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Preliminary PINC(Program for the Inspection of Nickel Alloy Components) RRT(Round Robin Test) - Pressurizer Dissimilar Metal Weld -

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Abstract After several damages by PWSCC were found in the world, USNRC and PNNL(Pacific Northwest National Laboratory) started the research on PWSCC under the project name of PINC. The aim of the project was 1) to fabricate representative NDE mock-ups with flaws to simulate PWSCCs, 2) to identify and quantitatively assess NDE methods for accurately detecting, sizing and characterizing PWSCCs, 3) to document the range of locations and morphologies of PWSCCs and 4) to incorporate results with other results of ongoing PWSCC research programs, as appropriate. Korea nuclear industries have also been participating in the project. Thermally and mechanically cracked-four mockups were prepared and phased array and manual ultrasonic testing(UT) techniques were applied. The results and lessons learned from the preliminary RRT are summarized as follows: 1) Korea RRT teams performed the RRT successfully. 2) Crack detection probability of the participating organizations was an average 87%, 80% and 80% respectively. 3) RMS error of the crack sizing showed comparatively good results. 4) The lessons learned may be helpful to perform the PINC RRT and PSI /ISI in Korea in the future.

Keywords: Round Robin Test(RRT); Program for the Inspection of Nickel Alloy Components(PINC), Dissimilar Metal Weld(DMW), Nondestructive Examination (NDE), Ultrasonic Testing(UT), Primary Water Stress Corrosion Crack(PWSCC)

1. Introduction

During the period of year 1999-2006, PWSCCs were found in alloy 82/132/182 butt welds of PWR plants around the world. On October 7, 2000, a large quantity of boron were identified on the floor and protruding from the air boot around the "A" loop RCS hot leg pipe in VC SUMMER nuclear power plant in U.S.A.. UT, ET(eddy current testing) and VT(visual testing) were applied and identified an axial crack-like indication. The hot leg weld was cut out and destructively tested. The indication was determined to be an axial crack approximately 63.5 mm long and almost through wall which was caused by PWSCC (NRC Information Notice 2000-17).

During in-service inspections of Ringhals 3 in 1990 and Ranghals 4 in 2000 part-depth axial flaws were also found in alloy 182 reactor vessel outlet nozzle to hot leg safe end butt welds (Jenssen et al, 2002). In October 2002, an axial indication was discovered in a pressurizer surge line nozzle to safe-end butt weld at

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Tihange 2 (Thomas et al., 2003).

During an annual inspection in September of 2003, cracking and leakage were discovered on pressurizer safety and relief nozzles in Tsuruga power plant, unit 2 in Japan. All of the flaws found were axially oriented and located in the welds. The flaws did not extend into the base metal. During refueling outage 15 in October 2003, an indication was detected in a surge line nozzle to-safe end dissimilar metal weld at TMI-1. Full structural weld overlay repair using machined TIG welding, temper bead process and alloy 52 filler material was performed to maintain weld integrity (NRC Information Notice 2004-11).

At Wolf Creek in October 2006, three indications were found in the pressurizer surge nozzle-to-safe end weld, and two separate indications were in the safety and relief nozzle-to-safe end welds. These findings paid significant attention on the current inspection schedules and plans. According to the USNRC requirement, the baseline inspection of pressurizer for the same type of nuclear power plant was to be finished by Spring 2008 (USNRC Website).

Many other PWSCCs in addition to the above described were found around the world as well. Thus, USNRC and PNNL started the research on PWSCC under the project name of PINC. The aim of the project was 1) to fabricate representative NDE mock-ups with flaws to simulate PWSCCs, 2) to identify and quantitatively assess NDE methods for accurately detecting, sizing and characterizing PWSCCs, 3) to document the range of locations and morphologies of PWSCCs and 4) to incorporate results with other results of ongoing PWSCC research programs, as appropriate.

For this aim, Korea nuclear industries have also been participating in the project, as requested by USNRC to join the PINC project in May 2005. KINS organized a consortium in March 2006 and Pre RRT for RVHP(reactor vessel head penetration) and DMW was done for the preparation of PINC RRT. Three task groups, morphology Atlas(TG-Atlas) group (task group I), NDE technology assessment(TG-NDE) group (task group II) and data analysis(DA) group (task group III), were organized. For the preliminary DMW RRT, thermally and mechanically cracked-four mockups were prepared and three teams were involved in the round robin NDT. One team utilized phased array UT and other two teams used manual UT for the crack detection and sizing. Preliminary RRT results and lessons learned are discussed in this paper.

2. PINC Project and Participation of Korean Organizations

Morphology Atlas (TG-Atlas) group (task group I) aims 1) to compile existing work on crack morphology of PWSCC, 2) to correlate with NDE data, when available, 3) to develop an electronic Atlas (database) of NDE and metallography information and 4) to perform new NDE, fractography, and metallography. TG-Atlas group provides PINC members PWSCC/ NDE database. KINS, KPS(Korea Plant Service and Engineering) and KAERI(Korea Atomic Energy Research Institute) participated in this group. KPS supported three BMI(bottom mounted instrumentation) mock-ups and one of three mock-ups was used in the destructive test. KAERI fabricated BMI nozzles with autoclave and PWSCCs in BMI mockups. The cracked BMI nozzles were supplied for the PINC mock-ups.

NDE technology assessment(TG-NDE) group (task group II) aims 1) to perform round robin test(RRT) of NDE techniques on PWSCC and simulated cracks, 2) to apply techniques to detect and size cracks, 3) to assess techniques to manufacture test blocks, 4) to survey relevant materials and geometries, and 5) to integrate findings of regulatory application and process qualification. Currently, U.S.A., Japan, Europe and Korea have mockups of DMW, RVHP and BMI for RRT. Three organizations were involved in the preliminary RRT using four mockups.

Data analysis group(DAG) (task group III) aims 1) to analyze the procedures, 2) to analyze and characterize the flaws and 3) perform the regression analysis. All organizations were involved in DAG. Fig. 1 shows the DMW RRT schedule.

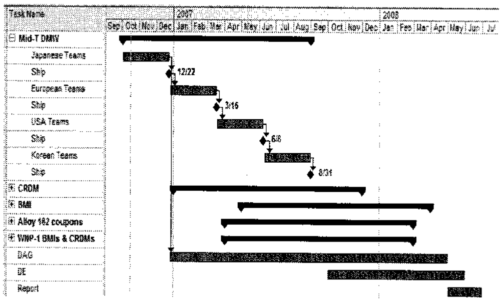


Fig. 1 PINC DMW RRT schedule

3. Preliminary RRT Teams and Mockups

Preliminary RRT was performed using four mockups and three Teams (one team for phased array UT technique and other two teams for manual UT) participated in the RRT as shown in Table 1 and Fig. 2. Details of crack information of each mockup are shown in Table 2 through 5.

Table 1 Preliminary RRT mockups and orientation of cracks

	Type	Owner	Indication
Mock up #1	crack	Doosan	Axial 2, Cir 4
Mock up #2	crack	Doosan	Axial 3, Cir 5
Mock up #3	M.F.	KPS	Cir 4
Mock up #4	T.F, M.F, Branch	Kaitec	Cir 12

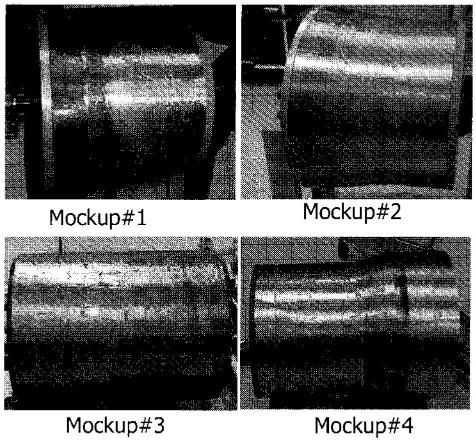


Fig. 2 Photo of Pre RRT mockups

Table 2 Crack information of mockup #1

Flaw No.	Orientation	Flaw Type	UP/DN	ID Length (Inch)	Height (%)
1	Circ.	Crack	DN	2.905	72.00%
2	Axial	Crack	UP	0.84	18.00%
3	Axial	Crack	DN	1.07	25.00%
4	Circ.	Crack	UP	3.21	65.00%
5	Circ.	Crack	UP	2.51	45.00%
6	Circ.	Crack	UP	1.86	35.00%

Table 3 Crack information of mockup #2

Flaw No.	Orientation	Flaw Type	UP/DN	ID Length (Inch)	Height (%)
1	Axial	Crack	UP	1.278	20.00%
2	Circ.	Crack	UP	3.977	69.00%
3	Axial	Crack	UP	0.861	15.00%
4	Circ.	Crack	UP	1.771	27.00%
5	Circ.	Crack	UP	2.992	50.00%
6	Circ.	Crack	UP	2.56	40.00%
7	Circ.	Crack	UP	2.047	34.00%
8	Axial	Crack	UP	1.17	14.00%

Table 4 Crack informtion of mockup #3

Flaw No.	Orientation	Flaw Type	ID Length (Inch)	Height (%)	Flaw C/L Deg.	TILT°	SKEW°	Geometry
1	Circ.	M.F.	.387	7.3%-.095	24.90°	0°	0°	FLUSH CAP
2	Circ.	M.F.	.498	10.9%-.146	129.80°	0°	0°	FLUSH CAP
3	Circ.	M.F.	.743	19.6%-.255	219.90°	0°	0°	FLUSH CAP
4	Circ.	M.F.	.517	10.4%-/136	289.80°	0°	0°	FLUSH CAP

Table 5 Crack information of mockup #4

Flaw No.	Orientation	Flaw Type	UP/DN	ID Length (Inch)	Height (%)
1	Circ.	T.F.	UP	0.793	19.65%
2	Circ.	T.F.	UP	0.877	28.20%
3	Circ.	BRANCH	UP	1.73	59.60%
4	Circ.	M.F	DN	1.405	48.90%
5	Circ.	T.F	UP	0.488	10.80%
6	Circ.	T.F	UP	0.354	10.00%
7	Circ.	M.F	DN	0.99	35.40%
8	Circ.	BRANCH	UP	1.32	46.40%
9	Circ.	M.F	UP	0.851	25.30%
10	Circ.	T.F	UP	0.51	18340%
11	Circ.	M.F	DN	1.445	48.00%
12	Circ.	T.F	UP	0.948	31.50%

4. RRT Results and Discussion

The result of detection for mockup #1 is shown in Table 6. As Table 6 shows, two teams did not find axial ID crack which was below 1 inch in length and 18% height in buttering region. The reason for the difficulty in the detection of defects #1 and #2 is demonstrated in Fig. 3.

Table 6 Detection result of mockup #1

Flaw		Company		
#	Type	A	B	C
1-1	Circ	○	○	X
1-2	Axial	○	X	X
1-3	Axial	○	○	○
1-4	Circ	○	X	○
1-5	Circ	○	X	○
1-6	Circ	○	X	○

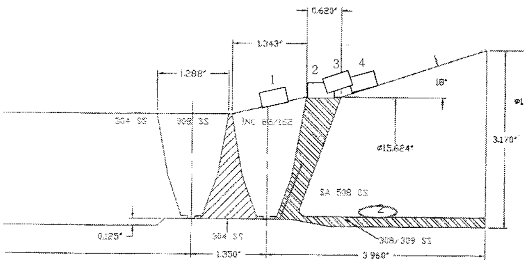


Fig. 3 The drawing of mockup #1

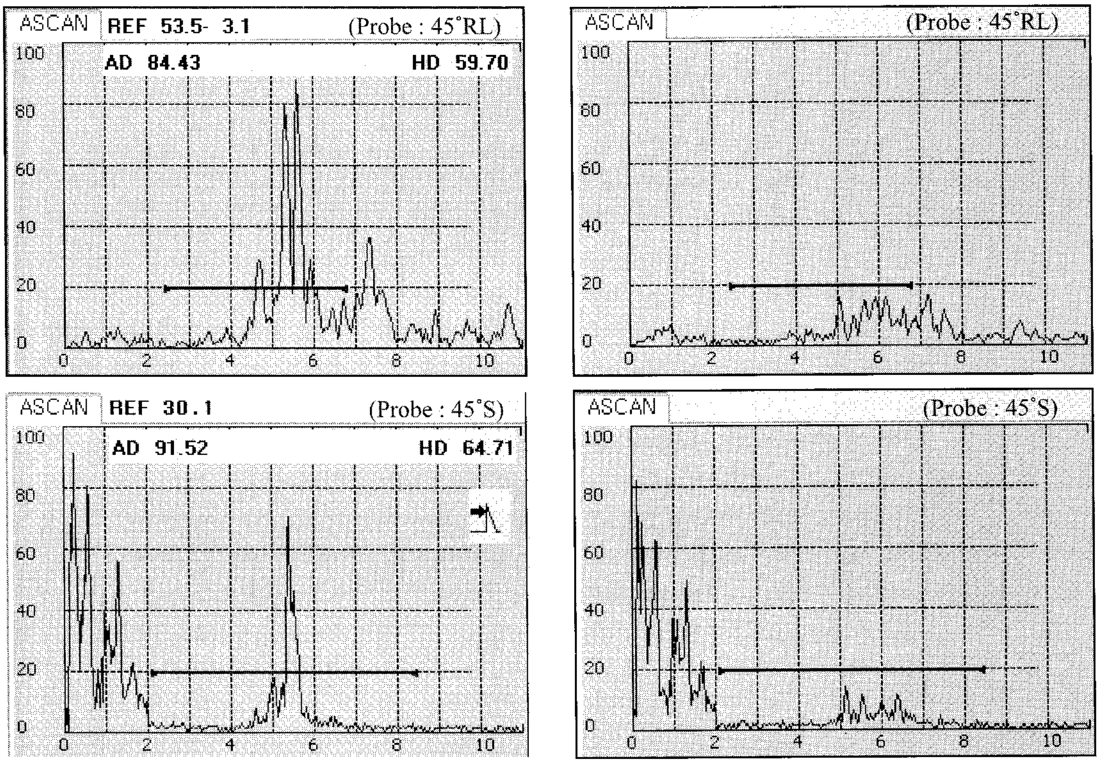


Fig. 4 The back echo signal from defect #1-2

If the transducer was located at 1, 2 or 4, defects #1-1 and 1-2 could be easily detected. It is important to keep in contact with the transducer properly during inspection. One solution would be proper application of couplant to occupy the examination space. Two teams had difficulties in examining because of the tilted surface and in-proper application of couplant. Fig. 4 shows the echo signals from defect #1-2, of which left one defected and right one from the area of non-defect. B team could not detect defects #1-3, 4 and 5. It was simply because the signal from boundary layer between weld and buttering was not separated well.

Table 7 demonstrates the results of detection for mockup #2. Fig. 5 shows the drawing of mockup #2. Two teams could not find axial ID crack below 1 inch in length and heights of 14%, 15%, and 20% respectively in alloy 82/182 weld metal.

The cracks #2-1, #2-3 and #2-8, which were axial in the weld center and buttering area, could not be detected by two teams. The skew of each defect was 90°. The cracks were evaluated as ci

Table 7 Detection result of mockup #2

Flaw		Company		
#	Type	A	B	C
2-1	Axial	○	X	X
2-2	Circ	○	○	○
2-3	Axial	○	X	X
2-4	Circ	○	○	○
2-5	Circ	○	○	○
2-6	Circ	○	○	○
2-7	Circ	○	○	○
2-8	Axial	○	X	X

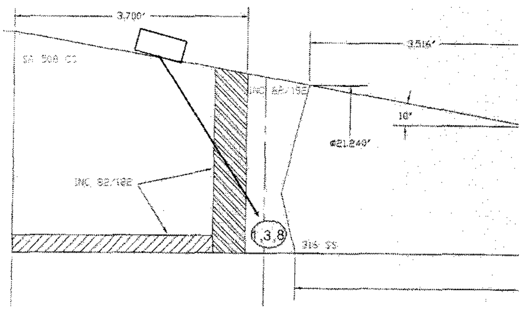
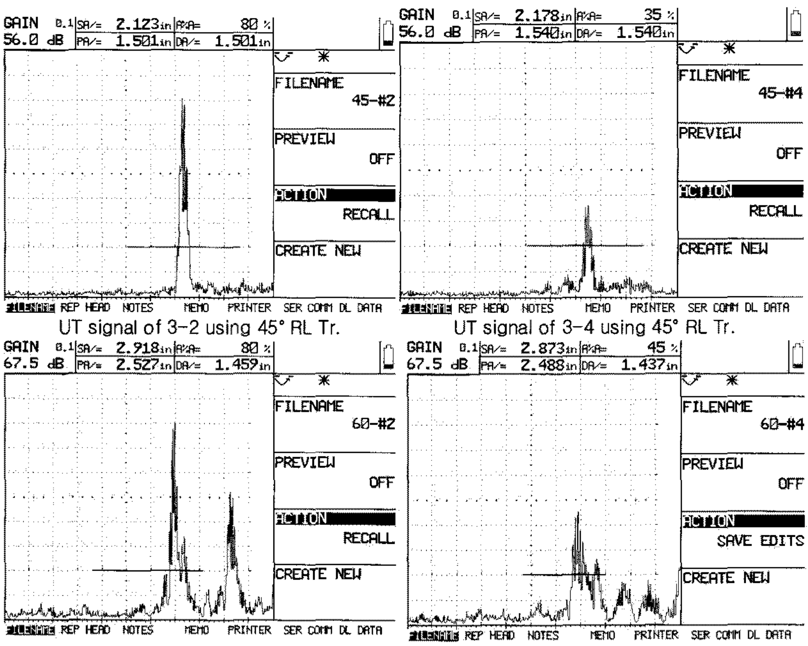


Fig. 5 The drawing of mockup #2



UT signal of 3-2 using 45° RL Tr.
UT signal of 3-4 using 45° RL Tr.
UT signal of 3-2 using 60° RL Tr.
UT signal of 3-4 using 60° RL Tr.

Fig. 6 The comparison between back echo signals and cracks #3-2 and #3-4 rcumferential by one team. The depths of these cracks were shallow (20%, 15%, and 14%, respectively) and the some parts of cracks were located in the buttering area. Thus, various signals from crack, root, weld and buttering were generated, which resulted in poor resolution and evaluation of axial cracks as circumferential. One team could not detect the crack due to the contact problem of using a big size transducer.

Table 8 shows the results of detection for mockup #3. Two teams could not find circumferential ID cracks below 12.7 mm in length and 7.3% and 10.4% of heights in buttering area of alloy 82/182. Three teams found crack # 3-2 of 10.9% height. Fig. 6 demonstrates the comparison of back echo signals of cracks #3-2 and 3-4. Cracks #3-1, #3-2, #3-3 and #3-4 were located in the inner part of buttering and cracks #3-2 and #3-3 were in the center of buttering. Crack #3-1 (9.83 mm in length and 2.44 mm in height) and #3-4 (12.95 mm in length and 3.45 mm in height) were very small and close to the weld root, which resulted in poor resolution and evaluation for the detection.

Table 9 shows the result of detection for mockup #4. Three teams could not find circumferential ID cracks below 8.89 mm in length and 10% height in buttering area of alloy 182. Three teams found crack #4-5 of 10.8% height. Fig. 7 demonstrates the comparison of back echo signals of cracks #4-5 and 4-6. Cracks #4-5 (11.51 mm and 10.8% depth), and #4-6 (8.99 mm and 10% depth) showed similar size (crack #4-6 is 2.54 mm smaller) but were located in different locations (weld and cladding respectively). Each team found crack #4-5 but could not find #4-6, which meant that 2.54 mm difference in length and location were of great significance in terms of detection.

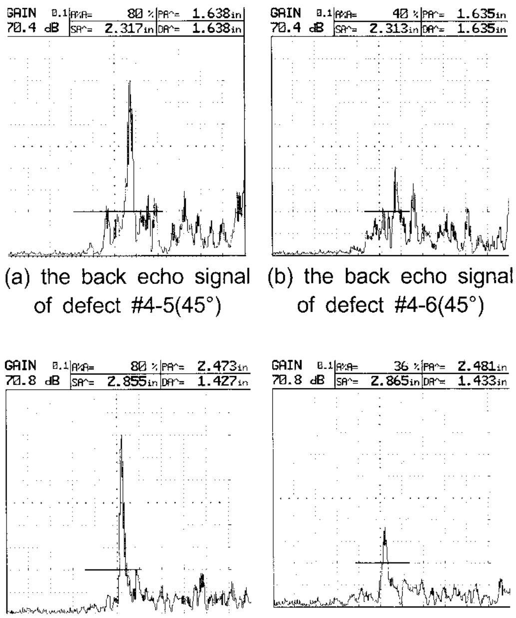
Preliminary RRT results for detection is summarized in Table 10. As Table 10 demonstrates, crack detection probability of team A was average 87% (84% of circumferential

Table 8 Detection result of mockup #3

Flaw		Company		
#	Type	A	B	C
3-1	Circ	X	X	○
3-2	Circ	○	○	○
3-3	Circ	○	○	○
3-4	Circ	X	○	X

Table 9 Detection result of mockup #4

Flaw		Company		
#	Type	A	B	C
4-1	Circ	○	○	○
4-2	Circ	○	○	○
4-3	Circ	○	○	○
4-4	Circ	○	○	○
4-5	Circ	○	○	○
4-6	Circ	X	X	X
4-7	Circ	○	○	○
4-8	Circ	○	○	○
4-9	Circ	○	○	○
4-10	Circ	X	○	○
4-11	Circ	○	○	○
4-12	Circ	○	○	○



(a) the back echo signal of defect #4-5(45°)
(b) the back echo signal of defect #4-6(45°)
(c) the back echo signal of defect #4-5(60°)
(d) the back echo signal of defect #4-6(60°)

Fig. 7 The comparison the back echo signal of cracks #4-5 and #4-6 cracks and 100% of axial cracks), team B was average 80% (80% circumferential cracks and axial cracks, respectively) and team C was average 80%(88% circumferential cracks and 40% of axial cracks).

Preliminary RRT results for sizing is summarized in Table 11. Current criteria for sizing of ASME Code Sec.XI, Appendix VIII is 19.05 mm in length RMS and 3.18 mm in depth RMS. For length sizing, team A and C showed comparatively excellent. For depth sizing, A team was excellent result. When considered there were not any examiners for depth sizing manually in U.S.A., the examination result of A team was believed to be just excellent.

5. Lessons Learned

Lessons learned from the RRT can be discussed as follows:

1. It was difficult to detect small ID cracks (about 10% height) in the tapered part.
2. It was required to have sketches of accurate mockup configurations for the evaluation and analysis of cracks. It was also required to understand the ultrasonic characteristics (depth of field, mixing of signals with S-/L-waves in dual element transducer etc.) to identify signals in the screen.
3. It was required to develop specially designed transducers to cover whole range of examination areas. The gap between transducer and mockup surface was sometimes problem for the ultrasonic energy transmission.

6. Conclusions

Based on the qualitative examination, the followings were concluded.

1) Korea RRT teams performed the RRT successfully.
2) Crack detection probability of three teams wasd average 87%, 80% and 80%, respectively.
3) RMS error of the crack sizing showed comparatively good results. One team showed very good results when compared to the results of EPRI.
4) The lessons learned may be helpful to pefrorm the PINC RRT and PSI / ISI in Korea in the future.

Table 10 Summary of preliminary RRT result for detection

	Team A				Team B				Team C			
	Detection	Total No.	Detection	Miss	Detection	Total No.	Detection	Miss	Detection	Total No.	Detection	Miss
시편 #1	Circ. Flaw	4	4	0	Circ. Flaw	4	1	3	Circ. Flaw	4	3	1
	Axial Flaw	2	2	0	Axial Flaw	2	1	1	Axial Flaw	2	1	1
시편 #2	Circ. Falw	5	5	0	Circ. Falw	5	5	0	Circ. Falw	5	5	0
	Axial Flaw	3	3	0	Axial Flaw	3	0	3	Axial Flaw	3	1	2
시편 #3	Circ. Falw	4	2	2	Circ. Falw	4	3	1	Circ. Falw	4	3	1
	Axial Flaw	0	0	0	Axial Flaw	0	0	0	Axial Flaw	0	0	0
시편 #4	Circ. Falw	12	10	2	Circ. Falw	12	11	1	Circ. Falw	12	11	1
	Axial Flaw	0	0	0	Axial Flaw	0	0	0	Axial Flaw	0	0	0
Total	Circ. Falw	25	21	4	Circ. Falw	25	20	5	Circ. Falw	25	22	3
	Axial Flaw	5	5	0	Axial Flaw	5	1	4	Axial Flaw	5	2	3
	Sum	30	26	4	Sum	30	21	9	Sum	30	24	6

Table 11 Summary of preliminary RRT result for sizing

	Team A				Team B				Team C			
	Length RMS(in)		Depth RMS(in)		Length RMS(in)		Depth RMS(in)		Length RMS(in)		Depth RMS(in)	
	Circ. Flaw	Axial Flaw	Circ. Flaw	Axial Flaw	Circ. Flaw	Axial Flaw	Circ. Flaw	Axial Flaw	Circ. Flaw	Axial Flaw	Circ. Flaw	Axial Flaw
시편 #1	0.44	1.52	0.04	0.12	0.20.56	0.03	**1.05**		0.63	1.07	**0.43**	0.02
시편 #2	0.53	0.12	**0.15**	0.13	**1.01**		**0.40**		0.44	1.17	**0.53**	0.04
시편 #3	**2.53**		0.09		**5.72**		**0.17**		**2.59**		**0.15**	
시편 #4	0.27		0.08		0.24		**0.31**		0.39		**0.14**	

Acknowledgments

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