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ENCLOSURE

EPRI REVIEW OF MILLSTONE UNIT 2 DISSIMILAR METAL WELD WALKDOWN INFORMATION

INTERNAL REPORT, IR-2007-277

JUNE 2007

(NOTE: In Section 3 of this EPRI report an error exists in the labeling of the components, but it does not affect the coverage calculated and depicted. All the RCP inlets or suction side dissimilar metal welds at MPS2 are actually fabricated with carbon steel elbows and not pipe.)

DOMINION NUCLEAR CONNECTICUT, INC.
MILLSTONE POWER STATION UNIT 2

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

EPRI Review of Millstone Unit 2 Dissimilar Metal Weld Walkdown Information

IR-2007-277

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IR-2007-277

Internal Report, June 2007

EPRI Project Manager

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ABSTRACT

Dominion Generation requested that the Electric Power Research Institute (EPRI) perform a technical review of walkdown information collected at Millstone Unit 2 in response to the Materials Reliability Program (MRP) industry guidance issued in letters MRP-2003-039, MRP-2004-05, and MRP-2004-038. Specifically, MRP-2004-05 recommends that each pressurized water reactor (PWR) perform a direct visual inspection of the bare metal at all Alloy 82/182 pressure boundary butt weld locations that normally operate at greater than or equal to 350° F in the primary system within the next two refueling outages. This may be performed either through removal of insulation, remote visual examination inside the insulation, or an equivalent alternative examination. The inspections are to be made with priority given to the hottest locations (such as the pressurizer and hot leg weld locations) during the next refueling outage. The MRP also recommends that these bare metal examinations be used to obtain plant-specific information on weld joint configurations and available access to prepare for future volumetric examinations. Additionally, this guidance requested that:

- Each plant verify the configuration of butt welds, including candidates for potential inspection sample expansion, should cracking be found in any inspected weld.
- Using the configuration information collected, review the Performance Demonstration Initiative (PDI) mockup library to determine if the as-built configuration is qualified for inspection. If not, construct site-specific mockups and qualify NDE procedures, as required by ASME Section XI, Appendix VIII, if meaningful ultrasonic examinations can be performed on the as-found configuration. If the configuration is too severe to enable successful ultrasonic examination, then alternative examination techniques should be considered.

These recommendations were made because weld geometry and inspection access conditions present at some of these locations may limit the applicability of existing qualified ultrasound examination (UT) procedures. In particular, existing dissimilar metal weld (DMW) qualifications to ASME Section XI, Appendix VIII, Supplement 10 have limitations on detection or sizing that depend upon joint contour, crown condition, and tapers. As stated above, some of the most critical locations for primary water stress corrosion cracking (PWSCC) susceptibility are at high temperature locations (for instance, pressurizer spray, relief, and surge lines), and this is the primary focus of this report. This information will enable Dominion Generation to adequately prepare for future volumetric examinations of these Alloy 600/82/182 butt welds.

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1
INTRODUCTION

Dominion Generation requested Electric Power Research Institute (EPRI) to perform a technical review of dissimilar metal butt weld configurations obtained during walkdown of Millstone Unit 2. This report focuses on specific dissimilar metal welds (DMWs) associated with the reactor coolant pump. A list of the eight specific welds included in this review is shown in Table 1-1.

Table 1-1
List of Components

Component ID	Plant/Unit	System	Size (All Dimensions in inches)
P-4-C-1	Millstone Unit 2	RCP Inlet	~ 36
P-5-C-3	Millstone Unit 2	RCP Outlet	~ 36
P-8-C-1	Millstone Unit 2	RCP Inlet	~ 36
P-9-C-3	Millstone Unit 2	RCP Outlet	~ 36
P-13-C-1	Millstone Unit 2	RCP Inlet	~ 36
P-14-C-3	Millstone Unit 2	RCP Outlet	~ 36
P-17-C-1	Millstone Unit 2	RCP Inlet	~ 36
P-18-C-3	Millstone Unit 2	RCP Outlet	~ 36

The walkdown data was compiled into a detailed report prepared by Dominion Generation staff, which contains contour information, including weld crown condition and access, and photos of the configurations/access for each weld.

Millstone Unit 2 used a detailed checklist to collect the field data needed for this evaluation. This checklist was developed by the Dominion Generation staff and was similar to the checklist recommended in the Materials Reliability Program (MRP) guidance documents.

Dominion Generation requested that EPRI's primary task be to review the information collected to determine if it is consistent with recommendations made by MRP and provide any technical recommendations for Millstone Unit 2 to use in preparing for examination of these welds. EPRI's primary goals in this review were:

1. Confirm that the welds are covered under the PDI program.
2. Determine if site-specific mockups are required to expand PDI's generic ultrasonic examination (UT) procedure to cover the specific configuration.
3. Review surface preparation for each weld to determine if it can be improved to increase coverage of the weld and butter, if necessary.

4. Recommend the correct search unit(s) for examination of the specific weld.
5. Calculate the expected obtainable coverage.
6. Provide recommendations on alternative examinations that may be performed or other measures that may be taken to improve the ease of inspection of the welds.

The calculated examination coverage presented in this report is based on simple geometric renditions of the ultrasonic beams illustrated as straight lines for individual probes. It should be noted that there is not yet a consensus in the industry on how to determine examination coverage or how to introduce the relative effectiveness of individual scans in a composite coverage figure.

2
EVALUATION PROCESS

2.1 Assessment of Coverage

PDI's Generic Procedure PDI-UT-10, Revision C was used during this assessment. This procedure requires the examination of the volume shown in Figure 2-1, which includes 100% of the weld and butter for the full thickness of the component, including 0.25" of base material on each side of the weld and butter.

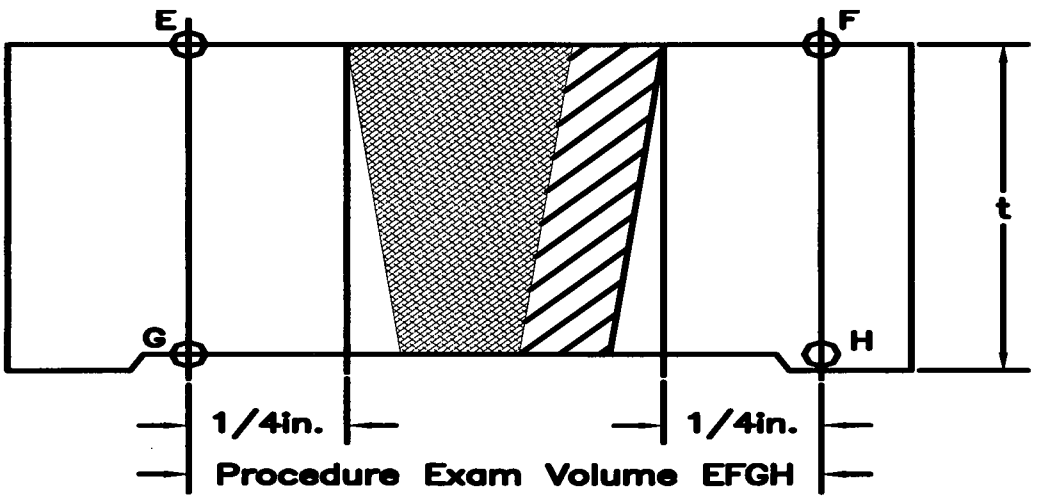


Figure 2-1
Examination Volume

The primary initiation point for stress corrosion cracking (SCC) is the inside surface of the sensitized material. ASME code defines the requirements for establishing volumetric coverage as 1/3t from the inner surface, in conjunction with projected lines from the outer diameter (OD) surface, which originate at a distance of 0.25" beyond the weld toes, including the weld butter (see Figure 2-3). PDI-UT-10, Revision C gives direction not to limit the examination to just the inside 1/3t, and has extended the examination requirements to the full thickness of the component (see Figure 2-1). The basis for this extended volume is due to the nature of the ultrasonic techniques employed; they are primarily refracted longitudinal search units, which are more capable of discerning the tip and/or face of a defect. The ASME code inner 1/3t requirement is still the critical criterion to be met, and volumetric coverage will continue to be determined by using this definition.

The use of the full volume for coverage assessments can artificially increase the percentage of coverage. An example of this is shown in Figure 2-2. The calculated coverage obtained by the 60° search unit would be 40%. However, most of the coverage obtained was from the upper volume of the weld. Only 9.5% of the code-required inner 1/3t was actually examined.

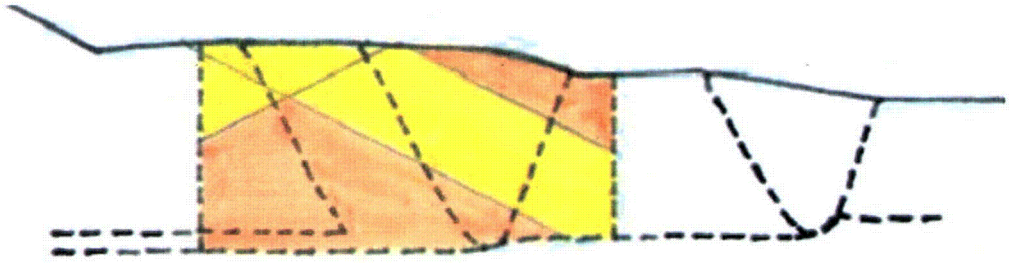
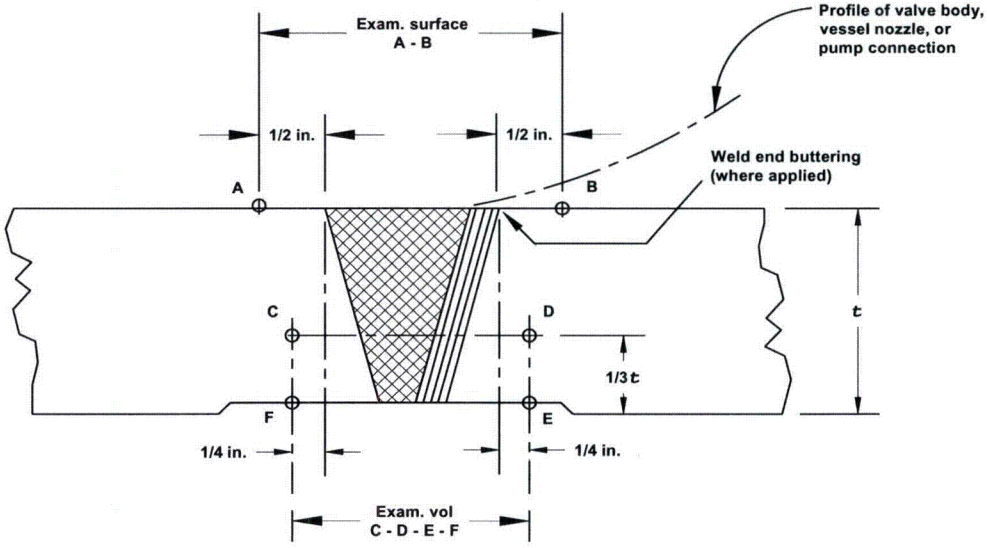


Figure 2-2
Coverage Plot

In this assessment, the coverage was evaluated for the purpose of determining if effective examinations can be performed on Alloy 600/82/182 butt welds. The examination volume shown in Figure 2-3 was used during this assessment. The examination volume is currently being evaluated by ASME Section XI and is also included in procedure PDI-UT-10, Revision C.



Note: When weld end buttering is present on both sides, the examination surface and volume shall be measured from the end of both butterings. It may include remnants of replaced welds and, may appear artificially deep on exposed surfaces due to fabrication processes. Buttering thickness may be determined from manufacture's drawings or presumed to be ½", if the true dimension is unknown.

Figure 2-3
Code Examination Volume

The calculated examination coverage presented in this report is based on simple geometric renditions of the ultrasonic beams illustrated as straight lines for individual probes. It should be noted that there is not yet a consensus in the industry on how to determine examination coverage or how to introduce the relative effectiveness of individual scans in a composite coverage figure.

However, the area covered by each angle in each direction was calculated. Additional drawings were also made showing the combined coverage of both angles.

The coverage calculations included in this report are based on the accuracy of the data provided by Dominion Generation. Design information from Combustion Engineering was used to determine some of the actual dimensions shown on the drawings.

2.2 Search Unit Selection

This analysis was performed using Generic Procedure PDI-UT-10, Revision C. This procedure places a great deal of emphasis on the proper search unit selection. Lower angle search units that rely on the corner trap response for detection are required to be focused within 75% to 125% of the thickness of the component. However, high angle search units that rely on a direct reflection of the beam off the face of a planar defect, rather than a corner trap response, need only be focused between 60% and 110% of the component thickness. The required focal length or depth will determine the size of the search unit required for examination. Increased metal path distances require a larger search unit to effectively focus the beam in the area of interest. Table 2-1 illustrates approximate achievable focal lengths for each search unit. Dominion Generation may note that in some cases the procedure may require a larger search unit than required for examination in the past and that the amount of coverage achieved may be less than previously calculated. However, EPRI has learned through the demonstration process that proper search unit selection is essential for a good examination.

Throughout this assessment, Dominion Generation may notice that lower angle search units that may have been recommended are not standard off-the-shelf items. The reason for this was to maximize the amount of coverage obtained based on the available access. In every case where multiple angles are required by the procedure, at least one angle was selected to rely on corner trap responses for detection. The other angle was equal or greater than 52°, which relies on flaw face reflection for detection.

It should also be noted that scanning with the search unit, even partially, on adjacent welds can dramatically reduce the penetrating capability of the ultrasonic beam. Thus, scan coverage was terminated when the edge of search units moved on top of any adjacent weld. In addition, coverage was credited only when the entire surface of the search unit was set flat. No coverage was claimed in areas where there was a gap $\geq 1/32"$ under the search unit.

Table 2-1
Focal Lengths of Refracted Longitudinal Search Units

Minimum and Maximum Focus Ranges for RL Transducers													
Element Size		2(7x10)		2(8x14)		2(10x18)		2(15x25)		2(20x34)		2(24x42)	
Freq.	Angle	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1.0	45			0.4	1.0	0.6	1.2	0.8	2.2	1.2	3.2	1.6	4.7
	60			0.4	0.8	0.6	1.2	0.8	1.8	1.0	3.0	1.4	4.3
	70			0.4	0.8	0.6	1.2	0.6	1.8	1.0	3.0	1.2	3.9
1.5	45			0.4	1.2	0.6	1.6	0.8	2.6	1.4	3.9	1.8	5.3
	60			0.4	1.2	0.6	1.6	0.8	2.4	1.2	3.5	1.6	4.9
	70			0.4	1.0	0.6	1.2	0.8	2.4	1.2	3.4	1.4	4.5
2.0	45	0.4	1.0	0.6	1.2	0.8	1.8	1.0	3.4	1.6	5.1	1.8	6.3
	60	0.4	1.0	0.4	1.2	0.6	1.6	0.8	3.0	1.2	4.7	1.6	5.5
	70	0.4	0.8	0.4	1.0	0.6	1.4	0.8	2.8	1.2	4.3	1.4	4.9
4.0	45	0.4	1.4	0.8	2.4	1.0	3.5	1.2	3.9				
	60	0.4	1.4	0.6	2.2	0.8	2.8	1.0	3.5				
	70	0.4	1.2	0.4	2.0	0.6	2.6	0.8	3.4				

3
MILLSTONE UNIT 2 REACTOR COOLANT PUMP INLET NOZZLES

3.1 Configuration

Dominion Generation supplied information on three reactor coolant pump inlet nozzles for Millstone Unit 2: P-4-C-1, P-13-C-1, and P-17-C-1. The general component dimensions for all welds are shown in Table 3-1. A thorough review of the configuration design basis drawing was performed in conjunction with the assessment.

Table 3-1
Component information – Millstone Unit 2 Reactor Coolant Pump Inlet Nozzles

Component 1	**Pipe (All Dimensions in Inches)**
Component 1 OD	~ 36.3
Component 1 actual measured thickness	~3.48 to 3.61
Component 1 material	carbon steel pipe
Component 1 cladding	stainless steel
Bevel face buttering	Inconel
Bevel face buttering thickness	~0.10 to 0.15
Weld material	Inconel
Weld type	Butt
Component 2	**Safe-End**
Component 2 OD	~ 36.0
Component 2 actual measured thickness	~3.1 to 3.48
Component 2 material	A-351 Gr. CF8M cast stainless steel
Component 3	**Pump**
Component 3 OD	~ 36.0
Component 3 material	cast stainless steel (type not specified)
Weld material	cast stainless steel (type not specified)

3.2 Assessment of Coverage

EPRI has performed a detailed assessment of the examination coverage obtainable with this configuration. Examination coverage calculations were based on the examination criteria defined in PDI-UT-10, Revision C.

Figure 3-1 is the as-found condition and Figure 3-2 is a photograph of P-4-C-1. Figure 3-7 is the as-found condition and Figure 3-8 is a photograph of P-13-C-1. Figure 3-13 is the as-found condition and Figure 3-14 is a photograph of P-17-C-1.

Figures 3-3 through 3-6 below are the detailed sketches of the weld profiles, and the estimated coverage obtainable for each scan direction and search unit angle for nozzle P-4-C-1.

Figures 3-9 through 3-12 below are the detailed sketches of the weld profiles, and the estimated coverage obtainable for each scan direction and search unit angle for nozzle P-13-C-1.

Figures 3-15 through 3-18 below are the detailed sketches of the weld profiles, and the estimated coverage obtainable for each scan direction and search unit angle for nozzle P-17-C-1.

No field data was provided for component P-8-C-1.

In several cases the profiles provided did not extend far enough to cover the entire scan distance needed for the evaluation. In these cases the surface condition was assumed to be flat and the profile was extended using dotted lines.

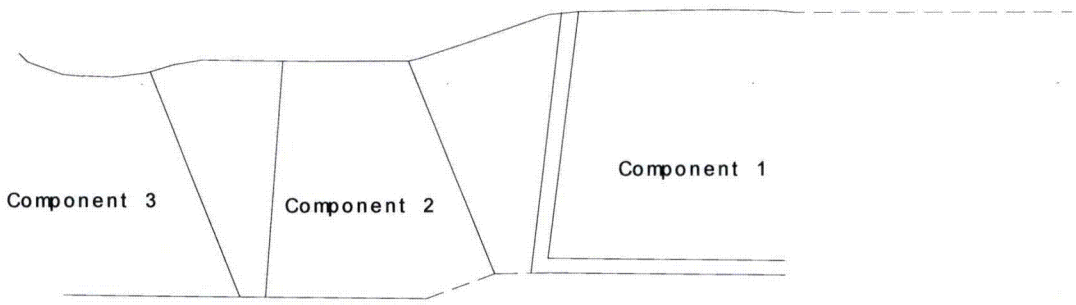


Figure 3-1
Reactor Coolant Pump Inlet Nozzle P-4-C-1 Millstone Unit 2 Configuration

Figure 3-2
Reactor Coolant Pump Inlet Nozzle P-4-C-1 Millstone Unit 2 Photograph

45° RL Axial Scan Coverage

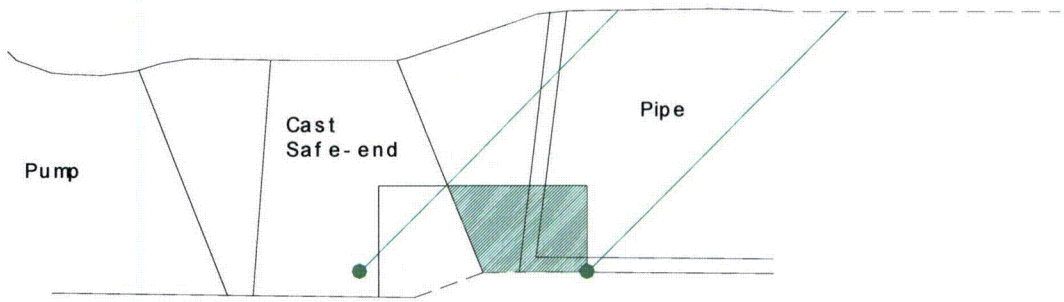


Figure 3-3
Reactor Coolant Pump Inlet Nozzle P-4-C-1 Millstone Unit 2 Profile and Coverage Drawings of 45°RL

Code volume area is 3.49 square inches
Estimated obtainable area covered by 45° RL is 1.99 square inches
Estimated percent covered by 45° RL is 57%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

60° RL Axial Scan Coverage

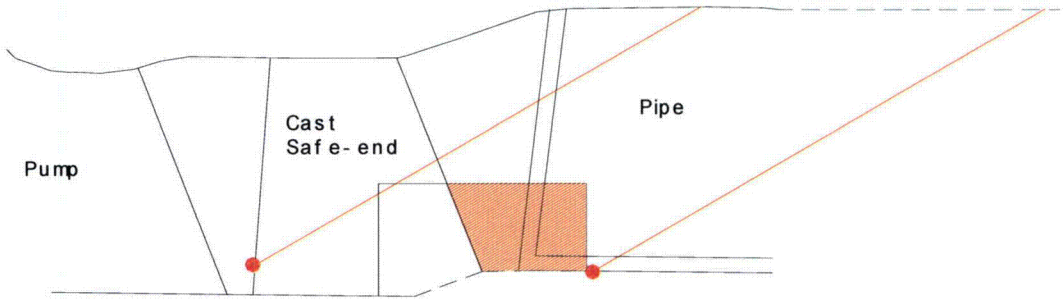


Figure 3-4
Reactor Coolant Pump Inlet Nozzle P-4-C-1 Millstone Unit 2 Profile and Coverage Drawings of 60°RL

Code volume area is 3.49 square inches
Estimated obtainable area covered by 60° RL is 1.99 square inches
Estimated percent covered by 60° RL is 57%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.15 inches
Exit point to rear of search unit dimension is 1.21 inches

Combined Angles Axial Scan Coverage

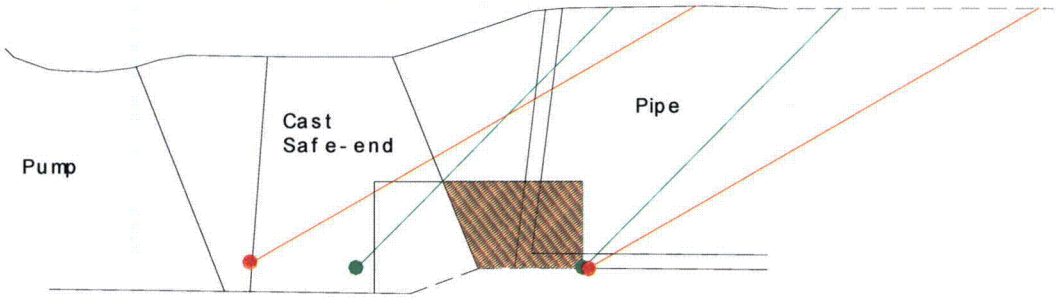


Figure 3-5
Reactor Coolant Pump Inlet Nozzle P-4-C-1 Millstone Unit 2 Combined Axial Coverage of 45/60°RL

Area covered by both angles is 1.99 square inches, 57%.

45° RL Circumferential Scan Coverage

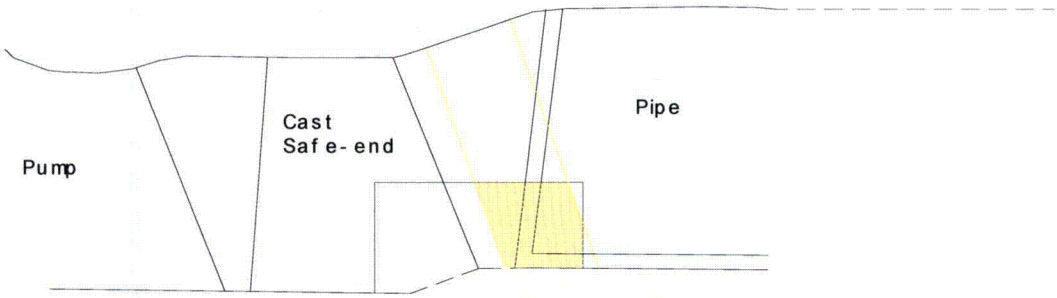


Figure 3-6
Reactor Coolant Pump Inlet Nozzle P-4-C-1 Millstone Unit 2 Profile and Circ Coverage for 45°RL

Code volume area is 3.49 square inches
Estimated obtainable area covered by 45° RL is 1.45 square inches
Estimated percent covered by 45° RL is 41%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Centerline to edge of transducer dimension is 0.60 inches

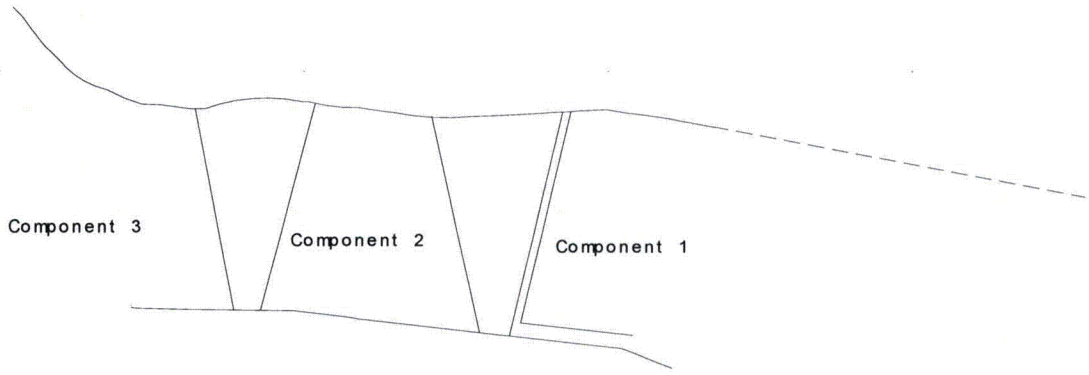


Figure 3-7
Reactor Coolant Pump Inlet Nozzle P-13-C-1 Millstone Unit 2 Configuration

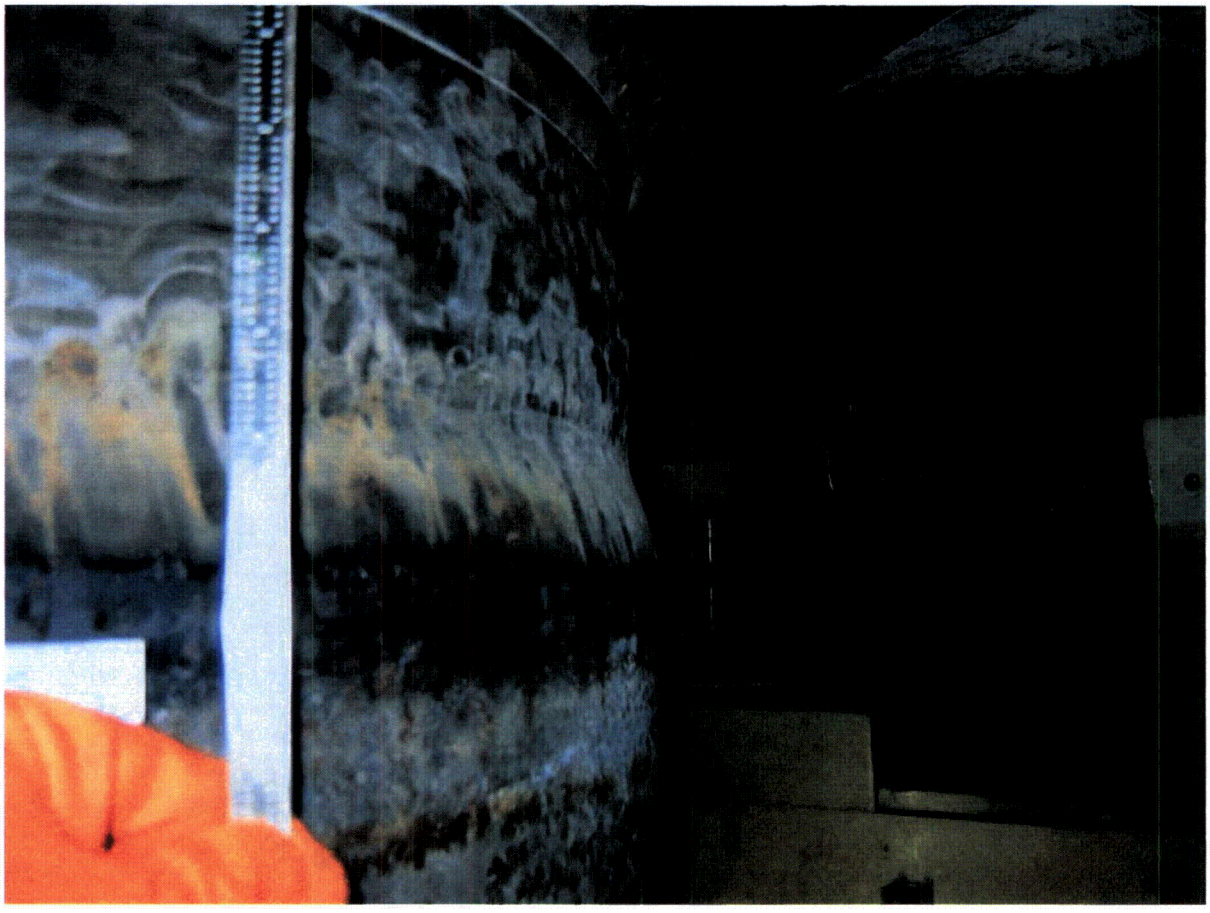


Figure 3-8
Reactor Coolant Pump Inlet Nozzle P-13-C-1 Millstone Unit 2 Photograph

45° RL Axial Scan Coverage

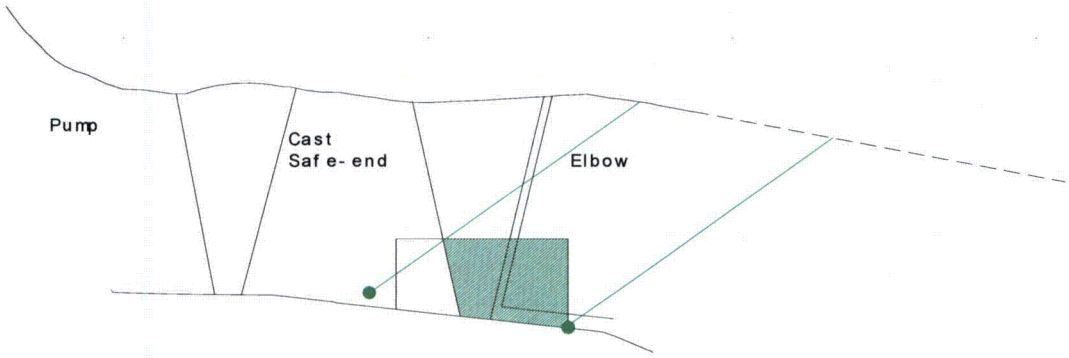


Figure 3-9
Reactor Coolant Pump Inlet Nozzle P-13-C-1 Millstone Unit 2 Profile and Coverage Drawings of 45°RL

Code volume area is 3.27 square inches
Estimated obtainable area covered by 45° RL is 2.30 square inches
Estimated percent covered by 45° RL is 70%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

60° RL Axial Scan Coverage

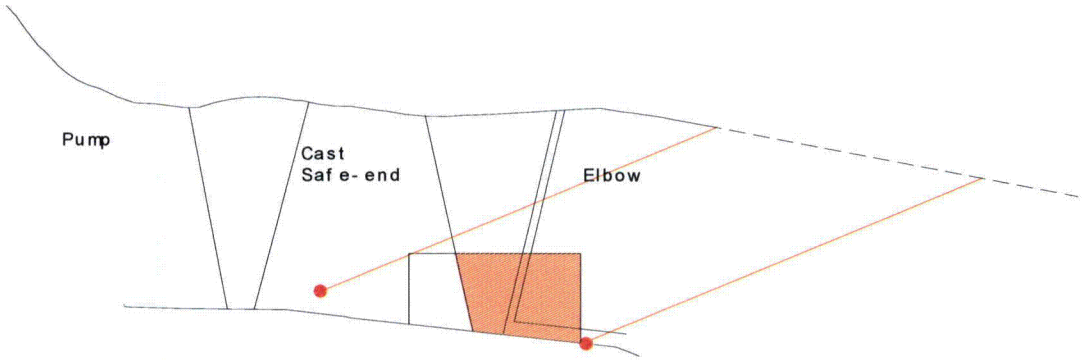


Figure 3-10
Reactor Coolant Pump Inlet Nozzle P-13-C-1 Millstone Unit 2 Profile and Coverage Drawings of 60°RL

Code volume area is 3.27 square inches
Estimated obtainable area covered by 60° RL is 2.30 square inches
Estimated percent covered by 60° RL is 70%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.15 inches
Exit point to rear of search unit dimension is 1.21 inches

Combined Angles Axial Scan Coverage

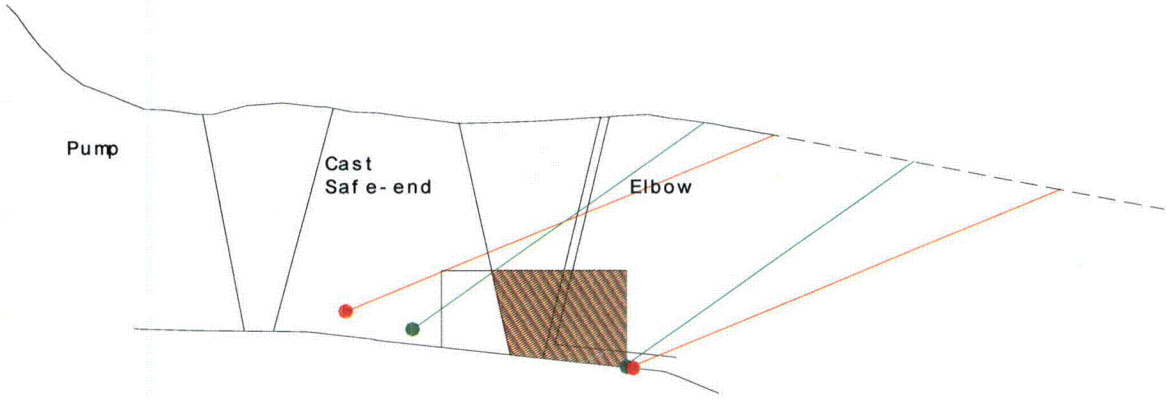


Figure 3-11
Reactor Coolant Pump Inlet Nozzle P-13-C-1 Millstone Unit 2 Combined Axial Coverage of 45/60°RL

Area covered by both angles is 2.30 square inches, 70%.

45° RL Circumferential Scan Coverage

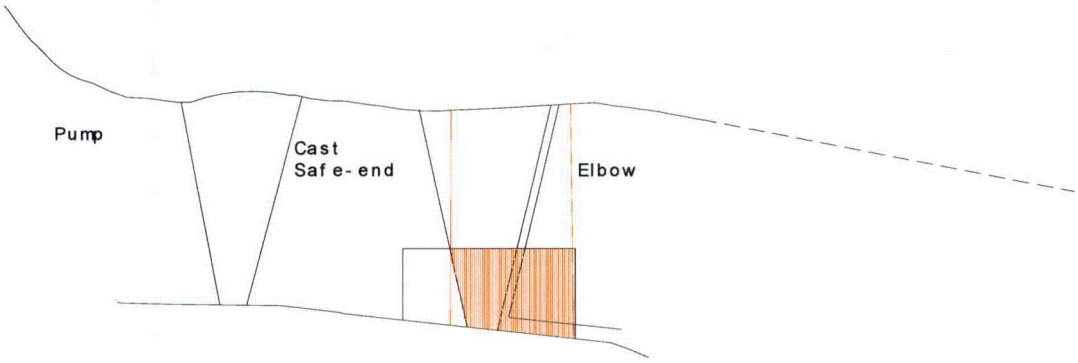


Figure 3-12
Reactor Coolant Pump Inlet Nozzle P-13-C-1 Millstone Unit 2 Profile and Circ Coverage for 45°RL

Code volume area is 3.27 square inches
Estimated obtainable area covered by 45° RL is 2.28 square inches
Estimated percent covered by 35° RL is 70%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Centerline to edge of transducer dimension is 0.60 inches

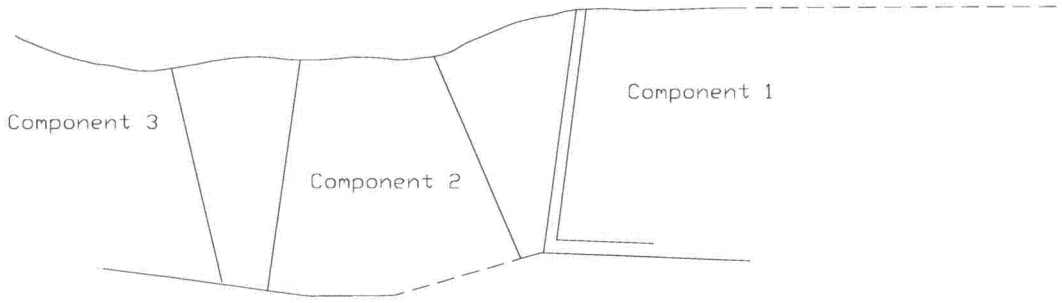


Figure 3-13
Reactor Coolant Pump Inlet Nozzle P-17-C-1 Millstone Unit 2 Configuration

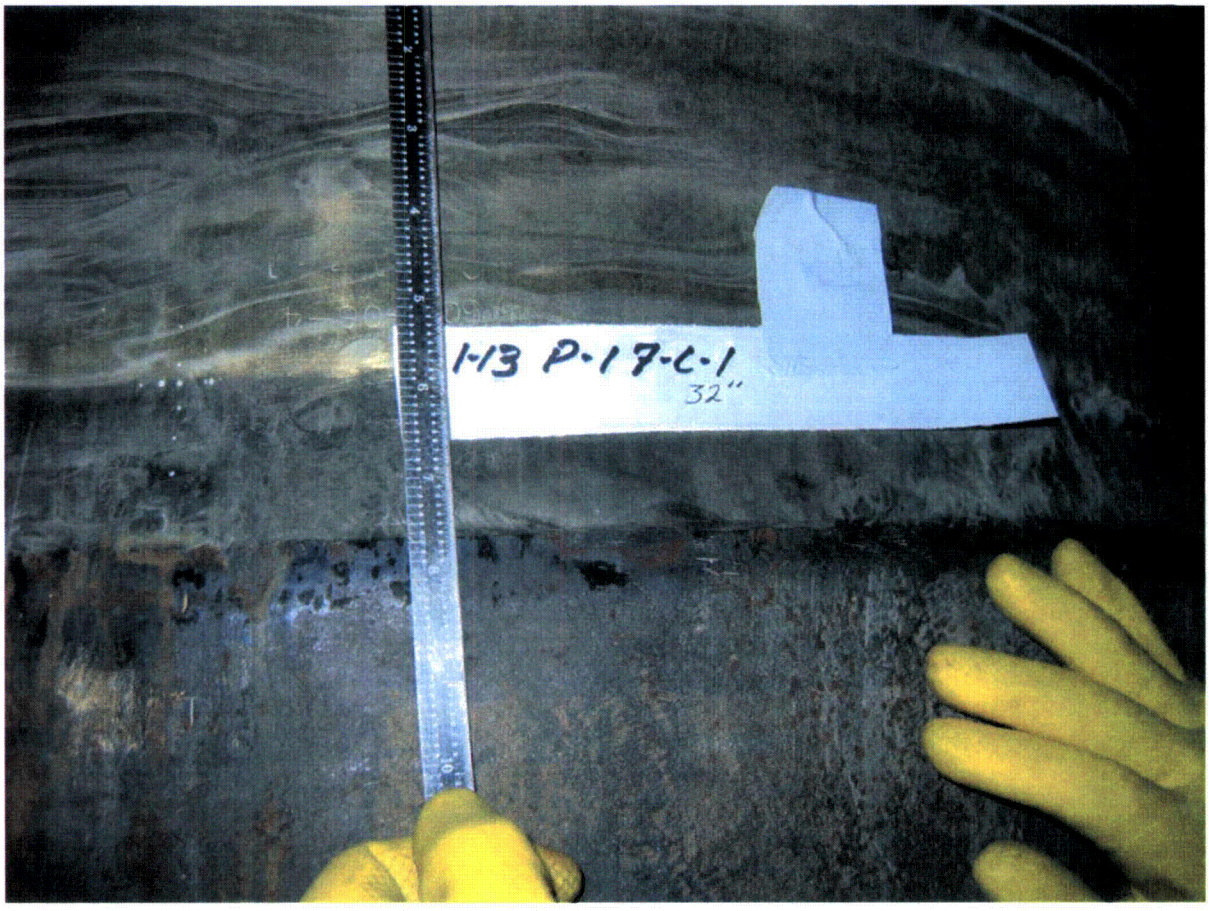


Figure 3-14
Reactor Coolant Pump Inlet Nozzle P-17-C-1 Millstone Unit 2 Photograph

45° RL Axial Scan Coverage

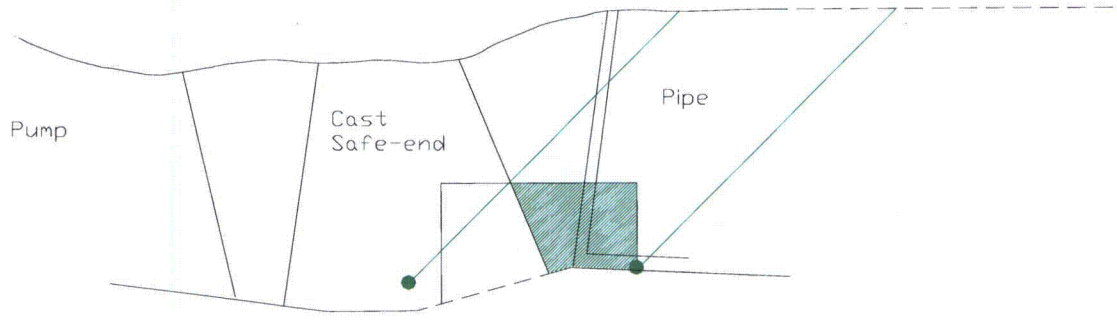


Figure 3-15
Reactor Coolant Pump Inlet Nozzle P-17-C-1 Millstone Unit 2 Profile and Coverage Drawings of 45°RL

Code volume area is 3.64 square inches
Estimated obtainable area covered by 45° RL is 1.83 square inches
Estimated percent covered by 45° RL is 50%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

60° RL Axial Scan Coverage

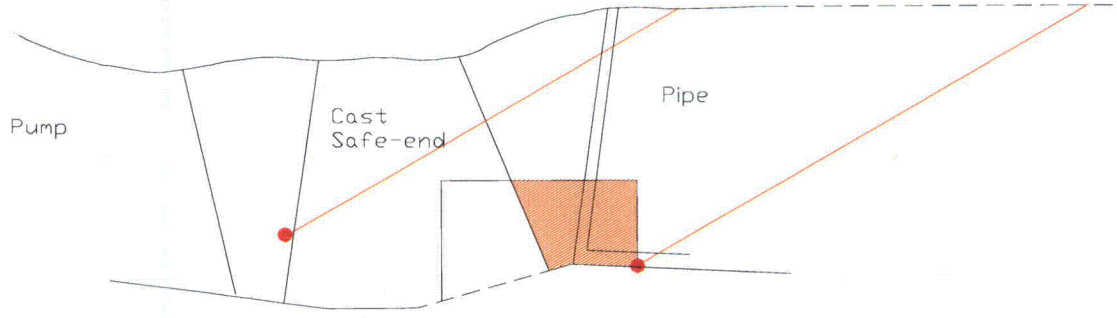


Figure 3-16
Reactor Coolant Pump Inlet Nozzle P-17-C-1 Millstone Unit 2 Profile and Coverage Drawings of 60°RL

Code volume area is 3.64 square inches
Estimated obtainable area covered by 60° RL is 1.83 square inches
Estimated percent covered by 60° RL is 50%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.15 inches
Exit point to rear of search unit dimension is 1.21 inches

Combined Angles Axial Scan Coverage

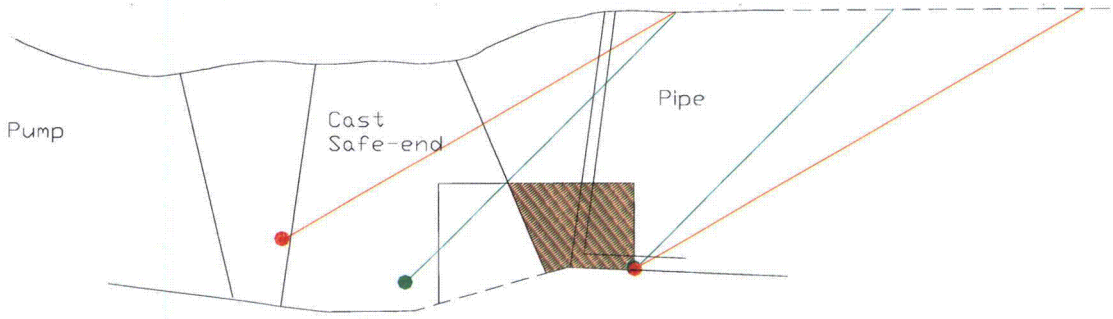


Figure 3-17
Reactor Coolant Pump Inlet Nozzle P-17-C-1 Millstone Unit 2 Combined Axial Coverage of 45/60°RL

Area covered by both angles is 1.83 square inches, 50%.

45° RL Circumferential Scan Coverage

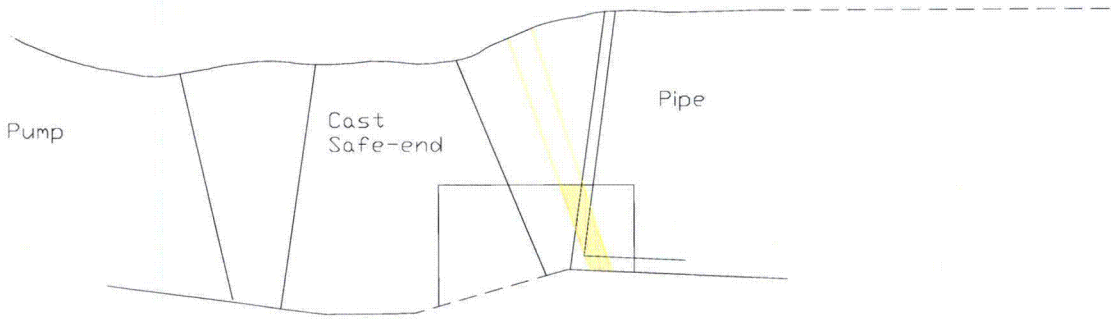


Figure 3-18
Reactor Coolant Pump Inlet Nozzle P-17-C-1 Millstone Unit 2 Profile and Circ Coverage for 45°RL

Code volume area is 3.64 square inches
Estimated obtainable area covered by 45° RL is 0.37 square inches
Estimated percent covered by 45° RL is 10%
Search unit size used – 2(24x42mm) (30x60mm) footprint
Centerline to edge of transducer dimension is 0.65 inches

3.3 Observations/Recommendations

Based on the contour information provided for these welds, it appears the examination will be limited in the axial scan direction due to the surface condition of the weld and adjacent base material. The profiles provided do not show the surface condition of the base material for the entire scan pattern, but for the purpose of this report, it is assumed to be smooth. Due to the cast safe-end, all coverage calculations were based on the beam terminating at the weld to cast interface and taking no credit for scanning from the cast safe-end side of the weld. It must be noted that even if the safe-end material was not cast, the surface condition of these safe-ends are not suitable for scanning, therefore no additional coverage would be gained. Due to the thickness of these welds, a long metal path is required for examination, requiring the use of a larger search unit that in some cases limits the amount of coverage obtainable. While the overall coverage in the axial scan direction is well below 90%, the examination actually covers a large percentage of the Inconel material and the adjacent ferritic base material.

Circumferential scanning with the conventional refracted longitudinal wave search units is limited due to the condition of the weld crown. It is very unlikely that the surface condition of these welds can be improved to an acceptable condition by grinding; however, machining coupled with the application of additional weld metal may improve the surface condition to an acceptable level. The use of tandem search units, which have a smaller footprint, may improve coverage in some of the areas around the circumference and allow adjustments of the beam to compensate for the tapered examination surface noted.

Based on review of all the information provided, it appears that the surface condition of these welds varies greatly around the circumference. Additional profiles that cover the entire scan surface should be taken in order to fully evaluate the profile of the weld. These profiles should, at a minimum, include the most limiting conditions along with additional examples of the nominal condition of the weld. Restrictions that further limit the amount of coverage should be documented for Dominion Generation to make an informed decision on the extent of coverage achievable.

While it is highly unlikely, conventional techniques could be expanded to significantly increase coverage of on these welds. Currently, there is a funded project that includes the fabrication of a mockup that is similar to this configuration. This mock-up could be used for evaluation of new technology such as Phased Array, which may help improve the overall coverage in at least the axial scan direction. In addition, new technologies are being developed for applications on rough and wavy surfaces, which may be applicable to these configurations. However, the presence of the cast safe-end will always reduce the obtainable coverage to a composite value of less than 90%. For this reason, the application of a pre-emptive weld overlay should also be considered for these welds. Extensive work is underway to develop and qualify techniques to examine these welds once an overlay is applied. This work also includes tasks to evaluate the effectiveness of examination of cast base material covered by the weld overlay. If viable techniques are not found, additional engineering work will be needed to address the examination limitations posed by cast base material.

If Dominion Generation decides to perform examinations on these welds, the search units shown in Table 3-2 below are recommended.

Table 3-2
Examination Technique for Unit 2 RCP Inlet Nozzles

Scan Direction	Angle (degrees)	Frequency (MHz)	Size	Focal Length in Sound Path (FS) (inches)	Contour (inches)	Comments
Axial	45	1.5	2(24 x 42)mm	4.5	40	
Axial	60	2.0	2(24 x 42)mm	5.5	40	Max FS
Circ	45	1.5	2(24 x 42)mm	5.1	40	
Circ	45	1.5	~24 mm wide tandem if possible	5.1	40	This probe is a tandem search unit designed to scan on the tapered weld with the beam corrected to compensate for the taper. The footprint of the search unit (s) would be about half the size of a normal side-by-side. There would have to be 2 search units one looking CW and the other looking CCW.

The suggested search units may have to be qualified on the PDI test samples prior to use. Please check the latest revision of Table 1 for PDI-UT-10 for qualification status. All of the search units should be manufactured using composite material which has been shown to improve the signal-to-noise ratio.

3.4 Mockup Recommendations

The thickness and diameter ranges of these welds fall within the ranges qualified by the PDI program. However, the unique weld crown and surface conditions, coupled with the cast safe end, are significantly different than any PDI samples currently in the program. As stated above, PDI mock-ups are being fabricated that can be used to evaluate and qualify specific techniques for these configurations. It must be noted that even if these mockups are fabricated, there is no guarantee that Dominion Generation will be successful increasing the estimated coverage significantly. In order to evaluate the applicability of these new mock-ups to the Millstone configurations, additional profiles that cover the entire scan surface should be taken in order to fully evaluate the profile of the weld. These profiles should, at a minimum, include the most limiting conditions along with additional examples of the nominal condition of the weld. Restrictions that further limit the amount of coverage should be documented.

4

MILLSTONE UNIT 2 REACTOR COOLANT PUMP OUTLET NOZZLES

4.1 Configuration

Dominion Generation supplied information on three reactor coolant pump outlet nozzles for Millstone Unit 2: P-5-C-3, P-9-C-3, P-14-C-3, and P-18-C-3. The general component dimensions for all welds are shown in Table 4-1. A thorough review of the configuration design basis drawing was performed in conjunction with the assessment.

Table 4-1
Component information – Millstone Unit 2 Reactor Coolant Pump Outlet Nozzles

Component 1	**Pipe (All Dimensions in Inches)**
Component 1 OD	~ 36.9
Component 1 actual measured thickness	~2.77to 2.90
Component 1 material	carbon steel pipe
Component 1 cladding	stainless steel
Bevel face buttering	Inconel
Bevel face buttering thickness	~0.10
Weld material	Inconel
Weld type	Butt
Component 2	**Safe-End**
Component 2 OD	~ 36.0
Component 2 actual measured thickness	~2.70 to 3.20
Component 2 material	A-351 Gr. CF8M cast stainless steel
Component 3	**Pump**
Component 3 OD	~ 36.0
Component 3 material	cast stainless steel (type not specified)
Weld material	cast stainless steel (type not specified)

4.2 Assessment of Coverage

EPRI has performed a detailed assessment of the examination coverage obtainable with this configuration. Examination coverage calculations were based on the examination criteria defined in PDI-UT-10, Revision C.

Figure 4-1 is the as-found condition and Figure 4-2 is a photograph of P-5-C-3. Figure 4-7 is the as-found condition and Figure 4-8 is a photograph of P-9-C-3. Figure 4-13 is the as-found condition and Figure 4-14 is a photograph of P-14-C-3. Figure 4-19 is the as-found condition and Figure 4-20 is a photograph of P-18-C-3.

Figures 4-3 through 4-6 below are the detailed sketches of the weld profiles, and the estimated coverage obtainable for each scan direction and search unit angle for nozzle P-5-C-3.

Figures 4-9 through 4-12 below are the detailed sketches of the weld profiles, and the estimated coverage obtainable for each scan direction and search unit angle for nozzle P-9-C-3.

Figures 4-15 through 4-18 below are the detailed sketches of the weld profiles, and the estimated coverage obtainable for each scan direction and search unit angle for nozzle P-14-C-3.

Figures 4-21 through 4-24 below are the detailed sketches of the weld profiles, and the estimated coverage obtainable for each scan direction and search unit angle for nozzle P-18-C-3.

In several cases the profiles provided did not extend far enough to cover the entire scan distance needed for the evaluation. In these cases the surface condition was assumed to be flat and the profile was extended using dotted lines.

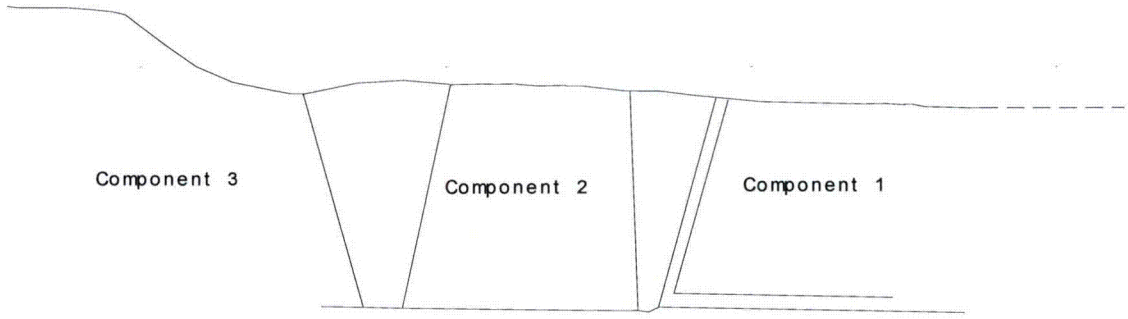


Figure 4-1
Reactor Coolant Pump Outlet Nozzle P-5-C-3 Millstone Unit 2 Configuration

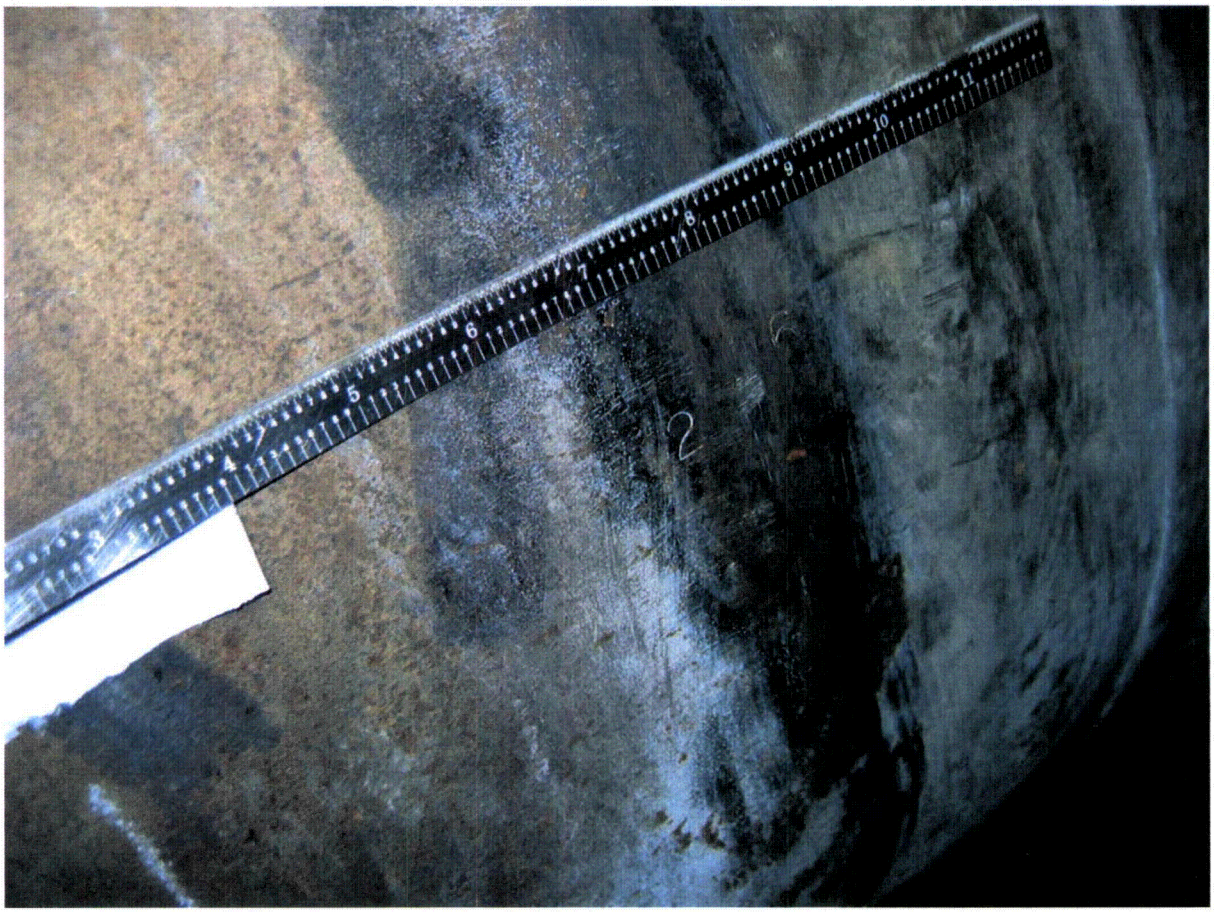


Figure 4-2
Reactor Coolant Pump Outlet Nozzle P-5-C-3 Millstone Unit 2 Photograph

45° RL Axial Scan Coverage

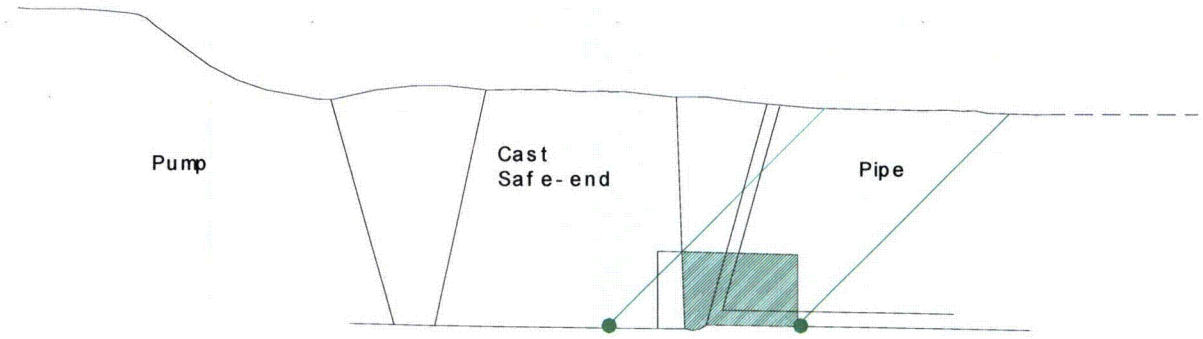


Figure 4-3
Reactor Coolant Pump Outlet Nozzle P-5-C-3 Millstone Unit 2 Profile and Coverage Drawings of 45°RL

Code volume area is 1.92 square inches
Estimated obtainable area covered by 45° RL is 1.55 square inches
Estimated percent covered by 45° RL is 81%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

60° RL Axial Scan Coverage

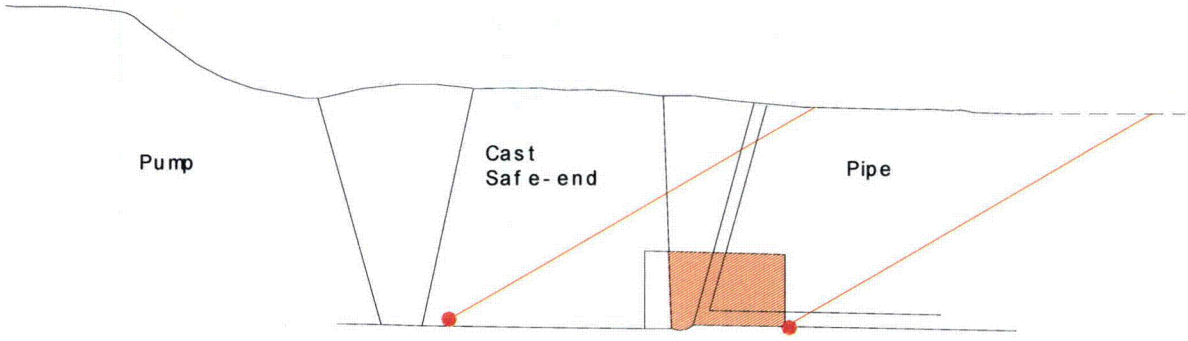


Figure 4-4
Reactor Coolant Pump I Outlet Nozzle P-5-C-3 Millstone Unit 2 Profile and Coverage Drawings of 60°RL

Code volume area is 1.92 square inches
Estimated obtainable area covered by 60° RL is 1.55 square inches
Estimated percent covered by 60° RL is 81%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.15 inches
Exit point to rear of search unit dimension is 1.21 inches

Combined Angles Axial Scan Coverage

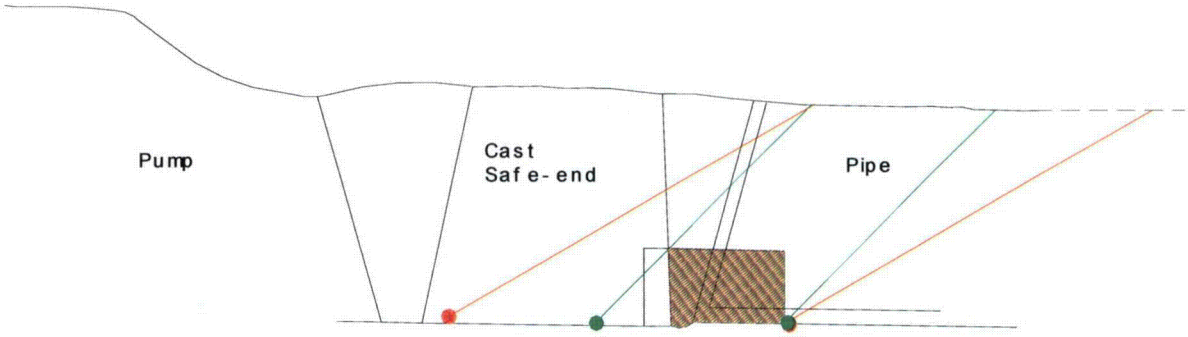


Figure 4-5
Reactor Coolant Pump Outlet Nozzle P-5-C-3 Millstone Unit 2 Combined Axial Coverage of 45/60°RL

Area covered by both angles is 1.55 square inches, 81%.

45° RL Circumferential Scan Coverage

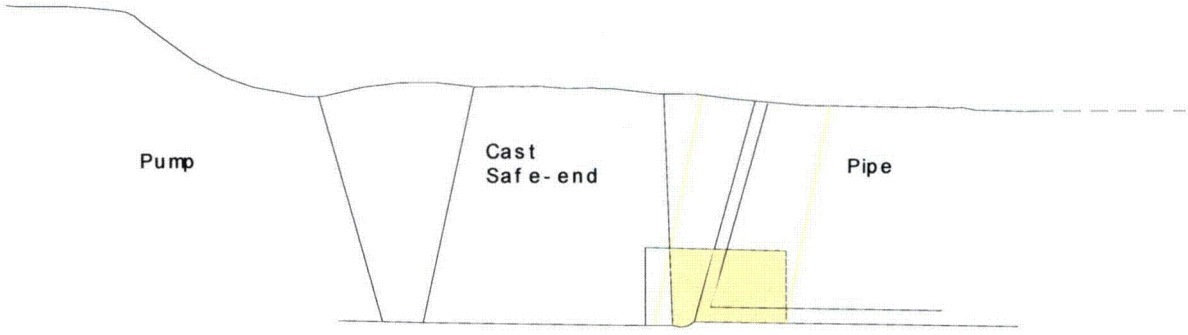


Figure 4-6
Reactor Coolant Pump Outlet Nozzle P-5-C-3 Millstone Unit 2 Profile and Circ Coverage for 45°RL

Code volume area is 1.92 square inches
Estimated obtainable area covered by 45° RL is 1.55 square inches
Estimated percent covered by 45° RL is 81%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

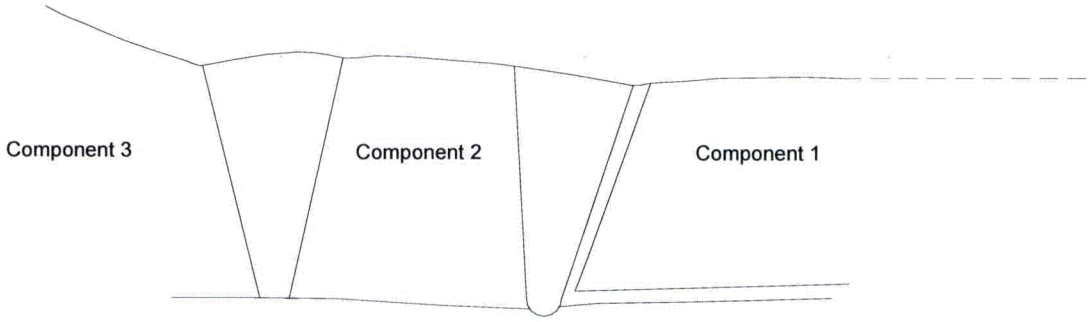


Figure 4-7
Reactor Coolant Pump Outlet Nozzle P-9-C-3 Millstone Unit 2 Configuration

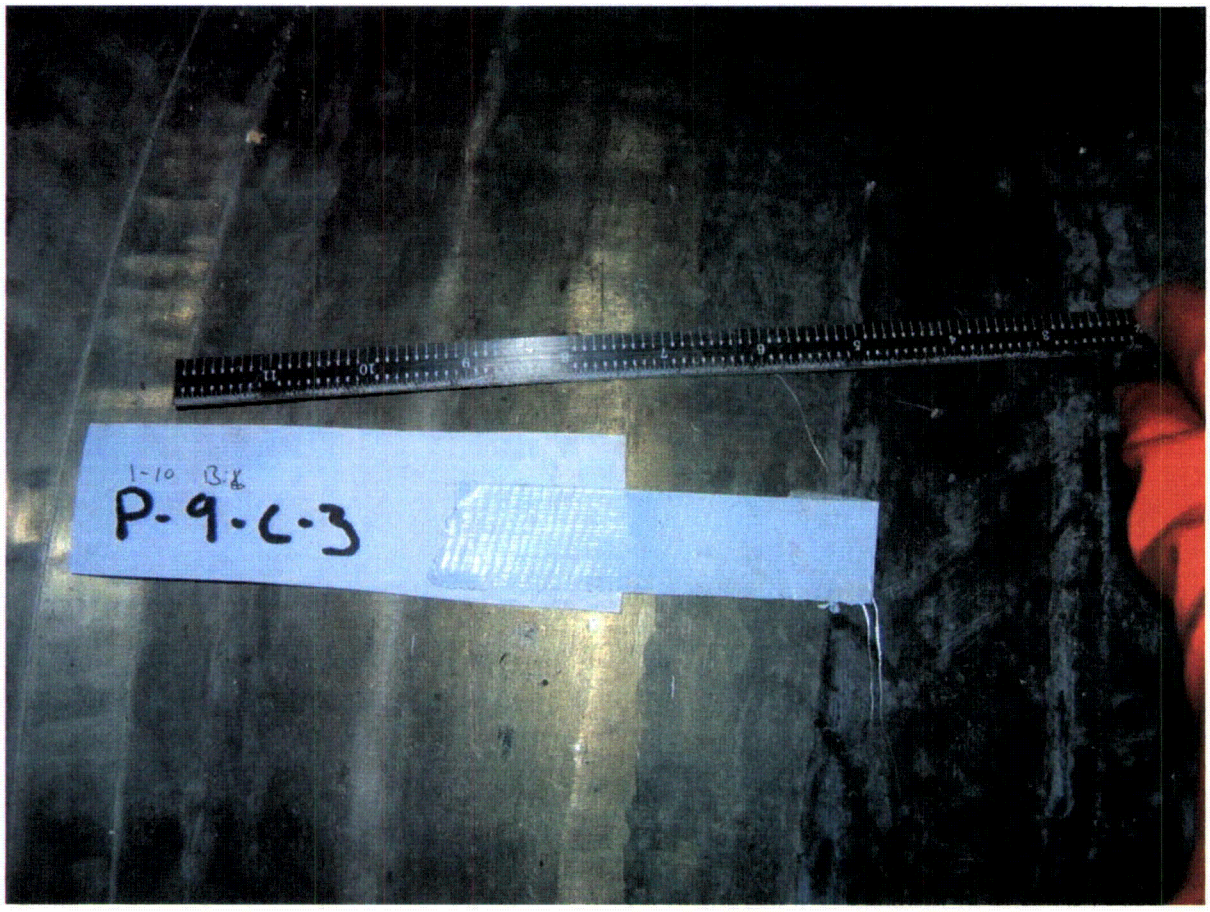


Figure 4-8
Reactor Coolant Pump Outlet Nozzle P-9-C-3 Millstone Unit 2 Photograph

45° RL Axial Scan Coverage

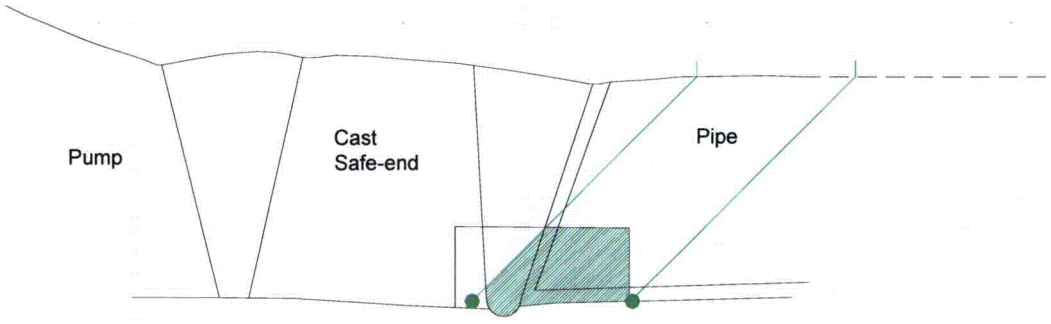


Figure 4-9
Reactor Coolant Pump Outlet Nozzle P-9-C-3 Millstone Unit 2 Profile and Coverage Drawings of 45°RL

Code volume area is 2.45 square inches
Estimated obtainable area covered by 45° RL is 1.66 square inches
Estimated percent covered by 45° RL is 68%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

60° RL Axial Scan Coverage

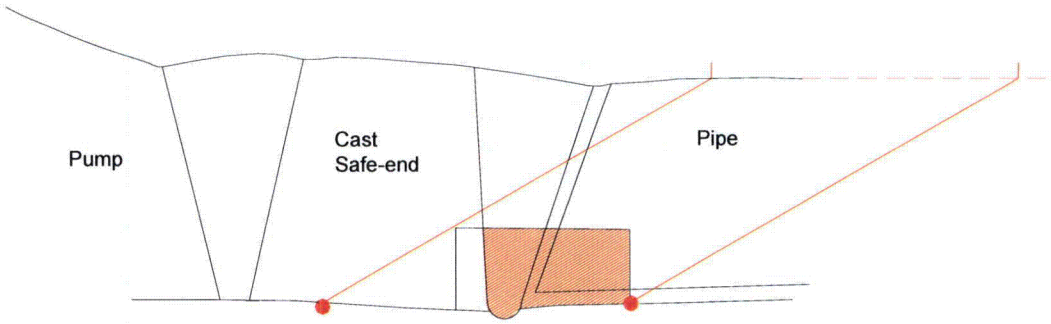


Figure 4-10
Reactor Coolant Pump Outlet Nozzle P-9-C-3 Millstone Unit 2 Profile and Coverage Drawings of 60°RL

Code volume area is 2.45 square inches
Estimated obtainable area covered by 60° RL is 2.02 square inches
Estimated percent covered by 60° RL is 82%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.15 inches
Exit point to rear of search unit dimension is 1.21 inches

Combined Angles Axial Scan Coverage

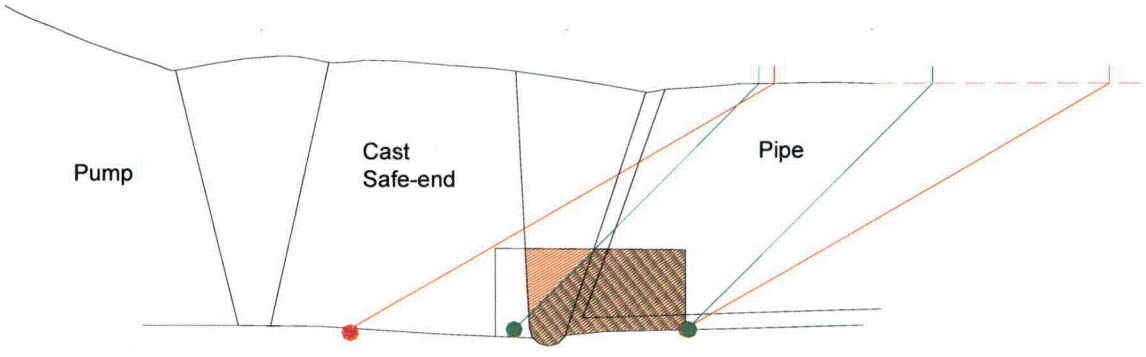


Figure 4-11
Reactor Coolant Pump Outlet Nozzle P-9-C-3 Millstone Unit 2 Combined Axial Coverage of 45/60°RL

Area covered by both angles is 1.66 square inches, 68%.

45° RL Circumferential Scan Coverage

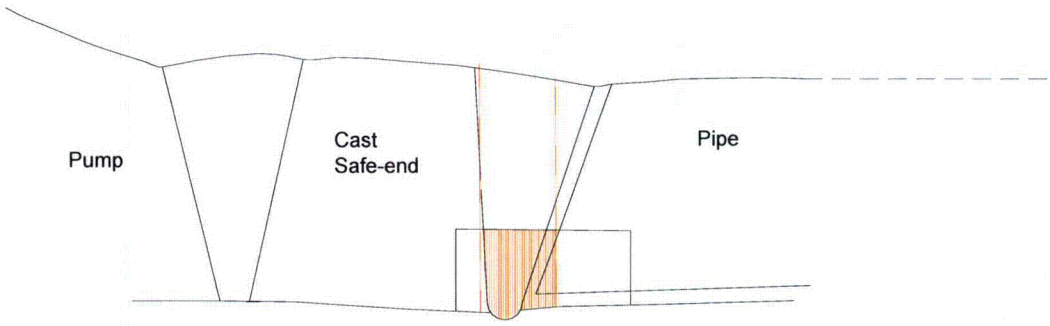


Figure 4-12
Reactor Coolant Pump Outlet Nozzle P-9-C-3 Millstone Unit 2 Profile and Circ Coverage for 45°RL

Code volume area is 2.45 square inches
Estimated obtainable area covered by 45° RL is 1.04 square inches
Estimated percent covered by 45° RL is 68%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

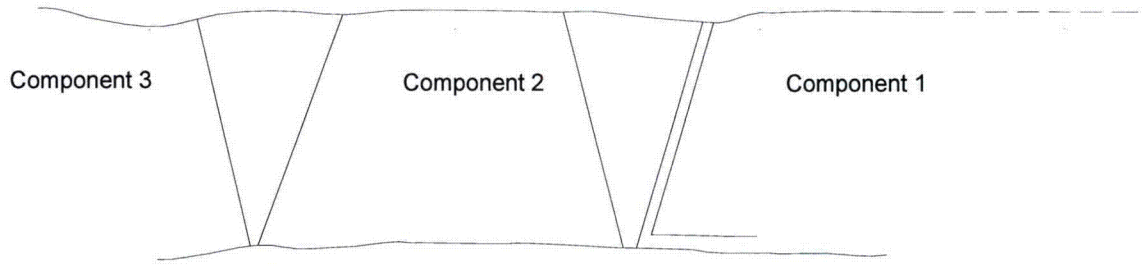


Figure 4-13
Reactor Coolant Pump Outlet Nozzle P-14-C-3 Millstone Unit 2 Configuration

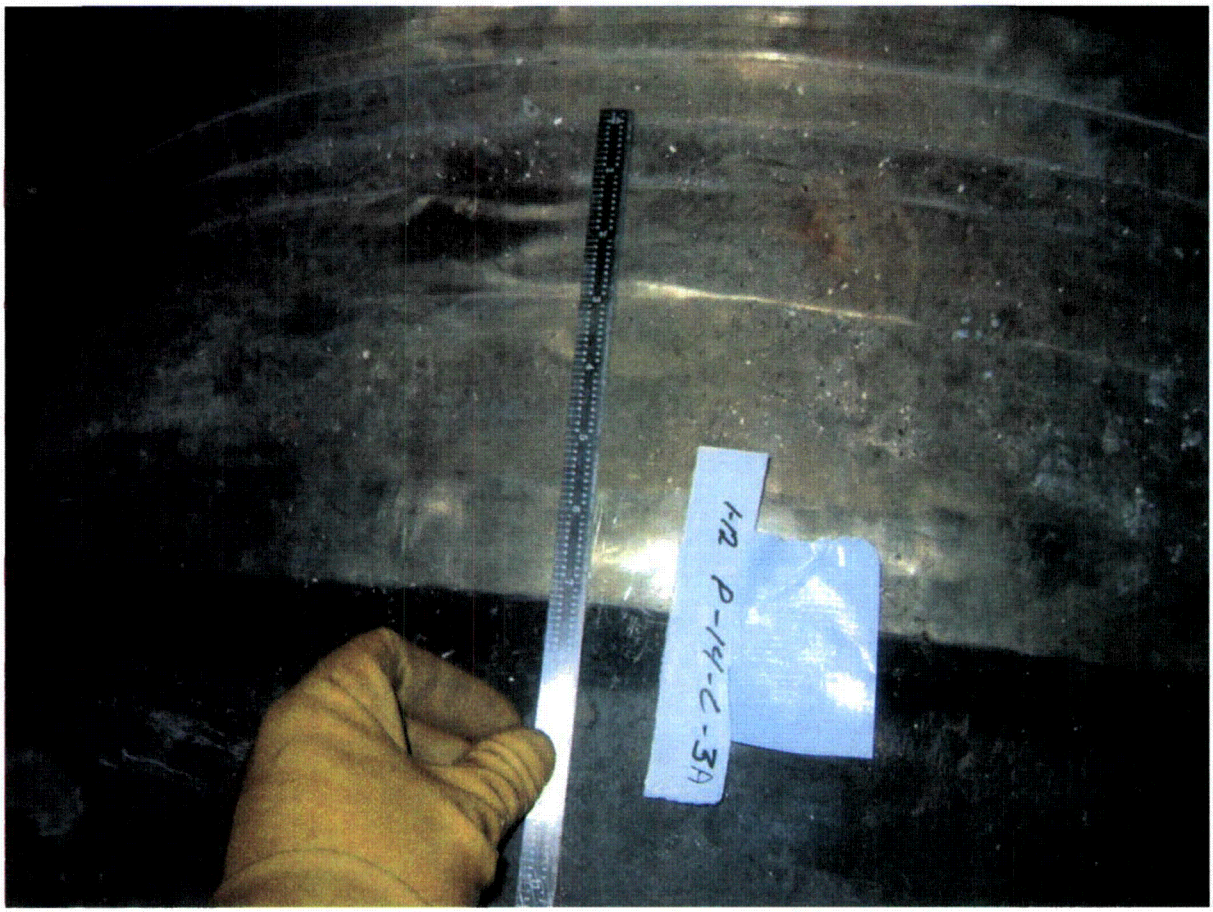


Figure 4-14
Reactor Coolant Pump Outlet Nozzle P-14-C-3 Millstone Unit 2 Photograph

45° RL Axial Scan Coverage

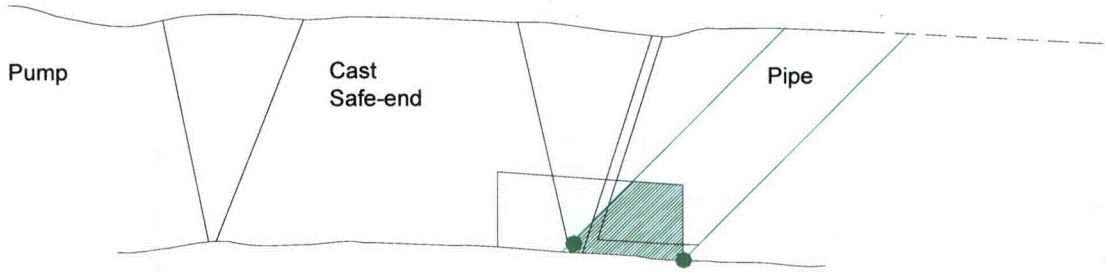


Figure 4-15
Reactor Coolant Pump Outlet Nozzle P-14-C-3 Millstone Unit 2 Profile and Coverage Drawings of 45°RL

Code volume area is 2.09 square inches
Estimated obtainable area covered by 45° RL is 0.97 square inches
Estimated percent covered by 45° RL is 46%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

60° RL Axial Scan Coverage

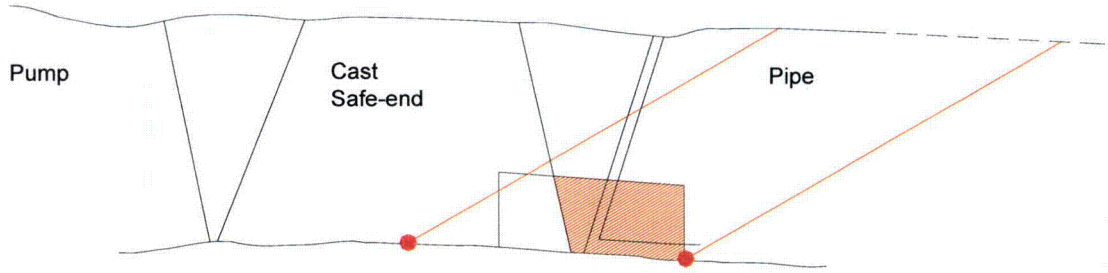


Figure 4-16
Reactor Coolant Pump Outlet Nozzle P-14-C-3 Millstone Unit 2 Profile and Coverage Drawings of 60°RL

Code volume area is 2.09 square inches
Estimated obtainable area covered by 60° RL is 1.38 square inches
Estimated percent covered by 60° RL is 66%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.15 inches
Exit point to rear of search unit dimension is 1.21 inches

Combined Angles Axial Scan Coverage

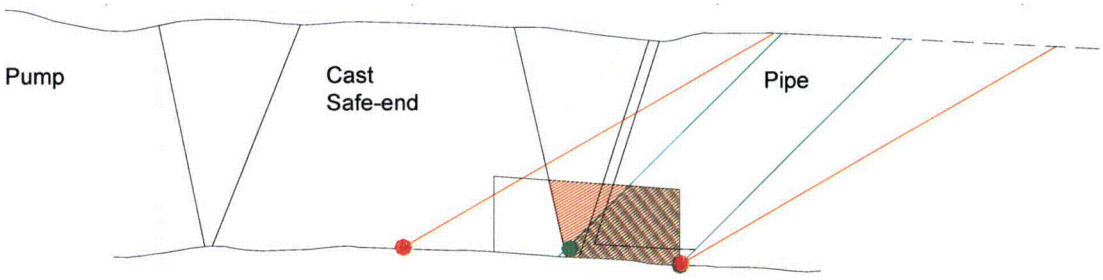


Figure 4-17
Reactor Coolant Pump Outlet Nozzle P-14-C-3 Millstone Unit 2 Combined Axial Coverage of 45/60°RL

Area covered by both angles is 0.97 square inches, 46%.

45° RL Circumferential Scan Coverage

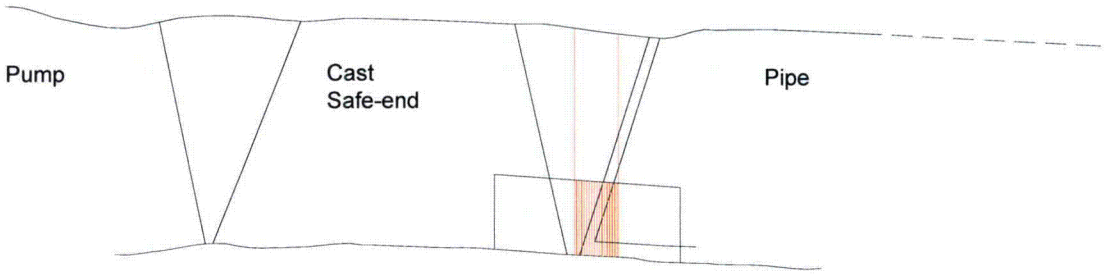


Figure 4-18
Reactor Coolant Pump Outlet Nozzle P-14-C-3 Millstone Unit 2 Profile and Circ Coverage for 45°RL

Code volume area is 2.09 square inches
Estimated obtainable area covered by 45° RL is 0.49 square inches
Estimated percent covered by 45° RL is 23%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

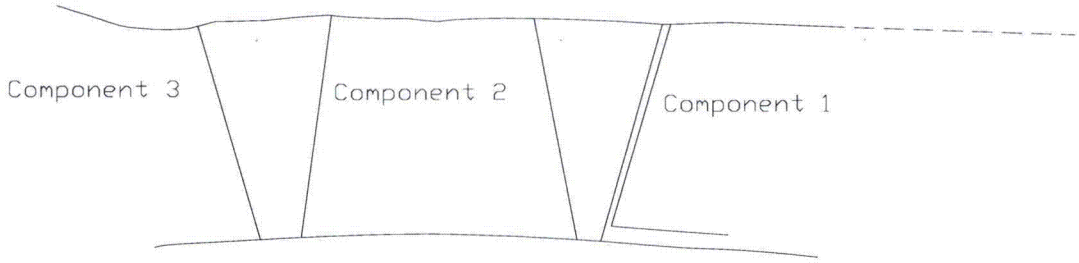


Figure 4-19
Reactor Coolant Pump Outlet Nozzle P-18-C-3 Millstone Unit 2 Configuration

Figure 4-20
Reactor Coolant Pump Outlet Nozzle P-18-C-3 Millstone Unit 2 Photograph

45° RL Axial Scan Coverage

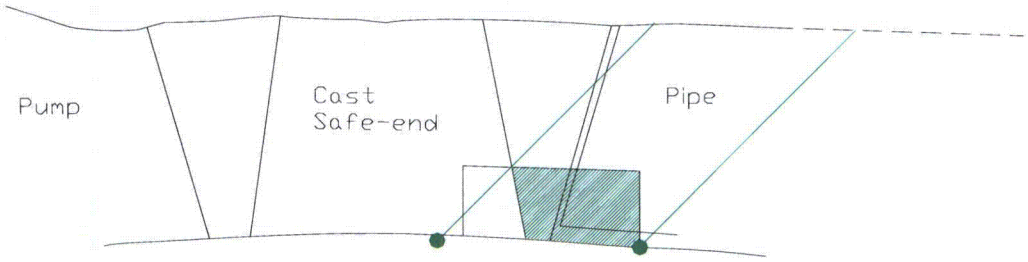


Figure 4-21
Reactor Coolant Pump Outlet Nozzle P-18-C-3 Millstone Unit 2 Profile and Coverage Drawings of 45°RL

Code volume area is 2.08 square inches
Estimated obtainable area covered by 45° RL is 1.44 square inches
Estimated percent covered by 45° RL is 69%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

60° RL Axial Scan Coverage

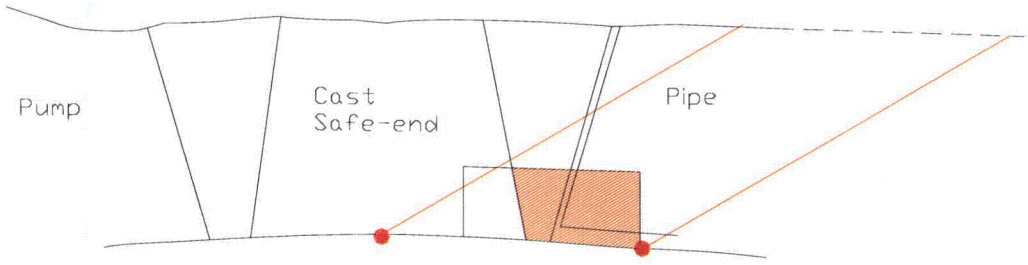


Figure 4-22
Reactor Coolant Pump Outlet Nozzle P-18-C-3 Millstone Unit 2 Profile and Coverage Drawings of 60°RL

Code volume area is 2.08 square inches
Estimated obtainable area covered by 60° RL is 1.44 square inches
Estimated percent covered by 60° RL is 69%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.15 inches
Exit point to rear of search unit dimension is 1.21 inches

Combined Angles Axial Scan Coverage

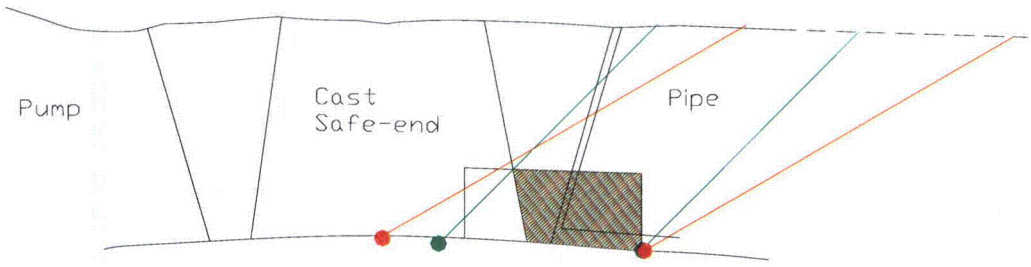


Figure 4-23
Reactor Coolant Pump Outlet Nozzle P-14-C-3 Millstone Unit 2 Combined Axial Coverage of 45/60°RL

Area covered by both angles is 1.44 square inches, 69%.

45° RL Circumferential Scan Coverage

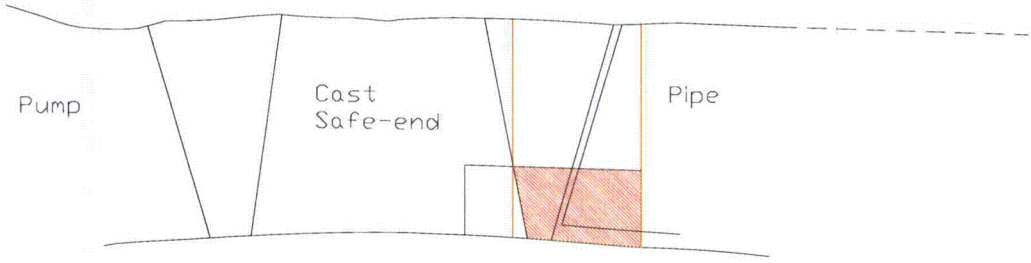


Figure 4-24
Reactor Coolant Pump Outlet Nozzle P-18-C-3 Millstone Unit 2 Profile and Circ Coverage for 45°RL

Code volume area is 2.08 square inches
Estimated obtainable area covered by 45° RL is 1.44 square inches
Estimated percent covered by 45° RL is 69%
Search unit size used – 2(24x42mm) (60x60mm) footprint
Exit point to front of search unit dimension is 1.10 inches
Exit point to rear of search unit dimension is 1.26 inches

4.3 Observations/Recommendations

Based on the contour information provided for these welds, it appears the examination will be limited in the axial scan direction due to the surface condition of the weld and adjacent base material. The profiles provided do not show the surface condition of the base material for the entire scan pattern, but for the purpose of this report it is assumed to be smooth. Due to the cast safe-end all coverage calculations were based on the beam terminating at the weld to cast interface and taking no credit for scanning from the cast safe-end side of the weld. It must be noted that even if the safe-end material was not cast, the surface condition of these safe-ends are not suitable for scanning and therefore no additional coverage would be gained. Due to the thickness of these welds, a long metal path is required for examination requiring the use of a larger search unit that in some cases limits the amount of coverage obtainable. While the overall coverage in the axial scan direction is well below 90%, the examination actually covers a large percentage of the Inconel material and the adjacent ferritic base material.

Circumferential scanning with the conventional refracted longitudinal wave search units is limited due to the condition of the weld crown. It is very unlikely that the surface condition of these welds can be improved to an acceptable condition by grinding; however, machining coupled with the application of additional weld metal may improve the surface condition to an acceptable level. The use of tandem search units, which have a smaller footprint, may improve coverage in some of the areas around the circumference and allow adjustments of the beam to compensate for the tapered examination surface noted.

Based on review of all the information provided, it appears that the surface condition of these welds varies greatly around the circumference. Additional profiles that cover the entire scan surface should be taken in order to fully evaluate the profile of the weld. These profiles should, at a minimum, include the most limiting conditions along with additional examples of the nominal condition of the weld. Restrictions that further limit the amount of coverage should be documented for Dominion Generation to determine an informed decision on the extent of coverage achievable.

While it is highly unlikely, conventional techniques could be expanded to significantly increase coverage of on these welds. Currently, there is a funded project that included the fabrication of a mockup that is similar to this configuration. This mock-up could be used for evaluation of new technology such as Phased Array, which may help improve the overall coverage in at least the axial scan direction. In addition, new technologies are being developed for applications on rough and wavy surfaces, which may be applicable to these configurations. However, the presence of the cast safe-end will always reduce the obtainable coverage to a composite value of less than 90%. For this reason, the application of a pre-emptive weld overlay should also be considered for these welds. Extensive work is underway to develop and qualify techniques to examine these welds once an overlay is applied. This work also includes tasks to evaluate the effectiveness of examination of cast base material covered by the weld overlay. If viable techniques are not found, additional engineering work will be needed to address the examination limitations posed by cast base material.

If Dominion Generation decides to perform examinations on these welds, the search units shown in Table 4-2 below are recommended.

Table 4-2
Examination Technique for Unit 2 RCP Outlet Nozzles

Scan Direction	Angle (degrees)	Frequency (MHz)	Size	Focal Length in Sound Path (FS) (inches)	Contour (inches)	Comments
Axial	45	1.5	2(24 x 42)mm	4.5	40	
Axial	60	2.0	2(24 x 42)mm	5.5	40	Max FS
Circ	45	1.5	2(24 x 42)mm	5.1	40	
Circ	45	1.5	~24 mm wide tandem if possible	5.1	40	This probe is a tandem search unit that is designed to scan on the tapered weld with the beam corrected to compensate for the taper. The footprint of the search unit (s) would be about half the size of a normal side by side. There would have to be 2 search units one looking CW and the other looking CCW.

The suggested search units may have to be qualified on the PDI test samples prior to use. Please check the latest revision of Table 1 for PDI-UT-10 for qualification status. All of the search units should be manufactured using composite material, which has been shown to improve the signal-to-noise ratio.

4.4 Mockup Recommendations

The thickness and diameter ranges of these welds fall within the ranges qualified by the PDI program. However, the unique weld crown and surface conditions; coupled with the cast safe-end, are significantly different than any PDI samples currently in the program. As stated above, PDI mock-ups are being fabricated that can be used to evaluate and qualify specific techniques for these configurations. It must be noted that even if these mockups are fabricated, there is no guarantee that Dominion Generation will be successful increasing the estimated coverage significantly. In order to evaluate the applicability of these new mock-ups to the Millstone configurations additional profiles that cover the entire scan surface should be taken in order to fully evaluate the profile of the weld. These profiles should, at a minimum, include the most limiting conditions along with additional examples of the nominal condition of the weld. Restrictions that further limit the amount of coverage should be documented.

5
SUMMARY

At the request of Dominion Generation, a detailed review was performed by EPRI on the walkdown data collected for Millstone Unit 2, Alloy 600/82/182 reactor coolant pump nozzle welds. The purpose of this review was to assist Dominion Generation with the evaluation of the data they collected in response to MRP recommendations detailed in MRP-2004-05. This document requires that utilities retrieve this data in an effort to plan for future volumetric examinations. The recent issuance of MRP-139 has amplified the need for this work to be performed.

Results of this review indicate that several of the welds will require surface preparation work prior to examination. Even with these surface improvements, it will not be possible to attain 90% or greater coverage of the examination volume for detection of circumferential flaws.

Attachment 1 provides a summary of the achievable coverage for each weld assessed in this report. The existing PDI dissimilar metal weld sample inventory will not cover the Millstone Unit 2 configurations.

Attachment 2 contains a summary list of the conventional search units needed for examination of welds included in this report.

Phased array technology could be used to improve the coverage on these components. Existing manually deployed, position encoded techniques, procedures, and personnel have been successfully qualified. However, in order to apply existing, qualified Phased Array techniques to these configurations, there would need to be demonstrations and a procedure expansion effort executed on the specific sample configurations that are presently being fabricated. In addition, the application of this technique would need to be evaluated on a component-by-component basis due to the potential physical mounting limitations of the scanner mechanism; further development of mechanized scanners should be a strong consideration.

These alternate inspection techniques are accompanied by a higher level "risk of failure," presenting no guarantee for success in achieving the required coverage of the inspection volume. If these alternate techniques are hindered by the component configuration or lack of successfully demonstrated results, Dominion Generation should consider the application of a pre-emptive overlay or other mitigation techniques.

A
APPENDIX-ATTACHMENTS

Attachment 1 - Coverage Calculations

Unit	Weld Description	Component Number	Axial Scan Coverage* (%)	Circumferential Scan Coverage (%)	Covered by PDI Program	Mock -Up Required
2	Inlet	P-4-C-1	57	41	No	Yes
2	Inlet	P-13-C-1	70	70	No	Yes
2	Inlet	P-17-C-1	50	10	No	Yes
2	Outlet	P-5-C-3	81	81	No	Yes
2	Outlet	P-9-C-3	68	42	No	Yes
2	Outlet	P-14-C-3	46	23	No	Yes
2	Outlet	P-18-C-3	69	69	No	Yes

* The percentages are based on the area covered by both procedurally required angles. Volume coverage will be less due to scan limitations from branch connections.

Attachment 2 - Recommended Search Units

Unit	Component	Scan Direction	Angle (degrees)	Frequency (MHz)	Size (mm)	Focal Length in Sound Path (FS) (inches)	Contour (inches)	Comments
2	RCP Inlet	Axial	45°	1.5	2(24 x 42)	4.5	40	
		Axial	60°	2.0	2(24 x 42)	5.5	40	
		Circ	45°	1.5	2(24 x 42)	5.1	40	Will require tandem design search unit
2	RCP Outlet	Axial	45°	1.5	2(24 x 42)	4.5	40	
		Axial	60°	2.0	2(24 x 42)	5.5	40	
		Circ	45°	1.5	2(24 x 42)	5.1	40	Will require tandem design search unit

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