of the reactor vessel pressure boundary as well as the reactor coolant leakage boundary.
- The ICH contains the in-core instrumentation. Unlike the CRDH which supports the CRD mechanisms, the ICH is passive and merely provides the enclosure for the in-core instrumentation. Unlike the CRDH which also provides the thermal barrier for the CRD mechanism, the ICH does not perform a similar function.

The objectives of the roll expansion are to satisfy the above described operational and safety functions by:

- Eliminating the leakage from the affected ICH penetration.
- Producing no deleterious metallurgical effects on the repaired ICH penetration which could affect the structural integrity of the penetration during future plant operation.

4.2 Roll Expansion Parameters

When applied to a CRDH, the roll expansion joint has to have sufficient structural capability to resist the CRD scram forces. The ICH does not have a similar load carrying structural requirement (i.e. no scram forces). In the absence of an external load carrying requirement, the determination of the roll expansion parameters (percent wall thinning and the roll band width) will be based on other criteria.

The degree of expansion (as measured by percent wall thinning) should be such that an effective leak barrier is assured. Field experience with CRD roll repairs suggests that nominal wall thinning of 4-6% is sufficient to assure a leak resistant seal. In the Oyster Creek ICH roll repair, the wall thinning was 2.8% with a length of 6.75 inches. It appears that the wall thinning required to eliminate leakage is somewhat lower for the ICH. Unless the process is pre-qualified (e.g. as described in Section 6.3) the percent wall thinning and the roll band length needed to assure an effective leak barrier have to be confirmed by qualification testing. The interface pressure on the roll expansion joint is a measure of leak resistance. The interface pressure resulting from the rolling is dependent on the yield strength of the material and the thickness of the housing. Figure 4-1 shows the free body equilibrium diagram to determine the interface pressure after rolling. The interface pressure can be calculated by assuming perfectly plastic behavior for the housing and that the rolling process causes the entire housing to yield.

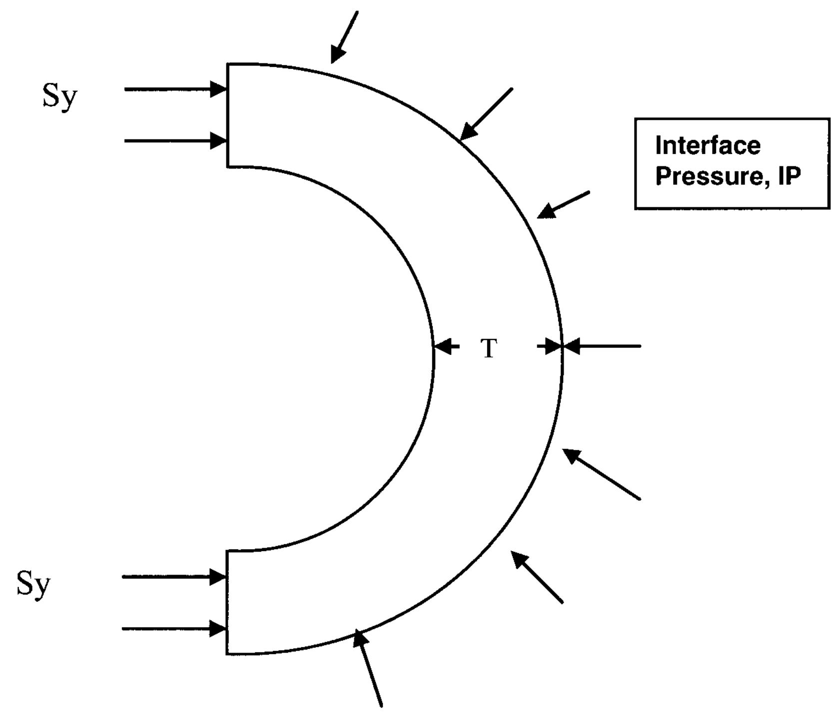

Figure 4-1
Interface pressure due to rolling

The interface pressure IP between the OD of the housing and the vessel bore is given by:

$$IP \times R = (1-p) \times T \times Sy \qquad \textbf{Equation 4-1}$$

where,

IP = Interface Pressure,
R = Outside Radius,
p = Fraction of thinning (e.g. 0.04 for 4% thinning),
T = Thickness of housing,
Sy = Yield Strength of Material

Equation 4-1 can be used to compare the differences between the CRDH and ICH roll repair in terms of the interface pressure. For example, for a six inch (OD), ½ inch thick stainless steel CRD with yield strength 35 ksi and 4% wall thinning, the interface pressure is 5600 psi. For a two inch (OD), ¼ inch thick stainless steel ICH housing with yield strength 35 ksi and 4% wall thinning the interface pressure is 8400 psi. Thus for similar material properties and percent wall thinning, the interface pressure is somewhat higher for the ICH roll repair. This suggests that the leak barrier for the ICH may be more effective than that in the CRDH with the same mechanical properties. The interface contact pressure is reduced to some extent during normal operation because of temperature and thermal cycling effects. However, the differential thermal expansion between the stainless steel (or Alloy 600) housing and the low alloy steel vessel bore creates additional interface contact pressure that more than makes up for the reduction due to temperature and thermal cycling effects.

For a given target wall thinning percentage (i.e., the amount of wall thinning intended to be achieved in the expansion), the actual wall thinning may be within ± 0.5% of the target value. The precise amount of wall thinning resulting from the radial expansion is dependent on the radial gap. As in the case of the CRD, because of the expected variations in the gap between the housing and the vessel bore the actual wall thinning achieved will be different than the target value. Based on the expected tolerance on the bore and housing diameters, the ± 0.5% range on the strain is realistic.

The load capability of the roll-repaired joint can be estimated using the same approach as described in BWRVIP-146 for the CRDH. As in the case of the CRDH, the clamping force due to the interface pressure is determined by assuming a value of 0.2 for the coefficient of friction. The load capability tests on roll repaired CRDH mockups show that the assumed friction factor of 0.2 is reasonable based on good comparisons between the calculated and measured load capability.

The load capability is $F_c = 0.2\ IP\ (2\pi RL)$ **Equation 4-2**

where IP is the interface pressure, R is the outside radius and L is the roll band length.

In the case of the CRDH roll repair, the roll band length was determined by equating the roll joint capability to the scram force. However, for the ICH, there is no explicit load carrying function. As an alternate the requirement is that the roll joint capability should be equal to the pressure blow-off load. In reality, if there is cracking in the weld (the most likely location of a leak) the cracked weld segment will still take the pressure load in compression and transfer it to the vessel bottom head. So the roll joint load capability offers additional margin to resist the pressure load.

The pressure blow-off load F_p is given by:

$F_p = P\ (\pi R^2)$ **Equation 4-3**

Where P is the vessel internal pressure and R is the ICH outside radius.

Equating the pressure load F_p to the roll joint capability F_c (including a Structural Factor, SF, enables the determination of the required roll joint length:

$$P\ (\pi R^2) = 0.2\ IP\ (2\pi RL)/SF = 0.4\pi\ \{(1-p) \times T \times Sy\}\ L/SF$$

$L = \{SF\ P\ (R^2)\}/\ [0.4\{(1-p) \times T \times Sy\}]$ **Equation 4-4**

For example, for a typical stainless steel ICH, the values in Equation 4-4 are:

P = vessel internal pressure = 1050 psi, yield strength S_y = 35,000 psi, Thickness T = 0.25 inch, Radius R = 1 inch, wall thinning fraction = 0.04 and the assumed structural factor, SF = 2.

Substituting the above values, Equation 4-4 results in a required length of 0.63 inch. The actual roll band length will have to be much higher than this to assure a leak barrier. As a practical matter, the code case requires a minimum of 2 in. for the roll band length.

The minimum roll band length shall be the higher of the following:

- The roll band length for which there is no leakage in mockup testing or in prior field applications of roll repair but not less than 2 in.
- The length L determined by Equation 4-4 for the ICH parameters.

As shown in the sample calculation above, the first requirement (assuring a leak barrier in the mockup testing) will most likely be the governing criterion.

The specific requirements for the roll repair are plant dependent (for example, different bottom head thickness) and are based on assuring that leakage is eliminated based on a roll expansion qualification. The practice in prior plant roll expansion applications has been to use as high a roll band length as possible, given the constraints of the local situation (e.g. the maximum potential length of a roll depends on whether the ICH in question is on the hill side location or closer to the center of the bottom head). The specific requirements for the plant application are identical to those described in BWRVIP-146 [2] and are as follows:

- The roll expansion is limited to Type 304, Type 316 stainless steel or Alloy 600 ICH housings and Low Alloy Steel (SA-302 Grade B, SA-302 Grade B Modified, or SA-533 Grade B) vessel material. Type 304 stainless steel has been used in extensive CRDH qualifications. Type 316 stainless steel and Alloy 600 are judged to be similar enough to Type 304 for the qualifications to be applicable as well. BWR in-core housings are made of either stainless steel (Type 304 or 316 stainless steel) or Alloy 600. The bottom head is made of Low Alloy Steel (LAS) in all cases.
- The actual percent wall-thinning is limited to the range 2% - 5%. This essentially means that the target wall thinning is in the 2.5%-4.5% range since the actual percent wall thinning may be ± 0.5% of the target value. The limit on percent wall thinning is based on the BWRVIP-17 [5] qualification and the ICH roll repair field experience at Oyster Creek. Wall thinning less than 2% may not assure a sufficiently tight mechanical seal that prevents leakage. Wall thinning in excess of 5% may not be warranted and could pose potential cold work concerns on the ID of the stainless steel housing. Thus, it is prudent to limit the wall thinning to 2% - 5%.
- The minimum roller top/bottom end radius is 1/4-inch (6 mm). This assures that no notches or stress concentration locations are developed at the end of the roll zone.
- The rollers shall be lubricated.
- The ratio of housing specified minimum yield strength to vessel head specified minimum yield strength shall be less than 1.0. This requirement is necessary for housing to experience

plastic deformation such that a mechanical seal is developed. This requirement is always met since the yield strength of the vessel bottom head (LAS) is well in excess of the yield strength of the housing material (stainless steel or Alloy 600).

- If more than one roll is required to achieve the required roll-band length, the minimum overlap for each roll shall be greater than or equal to 0.5-inches (13mm). This assures that the compressive strain (and therefore the tightness of the mechanical seal) is present everywhere in the housing.
- The direction of rolling should be from the top to the bottom. This assures that minimum tensile stress is applied to the housing welds due to the rolling. In no case shall rolling be performed on portions of the housing extending above or below the vessel bottom head. The objective is to expand the housing against the vessel bore. Expanding against the edge of the bore or in an area where there is no vessel bore to react against the roll expansion force results in distortion or excessive deformation of the housing.
- For locations away from the center of the bottom head, the vessel penetration is elliptic and elevation of the edge varies around the circumference. In such cases it is desirable that the elevation of the top of the roll area be below the lowest edge of the elliptic penetration. In cases where the bottom head is thinner there may not be sufficient area to roll against the vessel bore only. In such cases it may be necessary to roll against the attachment weld region. Mock-up testing may be used to justify rolling against the attachment weld.
- The roll band length shall not exceed 6 in. (150 mm). This provides added assurance that the roll expansion will be backed against the vessel material.
- A certified stress report demonstrating that the rolled housings meet the ASME Code Section III requirements must be prepared prior to on-site rolling.

5 TECHNICAL JUSTIFICATION FOR THE ROLL REPAIR

The technical justification for the roll expansion repair consists of demonstrating compliance with the following requirements:

- Demonstration of structural capability and ASME Code adequacy of the vessel attachment weld and the roll repair. It is also necessary to demonstrate compliance with Section XI [6] for the case of cracking in the vessel attachment weld.
- Inspections to verify structural integrity.
- Elimination of leakage.
- Analytical basis to justify leaving the cracks in place.
- Demonstration that there are no adverse metallurgical effects.

5.1 Section XI Compliance

The generic analysis for crack growth in the vessel for a postulated crack in the attachment (CRD) weld is described in Appendix A of [2] and in [3]. The analysis is based on typical stresses and cycles and is intended to serve as an example that licensees can use for their plant specific analysis. Both pressure and thermal cycling are considered in the fatigue crack growth analysis. The analysis in [2] was intended for the stub tube to vessel attachment weld and considered a radial crack (looking down from the lower plenum) that extended all the way through the weld. The CRDH fracture mechanics analysis in [2] is also applicable to the ICH weld. Since the ICH weld is smaller than the stub tube weld and the cyclic duty on the ICH is less severe than that of the CRD, the analysis in [2] is conservative for the AHC weld. The analysis is generic and does not represent any specific BWR plant. Nevertheless the results of the analysis suggest that crack growth into the vessel is not significant and the critical flaw size is large enough that even with uncertainties in crack growth there is sufficient fracture margin.

5.2 Inspection Criteria

Specific inspection requirements must be satisfied in order to qualify the roll repair under the code case. This section outlines the UT examinations and the system leakage test requirements for Code Case N-769. The inspection volumes for the UT examinations of the ICH are shown in Figures 5-1 and 5-2 for BWR/2-6 and ABWR plants respectively. The code case requires that the UT procedure used in the examinations shall be demonstrated on a mockup with flaws located in the area of interest, in accordance with Appendix I of the code case.

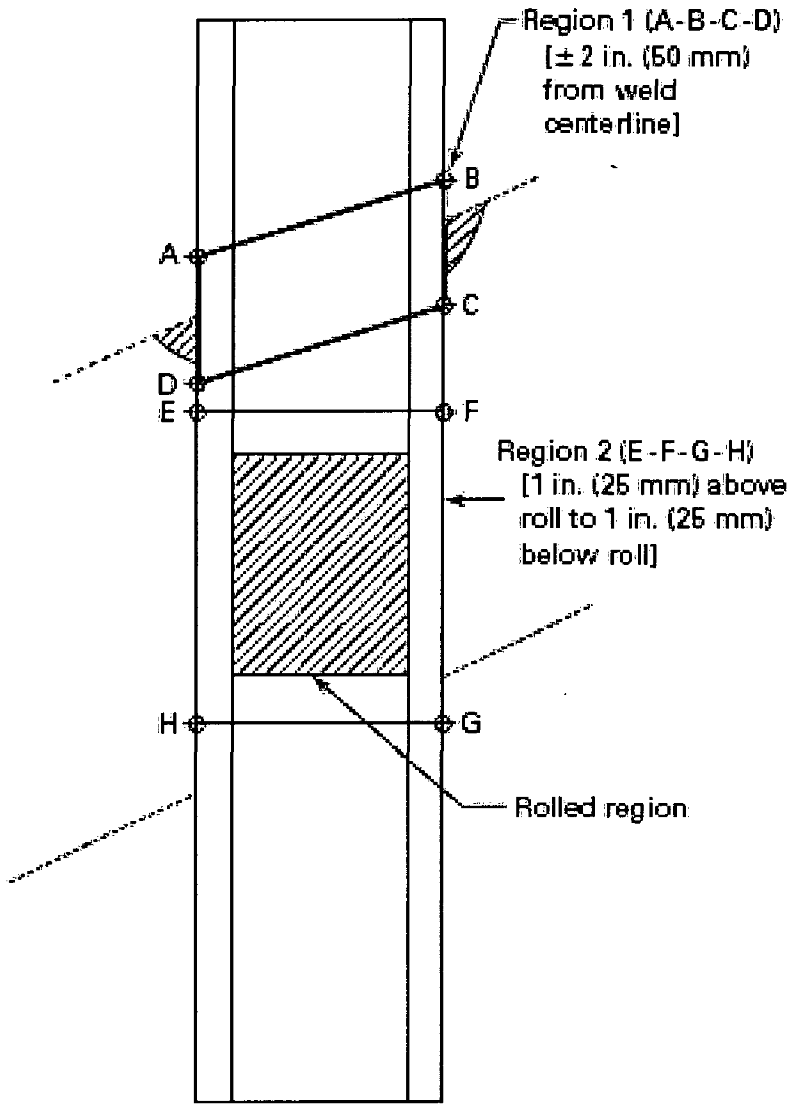

Figure 5-1
Examination volume for in-core housings (BWR/2-6)

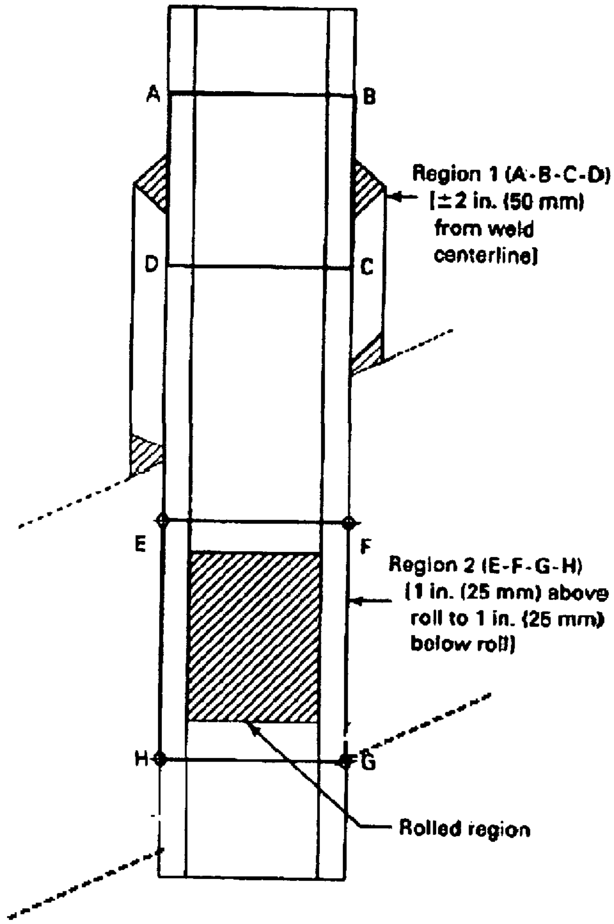

Figure 5-2
Examination volume for in-core housings (ABWR)

5.2.1 Inspections Prior to Roll Repair

a. Prior to roll expansion, ultrasonic (UT) examination shall be performed of the regions specified in Figures 5-1 and 5-2. Specifically, the region of the housing that is to be rolled (Region 2) and the vessel-to-housing weld (Region 1) shall be examined. If the leakage is due to through wall cracking of the housing, this code case is not applicable and shall not be used. The roll region (Region 2) shall not have any planar flaws.

b. If the location of the leakage has not been determined, an in-vessel VT-1 visual examination of the leaking ICH penetration shall be made before the end of the next scheduled refueling outage, to attempt to locate the leakage source and to determine the general condition of the housing. Cracks, wear, or localized accumulation of corrosion products shall require corrective action. Roll expansion satisfies the corrective action requirement.

5.2.2 Inspections After Roll Repair

a. After completion of the roll expansion, UT examination of the housing in the region of the vessel or stub tube attachment weld (Region 1 in Fig. 5-1 or 5-2) shall be performed. The examination results shall be evaluated in accordance with IWB-3523. If flaws exceed the acceptance standards of IWB-3523, they shall be evaluated to show that the requirements of IWB-3640 are satisfied. The generic fracture mechanics analysis in [2] is one way of demonstrating compliance with Section XI.

b. After completion of the roll expansion, UT examination of the rolled region (Region 2) shall be performed to establish that no planar flaws exist in the rolled region.

c. The UT procedure used in the examinations shall be demonstrated on a plant-specific mockup with flaws located in the area of interest, in accordance with Appendix I of the code case.

d. After completing the post-roll UT examination, the ICH housing penetration shall be tested in conjunction with a system leakage test in accordance with IWB-5000. For in-core housings subjected to roll expansion, the acceptance criterion is no leakage.

5.2.3 In-Service Inspections

The following examinations shall be added to the in-service inspection program:

a. A UT examination of roll-expanded in-core housings shall be performed in accordance with Figure 5-1 or 5-2 on at least 10% of previously-rolled housings or at least one rolled ICH (whichever is larger), during each inspection interval. If planar flaws are discovered in the roll region (Region 2) this Case may not be used. The examination results shall be evaluated in accordance with IWB-3523. If flaws exceed the acceptance standards of IWB-3523,
they shall be evaluated to show that the requirements of IWB-3640 are satisfied. If the requirements of IWB-3640 are not met, the defect shall be corrected by a repair/replacement activity.

b. If flaws are detected that fail to meet the acceptance standards of IWB-3523, the additional examination requirements of IWB-2430 shall be met. At subsequent system leakage tests in accordance with IWB-5000, in-core housings having roll expansion shall have no leakage.

c. The UT procedure used in the examinations shall be demonstrated on a plant-specific mockup with flaws located in the area of interest, in accordance with Appendix I of Code Case N-769.

5.3 Metallurgical Justification

The original qualification of a roll repair process described in References [2] and [5] included an evaluation of potential adverse metallurgical effects of rolling which could increase IGSCC susceptibility. These effects include cold work of the material in the rolled region, introduction of tensile stresses mainly above and below the rolled region, and strain induced phase changes of the material from an austenitic crystal structure to a martensitic crystal structure. The tests consisted of measurements of the degree of cold work produced on the housing due to rolling. Excessive cold work has been shown to increase the potential for IGSCC. Cold work in the rolled area is acceptable since the housing is in compression. The ends of the rolled area where there could be tensile stresses were evaluated in the metallurgical assessment. The degree of cold work in rolled mock-ups was estimated with hardness measurements. These estimates showed acceptable levels of cold work in areas with possible tensile stresses. From this testing, rolling was concluded to have no significant effect on the IGSCC resistance of the housings. While these tests specifically addressed roll expansion of CRD housings, the results are equally applicable to roll expansion repair of in-core housings.

5.4 Acceptability of the Displacements Resulting from Roll Repair

Unlike the CRD housings (which houses the CRD mechanism) displacements resulting from the roll repair wall thinning have no significance for ICH roll repair.

6
ROLL EXPANSION REPAIR QUALIFICATION

When the ICH is roll expanded against the vessel, creating a mechanical seal to eliminate leakage, the following requirements shall be met:

- The roll repair is applicable only when specific requirements (in Section 6.1) are met.
- The repair must be qualified by a test. In some cases, pre-qualified parameters may be used (see Table 6-2). In other cases, a plant specific one-time repair qualification may be needed.
- A performance demonstration is required to verify personnel capabilities prior to plant implementation.
- A roll expansion procedure specification (REPS) is required. The REPS defines the requirements for roll expansion for procedure qualification (if required), for performance demonstration, and for the in-plant rolling. The REPS also defines the target values for wall thinning and roll-band length as well as the procedure to be used to achieve these target values.

6.1 Requirements for ICH Roll Expansion Repairs

The specific requirements for the plant application are listed below. The rationale for each requirement has been previously discussed in Section 4.

- The roll expansion is limited to Type 304, Type 316 or Alloy 600 in-core housings and Low Alloy Steel Vessel material.
- The actual percent wall-thinning is limited to the range 2%-5%.
- The roll band length shall not exceed 6 in. (150 mm) and the roll expansion shall be backed against the vessel material.
- The minimum roller top/bottom end radius is 1/4 -inch.
- The ratio of housing specified minimum yield strength to vessel head specified minimum yield strength shall be less than 1.0.
- If more than one roll is required to achieve the required roll-band length, the minimum overlap for each roll shall be greater than or equal to 0.5-inches.
- Rollers must be lubricated and the direction of rolling should be from the top to the bottom.
- Target values for wall-thinning and roll-band length shall be specified. The target value for wall thinning for the rolling shall be 2½% to 4½%. Because of variations in the gap between the housing OD and the vessel bore ID surface, the actual amount of wall thinning may vary from 2% to 5%. In no case shall the total wall thinning exceed 5%. The required

wall thinning may be achieved using any number of intermediate partial rolls. The 5% wall thinning limit is somewhat smaller than the value (6%) used in Code Case N-730, but is considered reasonable because of the smaller ICH thickness and the higher interface pressure in the ICH compared to the CRDH.

- When multiple roll passes are required to achieve the desired roll band length the direction of the rolling shall be initiated from the top and progress downward toward the free end of the in-core housing.

6.2 Plant Specific Procedure Qualification

Except for the case where the parameters are prequalified (see Section 6.3), a plant specific procedure qualification is required. A REPS for the procedure qualification and for the in-plant application shall be developed. The procedure qualification shall be demonstrated on a mockup meeting the requirements of Table 6-1 as well as the critical requirements listed in 4.2. The vessel may be simulated in the mockup by a flat plate with thickness at least 1.5-in. (38 mm) greater than the target roll band length, but in no case less than 4 in. (100 mm).

a. The roll band length and percent wall thinning achieved in the procedure qualification shall be determined by measurement. The measured wall-thinning shall define the minimum qualified wall-thinning for use in plant application. The measured roll band length shall define the minimum qualified roll band length for use in plant application.

b. The mockup shall be rolled at ambient temperature, heated to 550°F (290°C), held at temperature for one hour, cooled to ambient temperature and then subjected to a leakage test at 1875 psig (13 MPa) for a minimum of one hour. Successful roll expansion requires visual verification of no leakage.

c. A plant may use a procedure qualification developed and qualified at another plant provided the qualification parameters listed in Table 6-1 and all other provisions of this Case are met. Transfer of the procedure qualification shall be subject to the following requirements:

   - The Owner that performed the procedure qualification shall certify in writing that the procedure qualification was developed in accordance with a Quality Assurance Program that satisfies the requirements of IWA-1400(n).
   - The Owner that performed the procedure qualification shall certify in writing that the procedure qualification meets the applicable provisions of this Case.

Table 6-1
Plant-specific procedure qualification requirements

Essential Variable	Acceptance Criteria
Percent wall thinning	Greater than or equal to target value not to exceed 5%
Roll band length	Greater than or equal to the value used, not to exceed 6 in. (150 mm) (backed by vessel material)
Housing outside diameter	Housing outside diameter ±0.0625 in. (1.5 mm) used for the mockup
Housing inside diameter	Housing inside diameter ±0.0625 in. (1.5 mm) used for the mockup
Housing material	The P-number used in the mockup qualifies any material in that P-number, i.e. any P-No. 8 material qualifies any other P-No. 8 material or any P-No. 43 qualifies any other P-No. 43 material
Vessel head material	Any P-No. 3 material used in the mockup qualifies any other P-No. 3 material

6.3 Prequalified Rolling Parameters

No plant-specific procedure qualification is required (the procedure is prequalified) if the in-plant rolling parameters are within the tolerances specified in Table 6-2. If the prequalified procedure is used, a mechanical roll expansion tool using a tapered shaft to effect expansion and a hard-stop to limit expansion shall be used.

Table 6-2
Pre-qualified rolling parameters

Essential Variable	Acceptance Criteria
Percent wall thinning	2% to 5%
Roll band length, L	2 in.$\leq L \leq$ 6 in. (50 mm $\leq L \leq$150 mm) (backed by vessel material)
Housing outside diameter	2 ±0.0625 in. (50 ± 1.5 mm)
Housing inside diameter	1.5 ±0.0625 in. (38 ± 1.5 mm)
Housing material	Any P-No. 8 material
Vessel head material	Any P-No. 3 material

6.4 Performance Demonstration

a. Prior to implementing a roll expansion in a plant, a performance demonstration shall be conducted to verify personnel capabilities. The performance demonstration shall be conducted on a mockup meeting the requirements of Table 6-3. The vessel may be simulated in the mockup by a flat plate with thickness at least 1.5 in. (38 mm) greater than the target roll band length, but in no case less than 4 in. (100 mm). Tooling shall be of the identical design and nominal dimensions as tooling to be used for in-plant roll.

b. Personnel responsible for performing any tasks required to achieve the essential variables of the REP in plant applications shall perform the same tasks in the performance demonstration. Performance of a task in the performance demonstration qualifies a person to perform that task in the plant. Each task to be performed by a person shall be demonstrated by that person within the 12-month period immediately prior to in-plant application. Personnel qualification shall be documented in the plant records of the roll expansion.

c. The REPS for the demonstration shall define the target values for wall thinning and roll band length as well as the location of the roll band to be achieved in the demonstration. These target values need not be identical to those specified for the in-plant rolling.

d. Acceptance criteria for the performance demonstration are: (1) Measured wall thinning equal to the target value plus or minus 0.5%; (2) measured roll band length equal to the target value plus 0.25 in. (6 mm) or minus 0 in. (0 mm); and, (3) the housing inside and outside diameter is the actual diameter value plus or minus 0.0625 in. (1.5 mm).

Table 6-3
Performance demonstration of essential variables

Variable	Acceptance Criteria
Percent wall thinning	Target wall thinning ±0.5%
Roll band length	Any value provided the roll band length is no more than 6 in. (150 mm). However, if multiple rolls will be required to achieve the required in-plant roll-band length, the performance demonstration shall require multiple rolls. (backed by vessel material)
Housing outside diameter	Actual housing outside diameter ±0.0625 in. (1.5 mm)
Housing inside diameter	Actual housing inside diameter ±0.0625 in. (1.5 mm)
Housing material	Same type as application (e.g., any P-No.8 or any P-No.43 material
Vessel head material	Any P-No. 3 material

7 TEST RESULTS

Extensive testing has been performed for the qualification of the roll repair process for CRD housings. These include pull testing to demonstrate the load carrying capability of roll repair, metallurgical evaluations, wall thinning and leakage tests. The applicability of the test results to in-core housings is described in the following.

7.1 Structural Load Capability Tests

The structural capability of roll repaired CRD housings is described in [2] and [3]. The analytical prediction of the load capability (Equation 4-2 in Section 4.2) was in reasonable agreement with the measured values [4]. The analytical predictions and test results are also applicable to ICH roll repairs. With the inclusion of the structural factor, the required minimum roll band length (Equation 4-3) will assure that the actual load capability of the ICH roll expansion joint will be sufficient to resist the pressure blow-off load. As shown in the sample calculation in Section 4.2 the leak barrier requirement in the mockup testing will most likely be the governing criterion. A successful leak test (i.e. no leakage) will assure that the structural requirements are also met.

7.2 Metallurgical Tests

Extensive testing has also been performed to evaluate the hardness, cold work and microstructure effects and residual stresses resulting from roll repair. The testing was limited to Type 304 stainless steel CRD housings. The key concern was the potential adverse effect of cold work from rolling on housing IGSCC. The conclusion from the metallurgical study was that in the rolled area, the cold work was higher, but this was in an area of compressive residual stress. Thus the cold work was mitigated by the compressive stress. In the transition area (the ends of the roll band) there were regions of tensile stresses, but the hardness was lower, below the threshold for IGSCC. The limitation on the wall thinning (5%) will further assure that cold work effects are minimized. As stated earlier, the 5% wall thinning limit (somewhat smaller than the 6% value used in Code Case N-730) is considered reasonable because of the smaller ICH thickness and the higher interface pressure in the ICH compared to the CRDH.

The above results are strictly applicable to stainless steel housings. For the Alloy 600 housings, the cold work (or higher hardness) results are less important since high nickel materials like Alloy 600 do not experience martensitic transformation. Alloy 600 is not particularly sensitive to cold work induced IGSCC. In the absence of creviced conditions, Alloy 600 has excellent IGSCC resistance in the BWR environment. The compressive residual stress results in the roll area are applicable to Alloy 600 housings.

7.3 Hydrostatic Leakage Test Results

Leak testing has been performed on CRD mock-ups subjected to 4% wall thinning. The mock-up leakage test included:

- Leak tests at 1875 psig following rolling
- Thermal cycling tests where the mock-up was heated to 550°F for one hour and then cooled to ambient temperature and then leak tested.

No leakage was observed in the CRD mock-up tests. In view of the fact that the interface pressure (Equation 4-1 in Section 4.2) is higher for the ICH compared to the CRDH, the favorable results from the CRD roll repair leak tests are valid, even more so, for the ICH roll repair. The fact that the ICH roll repair at Oyster Creek has been successful (with no leakage for 35 years) supports the effectiveness of the ICH roll repair in eliminating leakage.

8
REGULATORY EXPERIENCE

A number of BWR plants have performed roll repairs for the CRD and in-core housings. Many of the repairs have been in place for a long time and have been successful in controlling leakage. The NRC staff has reviewed the repairs and concluded that, based on industry experience; roll expansion of the bottom head to the RPV is an appropriate alternative repair for use in the BWRs where roll expansion repair has been implemented. Recently, the NRC staff approved the use of Code Case N-730 in justifying long term operation with CRDH roll repair at the Oyster Creek BWR/2 plant. Considering that the ICH has far less safety significance when compared to the CRDH, there is reason to believe that the code case for ICH roll repair will also receive regulatory approval.

9 CONCLUSIONS ON THE TECHNICAL BASIS

Extensive analytical results, mock-up test data and favorable field experience support the effectiveness of the roll expansion in addressing CRD and in-core housing leakage. In the five plants where roll repair was implemented, there was detailed review by the regulatory authorities and continued operation was approved on a short-term cycle-to-cycle basis. This report provides the technical justification for the ICH roll repair code case that justifies ASME acceptance. The ICH roll repair code case is very similar to Code Case N-730 for CRDH roll repair. The generic acceptance is justified by providing strict requirements for qualification, inspection and leak testing.

10 REFERENCES

1. Code Case N-730, Roll Expansion of Class 1 Control Rod Bottom Head Penetrations in BWRs, Section XI, Division 1, American Society of Mechanical Engineers, New York, NY.
2. *BWRVIP-146NP, Revision 1, BWR Vessel and Internals Project, Technical Basis for ASME Code Case N-730, Roll-Expansion of Class 1 Control Rod Drive Bottom Head Penetrations in BWRs*. September 2008. EPRI Technical Report 1016586.
3. *"Repair of Class 1 Control Rod Drive and In-Core Housing Bottom Head Penetrations in BWRs"*, G. Harttraft, R. Corieri, S. Ranganath, K. Wolfe, H.W. McCurdy and F. Corchon, Proceedings of PVP2005 2005 ASME Pressure Vessels and Piping Division Conference July 17-21, 2005, Denver, Colorado USA, ASME PVP2005-71144PVP2005-71144.
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