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Inspection Qualification II

Plant-Specific Applications of Qualified Nozzle UT Procedures Utilizing EPRI 3D Models - 2002 to 2006

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ABSTRACT

Since November 22, 2002, the ASME Boiler & Pressure Vessel Code, Section XI, Appendix VIII, Supplement 5 requires qualified inspection procedures for the examination of the nozzle inner corner region and the nozzle-to-shell weld [1]. For reactor pressure vessel nozzles inspected from the outside surface, the qualified procedures must incorporate mathematical modeling of the complex geometries involved (ASME Code Case N-552) [2]. This paper is excerpted from the first in a series of annual updates documenting plant specific applications of qualified nozzle inner radius and nozzle-to-shell weld UT techniques developed using the EPRI (NDE) Program 3D nozzle models [3]. The first update covers the period 2002 through 2006 [3].

BACKGROUND

It has been recognized for a long time that the geometry of nozzle inspection is so complex that the inspections can not be done without mathematical modeling. Nozzle modeling defines the examination parameters required (transducer probe skew, scan surface, radial position and metal path) to provide 100% coverage of the examination volume while minimizing the misorientation angle at the flaw. In the early 1990s, EPRI funded the development of computer models to assist in the complicated task of nozzle examinations [4, 5]. The WARay3D model was intended for ultrasonic probe design [4]. The Babcock model was intended for ultrasonic technique evaluation and visualization [5]. During the process of validating these two models, it was discovered that probes designed with the WARay3D model could not be verified with the evaluation technique of the Babcock model. The EPRI (NDE) Program developed an exact analytical solution (that is, the spreadsheet model) to act as an independent referee in order to verify and validate the WARay3D and Babcock models. The EPRI spreadsheet model is the systematic application of vector calculus to the development of ultrasonic inspection techniques and the documentation of examination performance [6]. Reactor pressure vessel, steam generator, and pressurizer nozzle inspections could not be performed, or even qualified, without accurate models of the nozzle geometry. The spreadsheet models produced and operated by EPRI have enabled the US nuclear fleet to meet its licensing commitments to perform qualified nozzle inspections [6-9].

A new federal law that went into effect starting November 2002 required that all reactor vessel nozzles must be inspected using procedures that are qualified by performance demonstration according to the requirements of the ASME Code Case 552 [1, 2]. Inspection services vendors need modeling to develop their procedures, the qualification agency (Performance Demonstration Initiative) needs modeling in order to evaluate and test the procedures, and the utilities need modeling to show that the qualified procedures were applicable to the plants' specific configurations. NDE Program staff operating the EPRI models has provided modeling services to inspection companies, the utilities, and the qualification agency (PDI).

INTRODUCTION

The importance of mathematical computer models of nozzle inspection has increased with nozzle qualifications becoming mandatory in November 2002. Revisions to 10CFR50.55a, initially published September 22, 1999, mandate the implementation of the ASME Code, Section XI, Division 1, Appendix VIII, “Performance Demonstration for Ultrasonic Examination Systems.” Appendix VIII requires qualification of the procedures, personnel, and equipment used to detect and size flaws in the inside corner region and nozzle-to-shell welds of reactor pressure vessel nozzle openings [1]. 10CFR50.55a requires the use of ASME Code Case N-552 for these qualifications [2].

Listed below are the three procedures that have been qualified to date using the EPRI 3D nozzle models:

EPRI NDE Program Procedure, PDI-UT-11, Revision B, "Generic Procedure for the Ultrasonic Detection and Sizing of Reactor Pressure Vessel Nozzle to Shell Welds and Nozzle Inner Radius" [8].

Framatome Technologies Inc. Procedure, 54-ISI-850-03, Revision 3, "Manual Ultrasonic Examination of BWR Reactor Vessel Nozzle Inner Radius Regions and Nozzle to Shell Welds (Inner 15%)".

WesDyne International Procedure, ISI-PDI-210 MD, Revision 3, "Manual Ultrasonic Procedure for Examination of Nozzle Inner Corner Radius Areas in Accordance with ASME Section XI, Including Appendix VIII".

Readers should contact the EPRI Performance Demonstration Initiative, to obtain access to the latest revisions of these procedures.

EPRI PDI-UT-11 PROCEDURE

This paper documents the nozzle geometries that have been examined using the EPRI NDE Program Procedure, PDI-UT-11, Revision B, "Generic Procedure for the Ultrasonic Detection and Sizing of Reactor Pressure Vessel Nozzle to Shell Welds and Nozzle Inner Radius" [8].

BOILING WATER REACTOR PRESSURE VESSEL

Core spray nozzle

Table 1 lists the range of core spray nozzle geometry parameters, i.e. Rbore Min, Rbore Max, etc., that have been examined using the EPRI PDI-UT-11 procedure [8]. The parameters in Table 1 cover the core spray nozzle inner radius (NIR) detection and sizing examinations as well as the nozzle-to-shell weld (NSW) examinations. Figure 1 shows the geometric parameters, which define the core spray nozzle.

Table 1 - BWR RPV Core Spray Nozzle Parameters for NIR and NSW Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Weld Start R	12.2	14.9	Weld End R	14.1	17.0
Rbore	5.0	6.1	Rnozzle	10.2	12.1
Rbi	2.1	2.3	Rbo	2.6	3.5
Rvi	92.7	103.2	Rvo	97.4	108.6

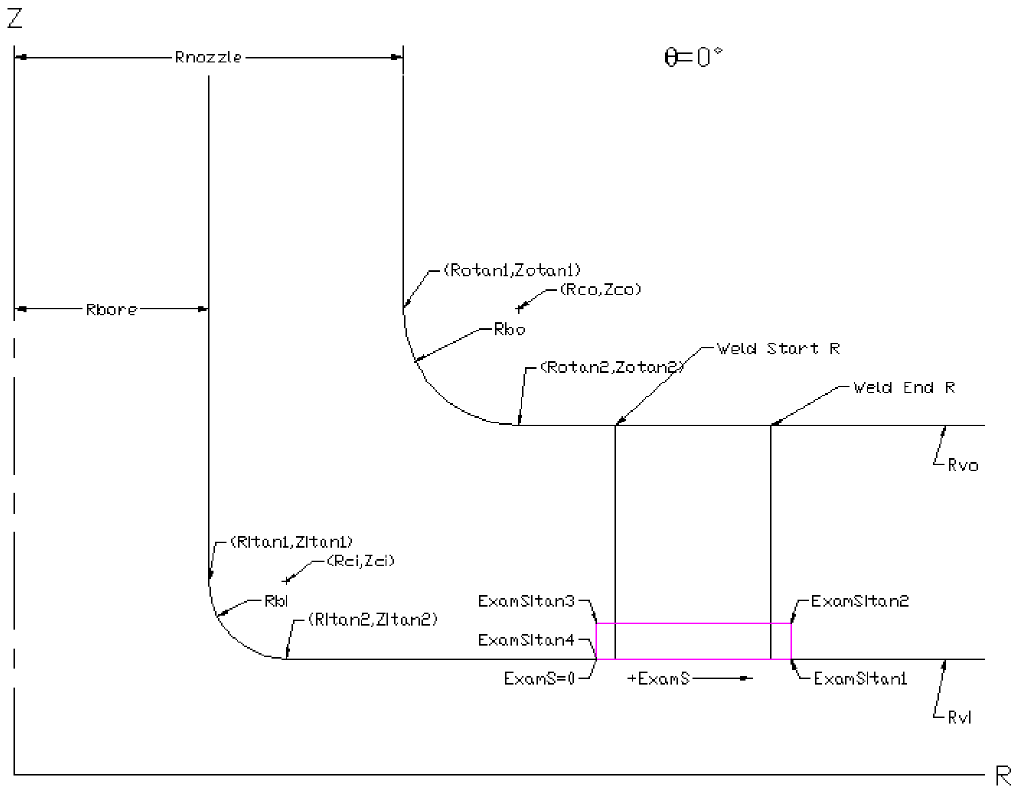

Figure 1 - Cross Section of Nozzle Defining Geometric Parameters for EPRI 3D Models

CRD-HYD system return nozzle

The parameters in Table 2 cover the CRD-HYD system return nozzle inner radius detection and sizing examinations. Figure 1 shows the geometric parameters, which define the CRD-HYD system return nozzle. The parameters in Table 3 cover the CRD-HYD system return nozzle-to-shell weld examinations.

Table 2 - BWR RPV CRD-HYD System Return Nozzle Parameters for NIR Detection and Sizing Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	1.8	2.1	Rnozzle	4.8	5.9
Rbi	1.8	2.9	Rbo	2.3	3.0
Rvi	92.7	110.2	Rvo	97.4	115.9

Table 3 - BWR RPV CRD-HYD System Return Nozzle Parameters for NSW Examinations

Inside Surface Dimensions	Min	Max	Outside Surface Dimensions	Min	Max
Weld Start R	6.4	8.0	Weld End R	8.2	10.1
Rbore	1.8	2.1	Rnozzle	4.8	5.9
Rbi	1.8	2.3	Rbo	2.3	3.0
Rvi	92.7	103.2	Rvo	97.4	108.6

Feedwater nozzle

The parameters in Table 4 cover the feedwater nozzle inner radius detection and sizing examinations as well as the nozzle-to-shell weld examinations. Figure 1 shows the geometric parameters, which define the feedwater nozzle.

Table 4 - BWR RPV Feedwater Nozzle Parameters for NIR and NSW Examinations

Inside Surface Dimensions	(Inches)	Outside Surface Dimensions	(Inches)
Weld Start R	13.1	Weld End R	14.9
Rbore	5.6	Rnozzle	10.6
Rbi	2.1	Rbo	2.8
Rvi	92.7	Rvo	97.4

Re-Machined feedwater nozzle

The parameters in Table 5 cover the re-machined feedwater nozzle inner radius detection and the nozzle-to-shell weld examinations. Figures 1 and 2 show the geometric parameters, which define the re-machined feedwater nozzle.

Table 5 - BWR RPV Re-machined Feedwater Nozzle Parameters for NIR Detection and NSW Examinations

Inside Surface Dimensions	(Inches)	Outside Surface Dimensions	(Inches)/ (Degrees)
Weld Start R	13.8	Weld End R	15.8
Ritan2	6.1	Rnozzle	11.5
Rbi	1.8	Rbo	3.0
Rvi	103.2	Rvo	108.6
Zci	105.7	Taper Angle 4I	60

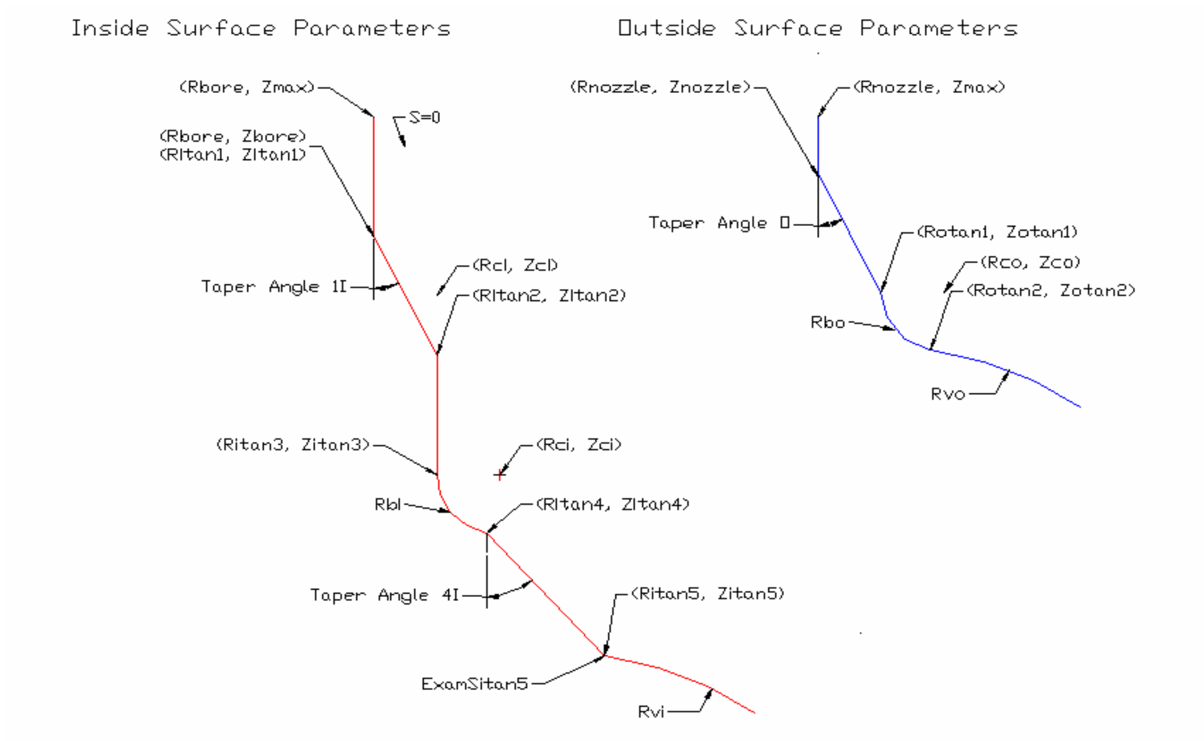

Figure 2 - Cross Section of Re-Machined Feedwater Nozzle Defining Geometric Parameters

Instrumentation nozzle

The parameters in Table 6 cover the instrumentation nozzle inner radius detection and sizing examinations as well as the nozzle-to-shell weld examinations. Figure 1 shows the geometric parameters, which define the instrumentation nozzle.

Table 6 - BWR RPV Instrumentation Nozzle Parameters for NIR and NSW Examinations

Inside Surface Dimensions	**(Inches)**	**Outside Surface Dimensions**	**(Inches)**
Weld Start R	5.4	Weld End R	7.2
Rbore	1.2	Rnozzle	3.5
Rbi	2.1	Rbo	2.5
Rvi	92.7	Rvo	97.4

Jet pump instrumentation nozzle

The parameters in Table 7 cover the jet pump instrumentation nozzle inner radius detection and sizing examinations. Figure 1 shows the geometric parameters, which define the jet pump instrumentation nozzle. The parameters in Table 8 cover the jet pump instrumentation nozzle-to-shell weld examinations.

Table 7 - BWR RPV Jet Pump Instrumentation Nozzle Parameters for NIR Detection and Sizing Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	1.9	2.1	Rnozzle	4.3	5.6
Rbi	2.3	3.3	Rbo	2.5	3.1
Rvi	92.7	109.8	Rvo	97.9	116.0

Table 8 - BWR RPV Jet Pump Instrumentation Nozzle Parameters for NSW Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Weld Start R	6.1	7.8	Weld End R	8.1	9.8
Rbore	2.1	2.1	Rnozzle	4.3	5.6
Rbi	2.3	2.6	Rbo	2.5	3.0
Rvi	92.7	103.2	Rvo	97.9	108.6

Main steam nozzle

The parameters in Table 9 cover the main steam nozzle inner radius detection and sizing examinations. Figure 1 shows the geometric parameters, which define the main steam nozzle. The parameters in Table 10 cover the main steam nozzle-to-shell weld examinations.

Table 9 - BWR RPV Main Steam Nozzle Parameters for NIR Detection and Sizing Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	8.0	11.8	Rnozzle	15.0	19.9
Rbi	2.3	4.8	Rbo	3.1	4.6
Rvi	92.7	120.1	Rvo	97.9	127.8

Table 10 - BWR RPV Main Steam Nozzle Parameters for NSW Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Weld Start R	17.7	20.4	Weld End R	19.7	22.5
Rbore	8.0	9.2	Rnozzle	15.0	16.5
Rbi	2.3	3.9	Rbo	3.1	3.9
Rvi	92.7	103.2	Rvo	97.9	108.6

Recirculation inlet nozzle

The parameters in Table 11 cover the recirculation inlet nozzle inner radius detection and sizing examinations. Figure 1 shows the geometric parameters, which define the recirculation inlet nozzle. The parameters in Table 12 cover the recirculation inlet nozzle-to-shell weld examinations.

Table 11 - BWR RPV Recirculation Inlet Nozzle Parameters for NIR Detection and Sizing Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	5.7	7.1	Rnozzle	10.6	14.1
Rbi	2.3	3.3	Rbo	2.5	3.5
Rvi	92.7	109.8	Rvo	97.9	116.0

Table 12 - BWR RPV Recirculation Inlet Nozzle Parameters for NSW Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Weld Start R	12.4	19.3	Weld End R	14.4	24.3
Rbore	5.7	7.1	Rnozzle	10.6	14.1
Rbi	2.3	3.2	Rbo	2.5	4.0
Rvi	92.7	117.0	Rvo	97.9	124.3

Recirculation outlet nozzle (tapered)

The recirculation outlet nozzle is a tapered nozzle so the dimensions in Table 13 cover the inside and outside surface taper angles and the radial (Rbore and Rnozzle) and axial (Zbore and Znozzle) starting points of the respective tapers (See Figure 3). The parameters in Table 13 cover the recirculation outlet nozzle inner radius detection examinations. The parameters in Table 14 cover the recirculation outlet nozzle inner radius sizing examinations. The parameters in Table 15 cover the recirculation inlet nozzle-to-shell weld examinations.

Table 13 - BWR RPV Recirculation Outlet Nozzle Parameters for NIR Detection Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Inside Taper Angle	15.0	15.0	Outside Taper	14.0	15.0
Rbore	10.1	14.4	Rnozzle	19.3	24.5
Rbi	2.3	2.5	Rbo	4.8	5.3
Rvi	92.7	110.2	Rvo	97.9	116.0

Table 14 - BWR RPV Recirculation Outlet Nozzle Parameters for NIR Sizing Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Inside Taper Angle	15.0	15.0	Outside Taper	14.0	15.0
Rbore	13.1	14.4	Rnozzle	24.4	24.5
Rbi	2.3	2.3	Rbo	5.3	5.3
Rvi	103.2	110.2	Rvo	108.6	116.0

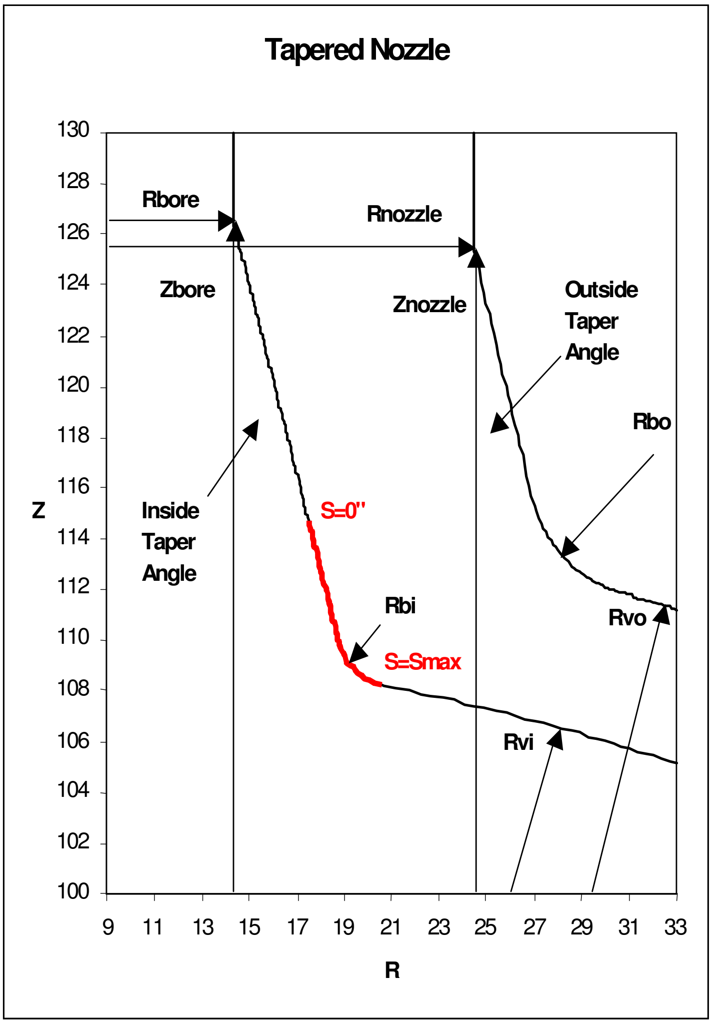

Figure 3 - Cross Section of Recirculation Outlet Nozzle Defining Geometric Parameters

Table 15 - BWR RPV Recirculation Outlet Nozzle Parameters for NSW Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Weld Start R	24.1	30.3	Weld End R	26.2	32.3
Inside Taper Angle	15.0	15.0	Outside Taper Angle	15.0	15.0
Rbore	10.1	13.1	Rnozzle	19.3	24.4
Rbi	2.3	2.5	Rbo	4.8	5.3
Rvi	92.7	103.2	Rvo	97.9	108.6

Standby liquid control nozzle

The parameters in Table 16 cover the standby liquid control nozzle inner radius detection and sizing examinations as well as the nozzle-to-shell weld examinations. Figure 1 shows the geometric parameters, which define the standby liquid control nozzle.

Table 16 - BWR RPV Standby Liquid Control Nozzle Parameters for NIR and NSW Examinations

Inside Surface Dimensions	**(Inches)**	**Outside Surface Dimensions**	**(Inches)**
Weld Start R	5.3	Weld End R	7.4
Rbore	1.2	Rnozzle	3.2
Rbi	0.5	Rbo	3.0
Rvi	103.2	Rvo	108.6

BOILING WATER REACTOR PRESSURE VESSEL HEAD

Head spray nozzle

The head spray nozzle is a “side-hill” nozzle so the dimensions in Table 17 cover the nozzle offset, Xoff (See Figure 4). The parameters in Table 17 cover the head spray nozzle inner radius detection and sizing examinations as well as the nozzle-to-shell weld examinations. Figure 1 shows the geometric parameters, which define the head spray nozzle-to-shell weld.

Table 17 - BWR RPV Head, Head Spray Nozzle Parameters for NIR and NSW Examinations

Inside Surface Dimensions	Min	Max	Outside Surface Dimensions	Min	Max
Weld Start R	5.8	8.4	Weld End R	7.2	9.6
Rbore	2.9	3.1	Rnozzle	4.5	5.6
Rbi	1.8	2.3	Rbo	1.8	2.8
Rvi	92.4	103.2	Rvo	96.4	106.2
Xoff	30.0	36.0			

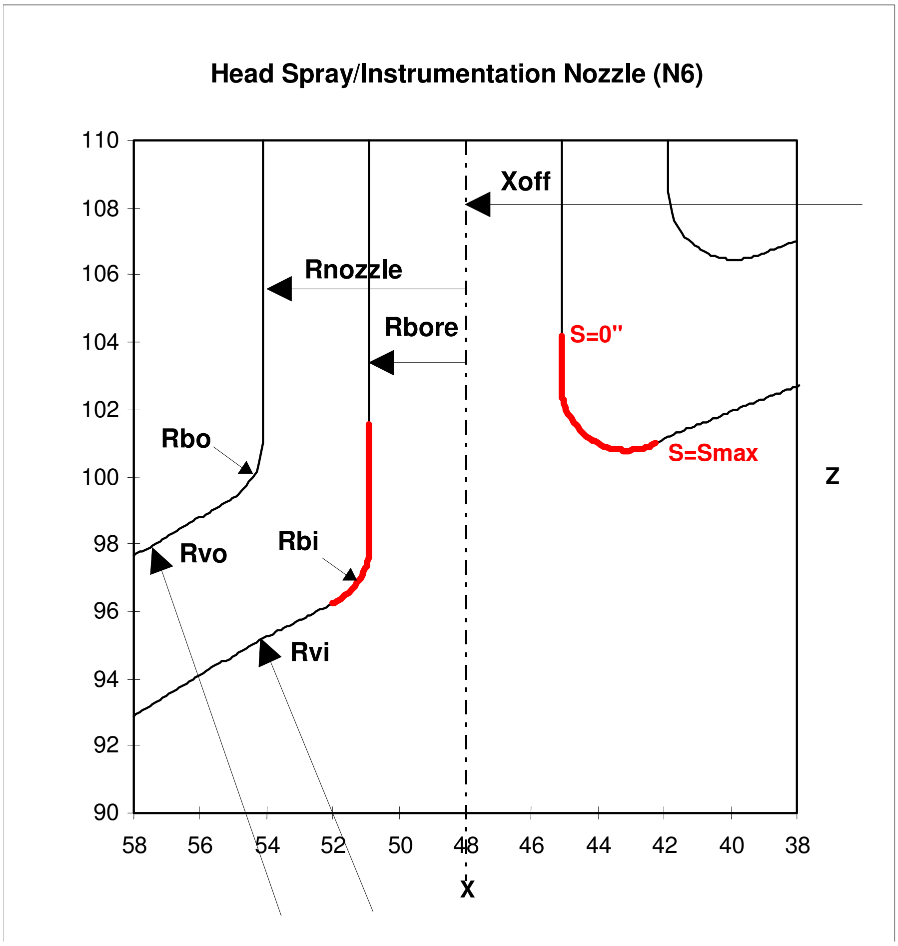

Figure 4 - Cross Section of Head Spray Nozzle Defining Geometric Parameters

Standby liquid control nozzle

The parameters in Table 18 cover the standby liquid control nozzle inner radius detection and sizing examinations. Figure 1 shows the geometric parameters, which define the standby liquid control nozzle-to-shell weld. The parameters in Table 19 cover the standby liquid control nozzle-to-shell weld examinations. Figure 1 shows the geometric parameters, which define the standby liquid control nozzle-to-shell weld.

Table 18 - BWR RPV Head Standby Liquid Control Nozzle Parameters for NIR Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	1.2	1.2	Rnozzle	1.6	3.5
Rbi	0.8	0.8	Rbo	0.8	2.5
Rvi	92.7	125.7	Rvo	97.9	131.9

Table 19 - BWR RPV Head Standby Liquid Control Nozzle Parameters for NSW Examinations

Inside Surface Dimensions	**(Inches)**	**Outside Surface Dimensions**	**(Inches)**
Weld Start R	5.3	Weld End R	7.3
Rbore	1.2	Rnozzle	3.5
Rbi	0.8	Rbo	2.5
Rvi	92.7	Rvo	97.9

Vent nozzle

The parameters in Table 20 cover the vent nozzle inner radius detection and sizing examinations as well as the nozzle-to-shell weld examinations. Figure 1 shows the geometric parameters, which define the vent nozzle.

Table 20 - BWR RPV Head Vent Nozzle Parameters for NIR and NSW Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Weld Start R	4.4	5.8	Weld End R	5.8	7.1
Rbore	1.9	2.1	Rnozzle	3.2	3.8
Rbi	0.8	1.8	Rbo	1.8	2.5
Rvi	92.4	103.2	Rvo	96.4	106.2

PRESSURIZED WATER REACTOR PRESSURIZER

Safety & relief nozzle

Some of the safety & relief nozzles are “side-hill” nozzles so the dimensions for these nozzles in Table 21 cover the nozzle offset, Xoff (See Figure 4). The parameters in Table 21 cover the safety & relief nozzle inner radius detection and sizing examinations.

Table 21 - PWR Pressurizer Safety & Relief Nozzle Parameters for NIR Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	2.8	3.0	Rnozzle	4.0	5.5
Rbi	1.0	1.5	Rbo	1.5	1.5
Rvi	43.0	48.4	Rvo	44.9	52.3
Xoff	0.0	18.5			

Spray nozzle

The parameters in Table 22 cover the spray nozzle inner radius detection and sizing examinations. Figure 1 shows the geometric parameters, which define the spray nozzle.

Table 22 - PWR Pressurizer Spray Nozzle Parameters for NIR Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	2.1	2.3	Rnozzle	4.2	4.5
Rbi	1.0	1.0	Rbo	1.5	1.5
Rvi	43.0	48.4	Rvo	44.9	52.3

Surge nozzle

The parameters in Table 23 cover the surge nozzle inner radius detection and sizing examinations. Figure 1 shows the geometric parameters, which define the surge nozzle.

Table 23 - PWR Pressurizer Surge Nozzle Parameters for NIR Examinations

Inside Surface Dimensions	**Min**	**Max**	**Outside Surface Dimensions**	**Min**	**Max**
Rbore	5.9	6.2	Rnozzle	9.5	10.3
Rbi	1.0	1.0	Rbo	2.0	2.5
Rvi	43.0	48.4	Rvo	45.6	52.3

PRESSURIZED WATER REACTOR REPLACEMENT STEAM GENERATOR

Feedwater nozzle

The parameters in Table 24 cover the feedwater nozzle inner radius detection and sizing examinations as well as the nozzle-to-shell weld examinations. Figure 1 shows the geometric parameters, which define the feedwater nozzle.

Table 24 - PWR Replacement Steam Generator Feedwater Nozzle Parameters for NIR and NSW Examinations

Inside Surface Dimensions	**(Inches)**	**Outside Surface Dimensions**	**(Inches)**
Weld Start R	16.9	Weld End R	17.8
Rbore	7.4	Rnozzle	13.5
Rbi	2.0	Rbo	3.3
Rvi	84.2	Rvo	87.6

DISCUSSION

This paper documents the nozzle geometries that have been examined using the EPRI generic procedure, PDI-UT-11, Revision B, [8]. The full report lists the procedures (EPRI PDI-UT-11, Framatome 54-ISI-850-03, and WesDyne ISI-PDI-210 MD) and the associated nozzle geometry ranges that have been modeled using EPRI 3D models [3]. Utility NDE staff can use the report to evaluate if a qualified UT procedure already exists for the specific nozzle geometry at their site.

REFERENCES

1. ASME Boiler & Pressure Vessel Code, Section XI, Appendix VIII, 1998 Edition with Addenda through 2000 (as modified by the PDI program description and the Federal Register, Part II, Nuclear Regulatory Commission, 10 CFR Part 50, Industry Codes and Standards; Amended Requirements; Final Rule, Dated 26 September 2002), New York, American Society of Mechanical Engineers, 2002
2. ASME Boiler & Pressure Vessel Code, Section XI, Code Case N-552 (Dated 12 December 1995), New York, American Society of Mechanical Engineers, 1995
3. Plant-Specific Applications of Qualified Nozzle Inner Radius and Nozzle-to-Shell Weld UT Procedures Using EPRI Computer Models - 2002-2006 1015152, Palo Alto, EPRI, 2007
4. WARAY3D System for Modeling UT Inspection with Application to BWR Nozzles TR-104603, Palo Alto, EPRI, 1994
5. Computer Modeling of Ultrasonics for ASME XI Appendix VII Applications—Training Notes RPC 6193, Renfrew, Babcock Energy Technology Centre, 1993
6. Ultrasonic Examination of Nozzle Inner Radius Regions TR-107493, Palo Alto, EPRI, 1997
7. Development and Qualification of Generic Nozzle Inside Corner Region Examination Procedure 1009639, Palo Alto, EPRI, 2004
8. PDI Generic Procedure for the Ultrasonic Detection and Sizing of Reactor Pressure Vessel Nozzle-to-Shell Welds and Nozzle Inner Radius, PDI-UT-11, Nondestructive Evaluation: Conventional Nozzle Inner Radius Generic Procedure and Modeling Process (Appendix A) 1013452, Palo Alto, EPRI, 2006
9. Nondestructive Evaluation: Conventional Nozzle Inner Radius Generic Procedure and Modeling Process 1013452, Palo Alto, EPRI, 2006