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Current Status of Ultrasonic Examination Performance Demonstration in Korea

Yongsik KIM[1,*], Byungsik YOON[1,] and Seunghan YANG[1]

[1] *Korea Hydro & Nuclear Power Company Central Research Institute(KHNP-CRI), 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, 305-343, KOREA*

ABSTRACT

The results of ultrasonic testing performed during in-service inspection period for main components of nuclear power plant are affected by the performance of each inspector. To enhance the reliability of inspection, the more restrictive qualification is required. The ASME B&PV code section XI adopted the performance demonstration requirements (Appendix VIII) for the ultrasonic examination of nuclear power plants in the 1989 winter addenda for the first time to enhance the inspection reliability. Korea Hydro & Nuclear Power Co. LTD (KHNP) has developed Korean Performance Demonstration (KPD) system for the ultrasonic examination to apply for pressurized light-water and pressurized heavy-water reactor power plants weld in accordance with ASME code section XI. This paper describes the current status of the ultrasonic examination performance demonstration for nuclear power plant in-service inspection in Korea.

KEYWORDS

Performance Demonstration, Ultrasonic Examination, KPD, ASME B&PV, Appendix VIII, piping welds, reactor vessel, overlay, reactor pressure vessel head penetration

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1. Introduction

NDT is recognized as a vital part of the safe and efficient operations of all kinds of industrial plants and other structures. In the early 1980's, a number of leaks in the pipe systems of boiling water reactors in USA were discovered which had previously been examined ultrasonically and found to be defect free. Efforts to demonstrate the effectiveness of in-service inspection mostly often resulted in demonstrating its' shortcomings. Programs for inspection steel components (PISC) I and II are examples. This led to recognition of need to demonstrate the performance of the inspections used for key components of all nuclear reactors. Performance demonstration (PD) was selected as the most appropriate solution. This scheme requires that particular procedure, equipment and personnel combinations are capable of detecting and sizing flaws of the concern. The ASME Code adopted the performance demonstration in the 1989 addenda of the 1989 Edition for the first time. Since 1990 a large number of major nations operating nuclear power stations have also adopted this approach or are considering some form of the performance demonstration program. KHNP has been developing and implementing performance demonstration system. In this paper, current status of ultrasonic examination performance demonstration in Korea will be discussed.

2. Implementation Schedule

Implementation schedule of PD for each component in Korea was governed by Ministry of Science and Technology (MOST) bulletin 2004-13. Governing rule has been changed from MOST bulletin 2004-13 to Ministry of Education and Science Technology (MEST) bulletin 2008-23, 2009-37 and now Nuclear Safety and Security Commission bulletin 2011-10. Only MOST bulletin 2004-13 addressed implementation schedule. Table 1 shows implementation schedule that was addressed in MOST bulletin 2004-13. For overlaid wrought austenitic piping, there was no overlay in 2006 and 1st overlay in Kori #1 nuclear power plant was done in December 2009. For reactor

*Corresponding author, E-mail: chosim@khnp.co.kr

pressure vessel upper head penetration, it does not have applicable supplement number and it was not addressed in MOST bulletin 2004-13. USNRC 10CFR50.55a dated September 2008 addressed implementation of reactor pressure vessel head penetration PD.

Table 1 Initial implementation schedule in Korea according to MOST bulletin 2004-13

Component Type	Supplement	Schedule
Wrought Austenitic Piping Welds Ferritic Piping Welds Bolts and Studs	2 3 8	2004.7.1
Clad/Base Metal Interface of Reactor Vessel Reactor Vessel Welds other than Clad/Base Metal Interface	4 6	2005.7.1
Overlaid Wrought Austenitic Piping Welds	11	2006.7.1
Nozzle Inside Radius Section Nozzle to Vessel Weld Dissimilar Metal Piping Welds	5 7 10	2006.7.1
Cast Austenitic Piping Welds	9	?

3. KPD Organization

From July 2004 to June 2011, KPD had been administrated by KEPRI(Korea Electric Power Research Institute). After that, KPD has been administrated by KHNP-CRI(Korea & Hydro & Nuclear Power Co.,Ltd-Central Research Institute) by government's nuclear R&D unification policy.

4. PD System in Korea

PD system in Korea is using both KPD system and EPRI system, each administrated by KHNP-CRI and EPRI. For similar piping welds like wrought austenitic and ferritic piping welds, bolts & studs, KPD has had its own system from the beginning. For components related reactor vessels like clad/base metal interface, welds other than clad/metal interface, nozzles inside radius section and nozzles to vessel weld, EPRI PD system is used for qualifying personnel, equipment and procedure instead of KPD system. For overlay, EPRI PD system is also used right now. For qualified personnel, equipment and procedure following EPRI PD system to be applied in the field, they should have received verification certificate issued by KPD organization based on what they had received from EPRI. For dissimilar metal piping welds (DMW), EPRI PD system was used and at the same time, KPD system had been developed at the 1st stage. After developing dissimilar metal weld KPD system in July 2011, DMW performance demonstration test was performed using its own system. Reactor vessel head penetration PD system followed similar steps of DMW PD system. For the time being, EPRI PD system was used for this component and KPD system was developed simultaneously. Reactor vessel head penetration PD system will follow similar steps of DMW PD system. From July 2011 to December 2014, EPRI PD system will be used and also KPD system will be developed simultaneously. After December 2014, the developed KPD system will be applied to reactor vessel head penetration examination. Table 2 shows PD system briefly that is applied in Korea.

Table 2 PD system in Korea

Component Type	**PD System**
Wrought Austenitic Piping Welds Ferritic Piping Welds Bolts and Studs	KPD KPD KPD
Clad/Base Metal Interface of Reactor Vessel Reactor Vessel Welds other than Clad/Base Metal Interface	EPRI EPRI
Overlaid Wrought Austenitic Piping Welds	EPRI
Nozzle Inside Radius Section Nozzle to Vessel Weld Dissimilar Metal Piping Welds	EPRI EPRI KPD
Reactor Pressure Vessel Head Penetration	EPRI→KPD

4.1. Similar metal piping welds and bolts, studs

A series of survey on the configurations of similar piping welds and bolts, studs in nuclear power plant in Korea was performed in order to design and fabricate the test specimens, which were the most important tasks for establishing the KPD system. The components to be surveyed were supplied by Westinghouse, Framatome, CE, and AECL. Centrifugal casting stainless steel piping, which was one of the components of reactor coolant systems in domestic PWR plants, was excluded in this survey because the code requirements were still in the course of preparation.

The specimen matrixes and numbers to be used in the KPD program were decided by the plant survey results, as mentioned above, and satisfied the ASME code, 1995 edition with 1996 addenda. Table 3 and 4 show selected KPD sample dimension that is used during KPD test now. Similar piping specimens have wide crown, counter-bore, ground flush, diameter shrinkage, etc. and cover all the similar piping welds in Korea. Studs and bolts specimens are used for qualifying system like personnel, equipment, and procedure. These personnel, equipment, and procedure should be demonstrated for expansion to apply for other bolts and studs.

Table 3 Similar piping welds specimen dimension

Wrought austenitic piping welds							
Small Category(<0. 5”)				Medium Category (≥0.50” to ≤1.60”)			
Sample ID	OD	SCH	T	Sample ID	OD	SCH	T
30216	2	160	0.344”	31280	12	80	0.688”
30440	4	40	0.337”	32410	24	100	1.5”
30480	4	80	0.337”	31280H	12	80	0.688”
30680	6	80	0.432”	32410H	24	100	1.5”
30480H	4	80	0.337”				
30680H	6	80	0.432”				

Ferritic piping welds											
Small Category(<0. 5”)				Medium Category(≥0.50” to ≤1.60”)				Large Category(>1.60”)			
Sample ID	OD	SCH	T	Sample ID	OD	SCH	T	Sample ID	OD	SCH	T
40280	2	80	0.218”	41280	12	80	0.688”	55040H	50		3.850”
40480	4	80	0.337”	41280H	12	80	0.688”				
40680	6	80	0.432”								
40480H	4	80	0.337”								
40680H	6	80	0.432”								

Table 4 Studs and Bolts

Sample ID	Diameter	Length
901	2.00	16.00
902	4.33	32.87
903	5.82	55.75
904	6.57	73.31

After designing the test specimens, these specimens were fabricated for the performance demonstration. After finishing making specimens, fingerprint for all the specimens was performed to verify that all the specimens had the intended flaws and no other extraneous signal existed. There are 3 generic procedures that can be used for piping and 2 generic procedures for bolts and studs. When KPD was developed, KHNP performed the semi-round robin test. The purpose of semi round robin test was to compare the accuracy difference between PD and DAC method. 6 persons from 3 in-service inspection vendors participated in round robin test. 2 persons from each company were composed of who had more than 100 months experience in field and who had less than 100 months experience. The results are showed below fig.1 and 2. The followings are deduced from this study.

- Comparing results about the length sizing and depth sizing, the PD method is better than the DAC method in general.

- The results from the PD method for the length sizing are very closer to the true value.
- In depth measurement, both methods overestimate the flaw depth for the shallow crack and underestimate the flaw depth for the deep crack comparing to the true depth.

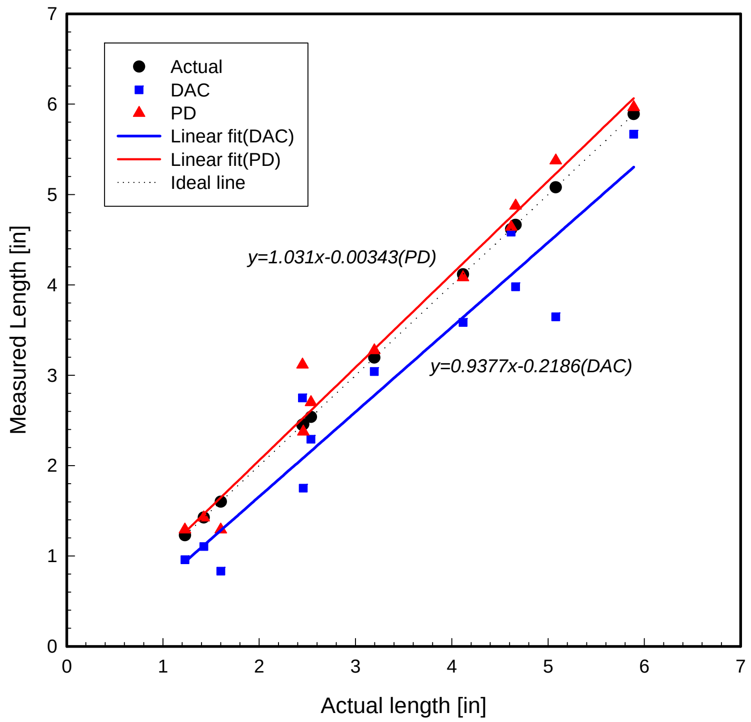


Fig. 1 Length comparison results between dB drop and PD method

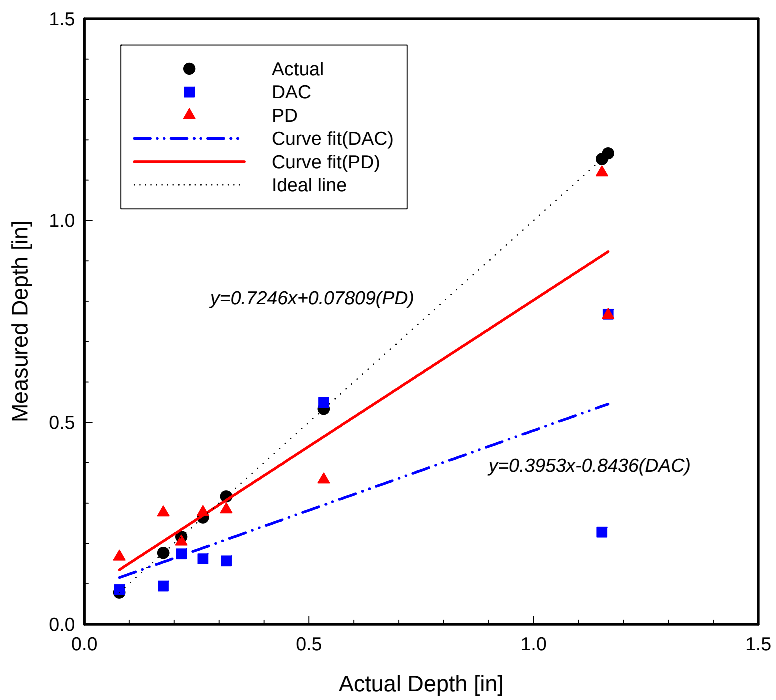


Fig. 2 Depth comparison results between dB drop and PD method

4.2. Reactor vessels and overlay

For components related reactor vessels and overlay, EPRI PD system is used for qualifying personnel, equipment or procedure. Before using it in Korea, inspection companies should receive verification certificate issued by KPD organization based on what they have received from EPRI.

4.3. Dissimilar metal piping welds(DMW)

Due to shortage of preparation, implementation schedule was delayed. Also, it was needed to gather information of field DMW configuration to develop DMW test specimens. Surface condition was very important to inspect DMW. From July 2006 to June 2011, EPRI PD system had been used and during that period, KPD system based on DMW configurations that could be found in Korea had been developed. After June 2011, it has been required to use personnel, equipment and procedures qualified by KPD DMW system for inspection.

During KPD DMW system development, sample design target was to cover all DMW configurations in Korea regardless of PWR and PHWR. Field survey had been done during the in-service inspection period. The specimen matrixes and numbers to be used in the KPD program were decided by the plant survey results and satisfied the ASME code case N-695. Table 5 shows selected KPD sample dimension and that DMW piping specimens have taper, adjacent weld and cladding. Some DMW samples have cast stainless steel nozzle.

Table 5 Dissimilar piping welds specimen dimension

Sample ID	Plant Type	Component System Name	Taper angle	Thickness at CL	Pipe OD
7011	OPR 1000	RCS Charging Inlet	20	1.38	2.2
7012	OPR 1000	RCS Charging Inlet	17	1.37	2.4
7013	OPR 1000	RCS Letdown Drain	15	0.98	2.44
7020	OPR 1000	RCS Spray	16	1.1	3.42
7030	OPR 1000	Pressurizer Spray	21	0.98	4.7
7040	W/F	Pressurizer Spray	6	0.86	4.86
7051	W/F	Pressurizer Safety Relief	6	1.26	6.63
7052	W/F	Pressurizer Safety Relief	9	1.26	6.63
7061	CANDU	Emergency Core Cooling / Shut Down Cooling	N/A	0.84	13
7062	CANDU		N/A	0.45	10.1
7071	OPR 1000	RCS Surge to Hot Leg	7	1.46	12.82
7072	OPR 1000	RCS Surge to Hot Leg	3	2.04	14.1
7073	OPR 1000	Pressurizer Surge	16	1.69	13.5
7074	OPR 1000	Pressurizer Surge	12	1.68	13.5
7080	OPR 1000	RCS Safety Injection	16	1.73	14.25
7090	OPR 1000	RCS Shutdown Cooling Nozzle	N/A	1.78	16.37
7101	OPR 1000	Shutdown Cooling Hx	N/A	0.97	16
7102	OPR 1000	Containment Spray Hx	N/A	0.58	16
7110	W/F	RPV Inlet/Outlet Nozzle	N/A	2.93	34.82
7121	W	Steam Generator Inlet/Outlet	16	4.81	36.3
7122	W	Steam Generator Inlet/Outlet	12	4.81	37.2
S7035	OPR 1000	PZR SDS Nozzle	28	0.84	5.22
S7036 (Nozzle-SE)	W	RPV Safety Injection	N/A	1.22	4.63
S7036 (SE-Pipe)	W	RPV Safety Injection	N/A	0.55	4.63
S7055	OPR 1000	PZR Safety Nozzle	29	2.0	8.5
S7085	W	PZR Surge Nozzle	N/A	1.41	14
S7086	F	PZR Surge Nozzle	N/A	1.41	14
S7116	F	RPV Inlet/Outlet Nozzle	6	3.68	35.06
S7123	W	Steam Generator Inlet/Outlet	13	3.26	37.4
S7124	W	Steam Generator Inlet/Outlet	17	3.26	37.4

S7125	W	Steam Generator Inlet/Outlet	21	3.26	37.4
S7126	W	Steam Generator Inlet/Outlet	16	3.7	37.4
S7127	F	Steam Generator Inlet/Outlet	26	3.04	36.68
S7128	W	Steam Generator Inlet/Outlet	12	3.54	37.4

After designing the test specimens, these specimens were fabricated for the performance demonstration. After manufacturing specimens, fingerprint for all the specimens using phased array ultrasonic inspection was performed to verify that all the specimens had the intended flaws and no other extraneous signal existed.

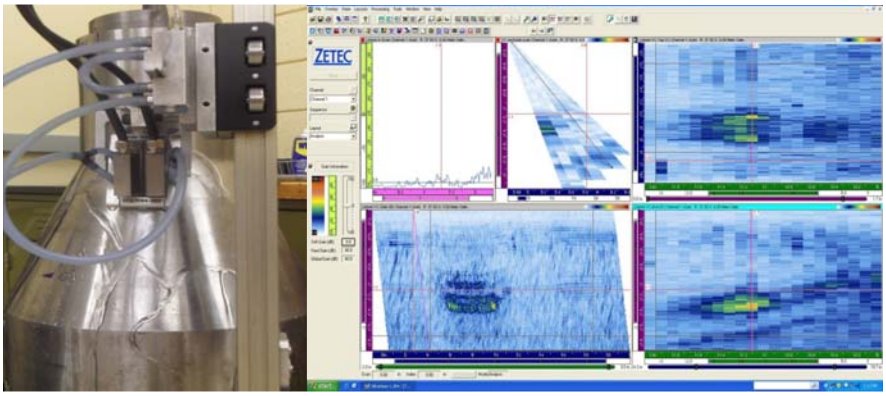
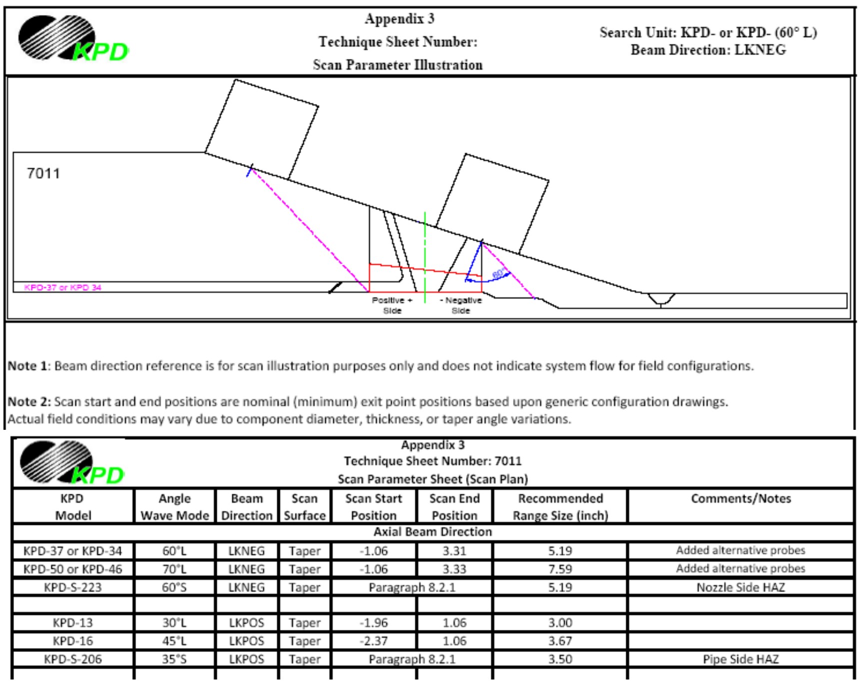


Fig. 3 Finger print by phased array UT

KHNP developed generic inspection procedure for adapting Korean DMW configuration. Procedure includes 3 appendixes. Appendix 1 is for equipment setting, appendix 2 is for selection of probe, and appendix 3 is for scan parameter and selection of search unit. Following figure shows an example of appendix 3.



KPD Model	Angle Wave Mode	Beam Direction	Scan Surface	Scan Start Position	Scan End Position	Recommended Range Size (inch)	Comments/Notes
Axial Beam Direction							
KPD-37 or KPD-34	60°L	LKNEG	Taper	-1.06	3.31	5.19	Added alternative probes
KPD-50 or KPD-46	70°L	LKNEG	Taper	-1.06	3.33	7.59	Added alternative probes
KPD-S-223	60°S	LKNEG	Taper	Paragraph 8.2.1		5.19	Nozzle Side HAZ
KPD-13	30°L	LKPOS	Taper	-1.96	1.06	3.00	
KPD-16	45°L	LKPOS	Taper	-2.37	1.06	3.67	
KPD-S-206	35°S	LKPOS	Taper	Paragraph 8.2.1		3.50	Pipe Side HAZ

Fig. 4 Example of appendix 3

4.4. Reactor pressure vessel upper head penetration

Service experience with the control rod drive mechanism/control element drive mechanism penetrations in PWRs worldwide has confirmed primary water stress corrosion cracking(PWSCC) in Alloy 600 at several plants. The NRC issued several bulletins related to this issue and, in early 2003, imposed further requirements for inspection. The NRC issued Order EA-03-009, requiring utilities to inspect the reactor pressure vessel head penetrations. In March 2006, the American Society of Mechanical Engineers(ASME) Section XI Subcommittee published Code Case N-729-1, which provides alternative examination requirements to Section XI for the examination of the upper head penetrations. This Code Case and the NRC 10 CFR 50.55a rule, dated September 10, 2008, provide requirements to qualify the ultrasonic procedures and personnel for the upper head penetrations and required demonstrated leak path assessment procedures.

KHNP decided to apply reactor pressure vessel upper head performance demonstration according to 10CFR50.55a rule. Korean reactor vessel upper head penetration tube maximum thickness is different from USA fleet. Maximum thickness demonstrated using EPRI PD system is 0.642 in. But maximum thickness of Korean reactor pressure vessel upper head penetration tube is over 1.0 in. So KHNP cannot use EPRI system like reactor vessel PD. Reactor vessel head penetration PD system will follow similar steps of DMW PD system. From July 2011 to December 2014, EPRI PD system will be used and also KPD system will be developed simultaneously. After December 2014, the developed KPD system will be applied to reactor vessel head penetration examination. Now, KHNP have finished designing CRDM performance demonstration test specimens.

4.5. Performance demonstration evaluation criteria

Performance demonstration tests following the ASME Code Section XI Appendix VIII are composed of detection, length sizing and depth sizing. In the detection test, specimens have flawed grading units and unflawed grading units. For the length sizing test of similar and dissimilar metal piping welds PD, the detected flaw must be measured and RMS error should be within 0.75 in. For the depth sizing test, the candidate shall determine the maximum depth of the flaw. The Root Mean Square(RMS) error of the estimated flaw depths should be within 0.125 in.

Flaw depth sizing criteria of RVHP PD are same as piping weld PD. However, flaw length sizing acceptance criteria are different from similar and dissimilar metal weld acceptance criteria. Similar and dissimilar metal weld length sizing criteria are less than 0.75 in. RMS error. CRDM length sizing criteria are less than 0.375 in. RMS error. The RMS error is calculated using the Equation 1.

$$\mathrm{RMS} = \left[\frac{\sum_{i=1}^{n} (m_i - t_i)^2}{n} \right]^{1/2} \qquad \begin{aligned} &\text{where} \\ &m_i = \text{measured flaw size} \\ &t_i = \text{true flaw size} \\ &n = \text{number of flaws measured} \end{aligned} \tag{1}$$

4.6. Administration software

The KPD system adopted sample management software to manage grading unit of the sample and to organize each sample set for testing. This software includes a test set making module and a test set verifying module according to ASME Sec. XI, Appendix VIII. All the samples are divided by many grading units and each grading unit provides flaw information such as flaw length, type, depth and geometric configurations. Each test set has to meet the requirements of ASME Sec. XI, Appendix VIII and has to be made based on grading units. The KPD sample set management module has a function to verify the code requirement, and the program manager can review the verification result and modify the test set. KPD grading software is designed for grading detection, length and through-wall sizing of a flaw. The software grades the demonstration test with code requirements, evaluates the ability of detecting flaws, and calculates the Root Mean Square(RMS) error value of the flaw length and depth. Performance Demonstration Qualification Summary(PDQS) for candidates who passed the test will be issued by the project manager.

5. Implementation status

From April 2004, KPD has done performance demonstration tests in Korea. KHNP performed similar metal weld, bolts, dissimilar metal welds performance demonstration test. Table 6 shows the number of qualified personnel by KPD system up to now.

Table 6 Performance demonstration status of qualified personnel by KPD system

Type of PD	Similar metal welds		Bolts		Dissimilar metal welds	Similar metal weld -AUTO
	Detection	Sizing	Bore	Straight		
Candidate No.	112	43	24	34	19	52

Nuclear Safety and Security Commission bulletin 2011-10 requires qualified personnel to receive annual hands-on practice. All personnel qualified for performing ultrasonic examinations in accordance with Appendix VIII shall receive 8 hours of annual hands-on training on specimens that contain cracks. This training must be completed no earlier than 6 months prior to performing ultrasonic examinations at a licensee's facility. Up to now, over 442 personnel received annual hands-on practice from KPD. Figure 5 shows performance demonstration facility and testing.

Fig. 5 Performance Demonstration Facility and Testing

6. Conclusion

KHNP developed its own ultrasonic examination performance demonstration system (called KPD) for piping welds, studs and bolts according to ASME Section XI, Appendix VIII requirements. Since April 2004, ultrasonic examination performance demonstration test for similar metal welds has been performed for the first time. Performance demonstration tests of the other components also have been performed sequentially. Now, KHNP is developing the reactor pressure vessel upper head penetration PD system according to 10CFR50.55a requirements. Inspector qualified by KPD system only can examine components defined by ASME Section XI, Appendix VIII in Korea. By accomplishing the performance demonstration, improvement of ultrasonic examination reliability, standardization of inspection due to the usage of standard examination procedures, and improvement of the level of examination techniques are expected.

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