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FEASIBILITY STUDY OF ULTRASONIC TESTING FROM OUTSIDE OF RPV TO NICKEL BASED ALLOY MATERIAL WELDS

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ABSTRACT

In order to validate capabilities of ultrasonic testing (hereinafter, UT) from outside surfaces of reactor pressure vessel (RPV) (ex-vessel UT) to detect cracks and determine the cracks size, Hamaoka nuclear power station unit 1 (Hamaoka unit-1) owned by Chubu Electric Power Co., Inc., which is under decommissioning work was selected to be used as a validation plant for ex-vessel UT since there were some cracks found on the nickel based alloy material welds of shroud support plate to RPV and of shroud support plate leg to RPV, and in the future the capabilities of the ex-vessel UT will be evaluated by comparing with direct measurement results of the crack samples taken out from the plant. Examination procedures of ex-vessel UT for those welds in Hamaoka unit-1 were established separately by two Japanese RPV suppliers and each company performed ex-vessel UT to the weld of shroud support plate and shroud support leg jointing to RPV by their own procedures. In the validation test, the results of crack sizing showed large differences between two companies. However, the differences could become smaller by conforming relative UT parameters of two companies to each other.

It was assumed that the reasons to cause the differences were due to differences of detectability on actual field work, beam orientation and angle, beam frequencies, automatic or encoded manual ultrasonic examinations (EMUT) of scanning and decision criteria of boundary between low alloy steel (RPV) and buildup welds. The reason for the discrepancy in the crack sizing results would be clarified in the evaluation by comparing with direct measurement results of the crack samples.

Keywords: ultrasonic testing, welds of nickel based alloy material, outside of RPV

INTRODUCTION

BWR plants which are licensed to conform to the new regulatory requirements will re-start sequentially in Japan. After the restart, in-vessel visual inspections will be performed to welds of nickel based alloy material, e.g. lower bottom portions of RPV and shroud support in long term operational plants in order to ensure maintenance of these component's structural integrity in accordance with JANSI[1] Guidelines for Inspection and Evaluation of Reactor Vessel Internals. If a crack is found, additional inspection should be performed in order to confirm that the crack does not reach to RPV base material (low alloy steel) and to determine the crack size. Ex-vessel UT is preferable since it is able to be performed minimizing impact to outage schedule. However, in case of applying UT for nickel based alloy material weld, it is basically difficult to detect a crack and to determine the crack size. Moreover, there are only a few experiences evaluating applicability of ex-vessel UT for in-service nuclear power plants from the viewpoint of detecting and sizing the crack. For these reasons, validation of ex-vessel UT needs to be performed.

Therefore, it was planned that ex-vessel UT for the nickel based alloy material welds of shroud support plate to RPV and of shroud support plate leg to RPV in Hamaoka unit-1 in which there were some cracks found on the welds, would be validated from the viewpoint of detecting and sizing the crack. The plan is as follows; (1) to perform ex-vessel UT for the cracks in those welds in Hamaoka unit-1 (2) to perform direct measurement survey by sampling the cracks, (3) to validate procedures of ex-vessel UT by comparing the results. So far, the ex-vessel UT was performed by two Japanese RPV suppliers separately in Hamaoka unit-1. Waiting for progresses of Hamaoka unit-1 decommissioning work, the procedures of ex-vessel UT will be validated in several years. Therefore, in order to make the ex-vessel UT more reliable and to establish a future plan of crack sampling, the results of the ex-vessel UT by two companies were compared.

Note 1: JANSI: Japan Nuclear Safety Institute

PROCEDURE FOR EX-VESSEL UT

Flaws to be measured

The orientations and positions of the cracks found by in-vessel visual test in the welds of shroud support in Hamaoka unit-1 are shown in figure 1 to 3. There are 15 cracks found from 15 degrees to 90 degrees and from 270 degrees to 340 degrees in the weld between shroud support plate and RPV (H9 weld joint), and 2 cracks found in the weld between shroud support leg and RPV (H11 weld joint) located in 216 degrees. These cracks were target flaws for ex-vessel UT. To prevent two companies from scanning different cracks, the locations of the cracks were marked on the outer surfaces of RPV and the same definition of reference position and coordinate were applied for scanning by two companies. The location marking of a crack is shown in figure 4.

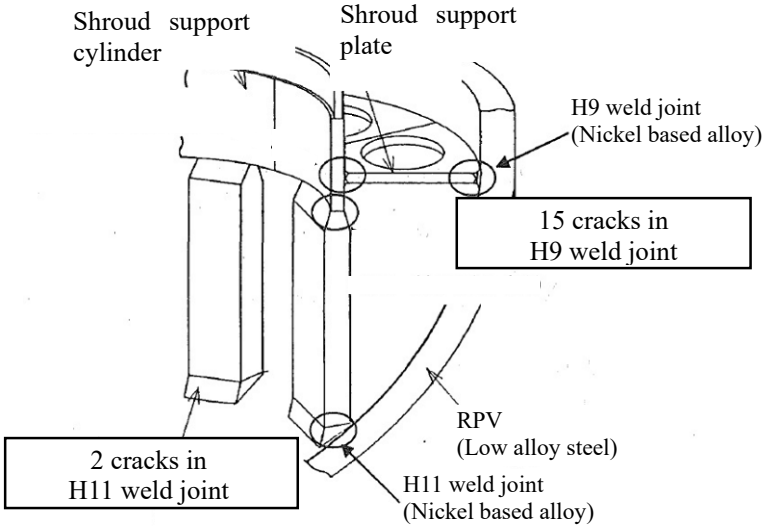


Figure 1. Cracks found in shroud support welds in Hamaoka unit-1

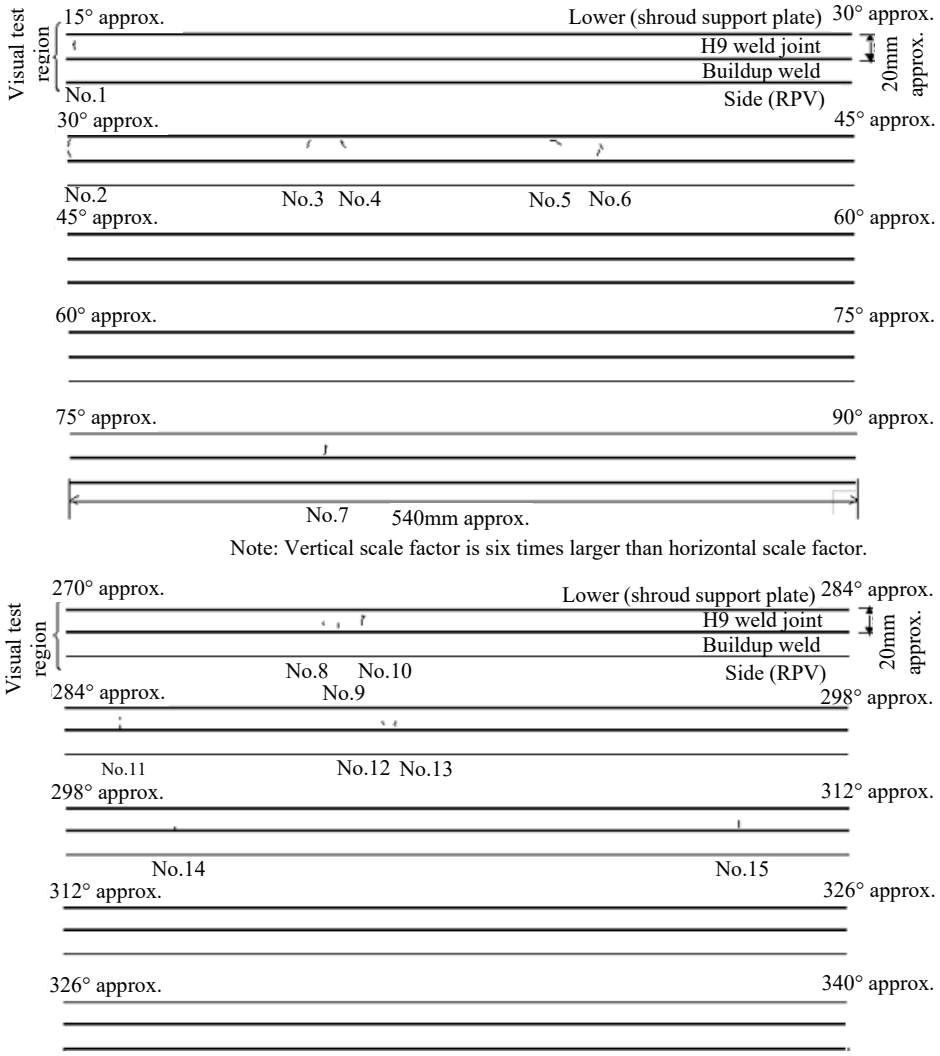


Figure 2. Positions of cracks in H9 weld joint
(15 cracks: No.1~No.15)

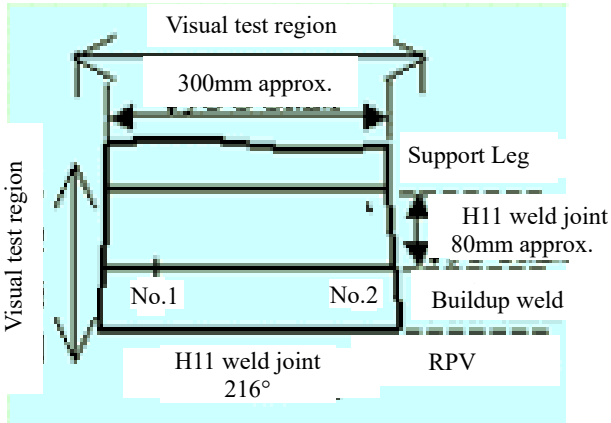


Figure 3. Positions of cracks in H11 weld joint

Procedure for UT

The procedures of ex-vessel UT followed JEAC4207-2008 including 2012 addenda and were reviewed by UT experts in CRIEPI[2] from the viewpoint that they specified mandatory items required by the code. CRIEPI did not assure if the contents of the detail procedures were appropriate or not.

Note 2: CRIEPI: The Central Research Institute of Electric Power Industry

Flaw dimensions to be evaluated

Flaw dimensions to be evaluated in ex-vessel UT; dimension-A and B are shown in figure-5. Dimension-A is length of a crack viewed from outside of the vessel and dimension-B is distance between the deepest point of a crack and boundary of nickel based alloy build up weld and RPV base material.

Table 1: Summaries of procedures of ex-vessel UT

Item	Company α	Company β
Flaw detector	Phased array instrument	
Probe	PAUT probe - Composite type - Used in combination with a wedge - Without extension cables	
Scanning device	Encoded Manual	Automatic
Contact medium	Glycerin paste	

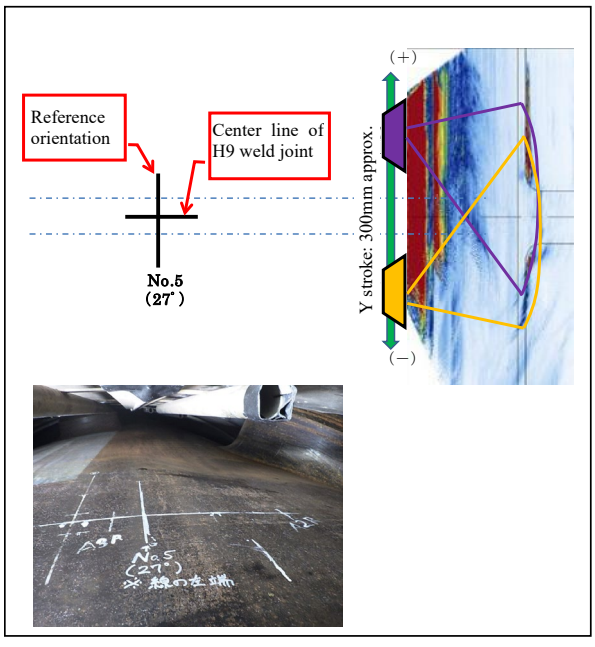
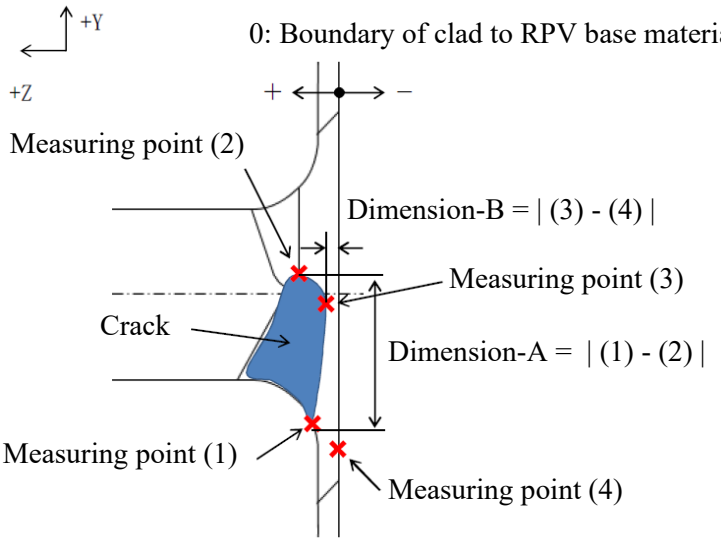


Figure 4. Making of the center line of H9 weld joint



Measuring point	Definition
(1)	Deepest point of flaw propagating to – Y
(2)	Deepest point of flaw propagating to + Y
(3)	Deepest point of flaw propagating to – Z
(4)	Average point of boundary of cladding

Figure 5. Definitions of measurement points for a crack
(e.g. H9 weld, longitudinal crack)

RESULTS AND DISCUSSION

Results of crack detection

Two companies detected the cracks as to be in almost same positions by ex-vessel UT. In H9 weld joint, UT indications were detected in the near area of 14 cracks (except for No.14 crack in Figure-2) out of 15 cracks observed in-vessel visual test. In H11 weld joint, UT indication was detected in the near area of 1 crack (No.2 crack in Figure-3) out of 2 cracks observed in-vessel visual test.

Results of crack detection

Results of crack sizing by two companies which were obtained by ex-vessel UT with the company internal basic definitions of a crack indication in each procedure are shown in Table-2. Some of the results are largely different between two companies. Note that it was confirmed that no cracks reached to the boundary of RPV base material.

Table 2: Sizing results of cracks
(evaluated with each company internal basic definition of crack indication)

Unit: mm

		Company-α		Company-β		Differences	
		Basic definition		Basic definition		between α and β	
Crack No.		A	B	A	B	A	B
H9 weld	1	41.0	8.1	17.2	12.0	23.8	3.9
joint	2	46.0	3.1	40.4	10.1	5.6	7.0
	3	44.0	3.3	29.5	9.5	14.5	6.2
	4	52.0	1.1	48.0	11.6	4.0	10.5
	5	55.0	3.5	38.2	11.5	16.8	8.0
	6	63.0	0.2	48.3	6.3	14.7	6.1
	7	48.0	3.9	39.5	8.6	8.5	4.7
	8	46.0	6.9	36.6	10.5	9.4	3.6
	9	54.0	6.2	38.0	10.1	16.0	3.9
	10	49.0	5.3	35.1	7.3	13.9	2.0
	11	49.0	6.7	41.6	9.1	7.4	2.4
	12	41.0	5.5	33.8	9.3	7.2	3.8
	13	36.0	7.9	31.2	11.5	4.8	3.6
	14	-	-	-	-	-	-
	15	48.0	7.9	35.8	11.3	12.2	3.4
H11 weld	1	40.0	27.3	20.2	39.7	19.8	12.4
joint	2	-		-		-	-

As a sample of scanning image, images of crack No.2 in H9 weld joint are shown in Figure-6. Scanning images are built up by merging ex-vessel UT data obtained at several probe positions in accordance with each examination procedure of the two companies. The merged data are displayed in the top and two side views (C-, B- and D-scopes), and the sectorial image and A-scope waveform are also used to confirm the crack tip. Dimension-A evaluated with each company internal basic definition of a crack indication (measuring point (1) and point (2)) was obtained by measuring echo length on the merged image. The crack tip (measuring point (3)) was evaluated on the merged image. The detail dimensions were evaluated based on the base data (the sectorial image and A-scope). The boundary of clad (measuring point (4)) was evaluated by using vertical element of sector scanning in area of the crack tip. Each intersection point of cursor lines (red, blue and green) in D-scope indicates each measuring point.

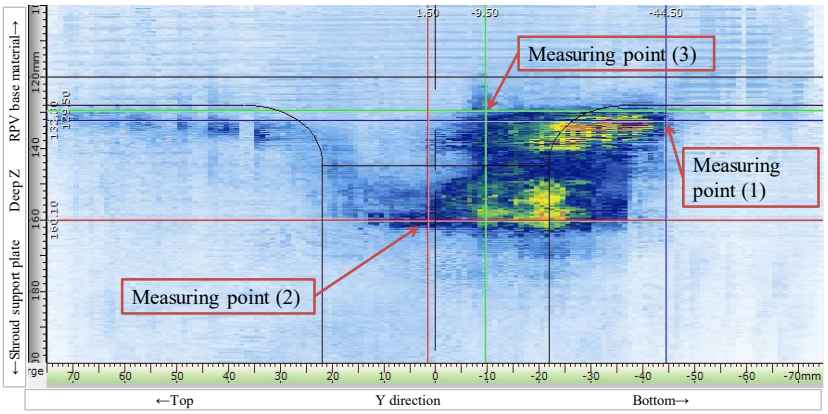


Figure 6 (1). A sample of scanning image
(H9 weld joint, company-α)

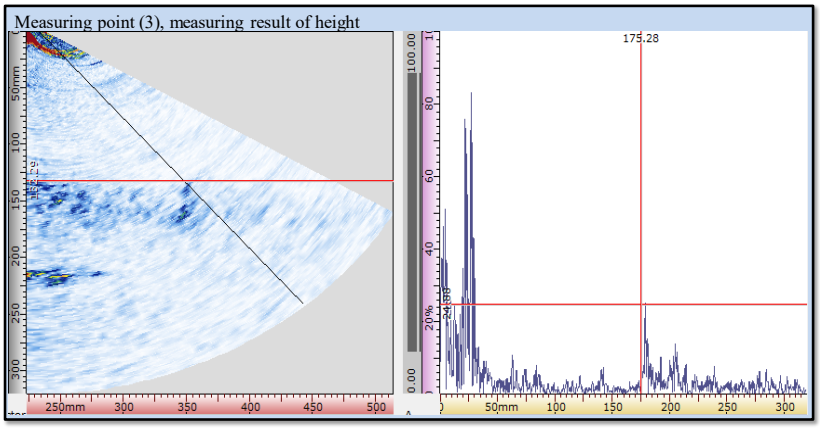


Figure 6 (2). A sample of scanning image
(H9 weld joint, company-α)

Crack sizing by different definition

Since the sizing results of cracks by two companies were different with a trend, CRIEPI conducted an independent review of the results and estimated reasons to cause the differences. CRIEPI confirmed that scanning methods of two companies were not deviated from the examination procedures of ex-vessel UT provided by two companies and that crack evaluation processes and methodology were not wrong. As reasons to cause the differences of crack sizing, some differences between two companies for scanning method and determination of crack indications were indicated by CRIEPI. Regarding the differences of decision of a crack, the crack sizing results could become different even if two companies used a same scanning data. In reaction to the following items (a) and (b) indicated by CRIEPI, Company-α prepared another definition of a crack indication and re-evaluated the UT data with the new definition.

(a) Treating indications of buildup weld
The tiny indications were confirmed around the boundary of buildup weld and stainless steel clad by both of two companies. Depending on whether such a tiny indication is treated as a crack or not, dimension-A and dimension-B could be different (Refer to figure-7). In the evaluation performed by Company-α with the original definition of a crack indication, this tiny indication was considered as part of a crack indication. In the case of applying another definition, the tiny indication was decided to be considered as part of crack or not in accordance with continuity of UT indication.

(b) Treating signals of crack tip
In evaluation of A-scope (scanning waveform), it could be different for two companies to decide a crack tip (Refer to Figure-8). In case of using the company internal basic definition of crack sizing performed by Company-α, size of a tiny crack could be conservatively evaluated to be larger than as it was. On the other hand, in case of using another definition of crack sizing, size of a crack was evaluated by eliminating conservativeness by indicating an obvious crack tip.

Company-α's sizing evaluation result with another definition of crack sizing and Company-β's sizing evaluation result with the company internal basic definition of crack sizing are shown in Table-3. Using another definition, it tends that the differences between two companies are becoming smaller.

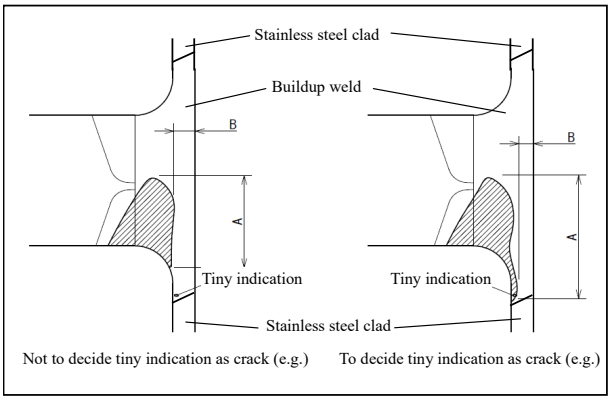
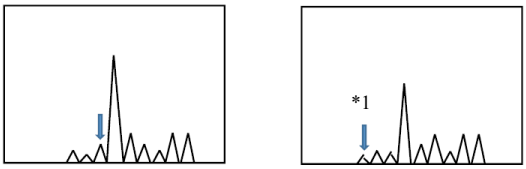


Figure 7. Image of assumed configuration of a crack



Note *1:
In case of the company-α internal basic definition of crack indication, it is decided to be a crack tip.
In case of the company-β internal basic definition of crack indication, it is not decided to be a crack tip.

Figure 8. Explanation of scanning waveform (Schematic diagram)

Table 3: Crack sizing results
- Company-α: Evaluated with another definition of crack indication
- Company-β: Evaluate with the company internal basic definition of crack indication)

Unit: mm

		Company-α		Company-β		Differences	
		Another definition		Basic definition		between α and β	
Crack No.		A	B	A	B	A	B
H9 weld	1	34.6	8.8	17.2	12.0	17.4	3.2
joint	2	42.1	5.6	40.4	10.1	1.7	4.5
	3	33.2	3.3	29.5	9.5	3.7	6.2
	4	46.5	2.7	48.0	11.6	1.5	8.9
	5	39.0	4.3	38.2	11.5	0.8	7.2
	6	56.5	1.0	48.3	6.3	8.2	5.3
	7	40.8	8.4	39.5	8.6	1.3	0.2
	8	35.8	7.5	36.6	10.5	0.8	3.0
	9	39.3	7.3	38.0	10.1	1.3	2.8
	10	37.9	7.9	35.1	7.3	2.8	0.6
	11	34.8	9.0	41.6	9.1	6.8	0.1
	12	31.4	7.7	33.8	9.3	2.4	1.6
	13	28.8	7.9	31.2	11.5	2.4	3.6
	14	-	-	-	-	-	-
	15	32.6	9.0	35.8	11.3	3.2	2.3
H11 weld	1	40.0	27.3	20.2	39.7	19.8	12.4
joint	2	-		-		-	-

Sizing performance of cracks

The crack sizing results of the ex-vessel UT showed different trends between the two companies. By making the company-α's original definition of a crack indication closer to the company-β's definition to treat tiny indications on buildup welds and to treat definition of crack tip signals, it was confirmed that the differences became much smaller between two companies except for some of the cracks. The reasons to cause the large differences in the results between two companies are assumed as followings;

・ Scanning performance in actual field work

The ex-vessel UT for shroud support welds is basically very difficult scanning technique to detect crack tip located in nickel based alloy material welds because of scanning through RPV base material and nickel alloy buildup welds. In the case of automatic scanning, some of portions were not able to be detected due to existing configuration objects of RPV thermocouples. In the case of EMUT, the work spaces were too

narrow to perform scanning with visual check. These work conditions could lead to cause the differences of two companies ex-vessel UT results.

・Beam entry orientations and angles

Since beam entry orientations and angles are different, crack detection performance is different. In the case of stress corrosion cracking (SCC) observed in nickel based alloy welds, most of SCC propagate with meandering so it could be assumed that there are two cases that one company detected a crack tip and the other company detected a bent part of SCC.

・Frequency

Detection performance would differ depending on frequencies of applied UT probe. Similar crack signals were obtained in two companies. However, due to difference of detection performance of crack tip signals, there might be a difference that a tiny indication of crack tip was able to be detected or not.

・Automatic scanning or EMUT

In the case of automatic scanning, generally, stable data could be obtained without affection of field work environment. On the other hand, in the case of EMUT, it could detect echo peak by appropriate skewing of UT prove. These different characteristics of scanning could cause the differences on detecting a tiny indication of crack tip or not.

・Measuring boundary position between low alloy steel and buildup weld

When estimating dimension-B, it is necessary to confirm a boundary position by UT. However, measurement results could be deviated because echo is unclear in boundary position between low alloy steel and buildup weld. Actual boundary positions are different depending on measurement area. The differences of dimension-B between two companies could be caused due to difference of measurement area of the boundary position.

Applicability of ex-vessel UT for actual plants

In the future, detectability and sizing performance of ex-vessel UT will be validated by comparing direct measurement results of the crack size in Hamaoka unit-1. Based on the UT results and the considerations mentioned above, applicability of ex-vessel UT for shroud support welds is evaluated as followings.

Regarding detectability, ex-vessel UT could have advantages to detect a crack which is propagating deep in welds. If it is able to say that ex-vessel UT has same detectability as visual test, ex-vessel UT could be applied as an alternate inspection method of in-vessel visual test. In order to say that, it is required to validate ex-vessel UT by comparing crack sample survey.

Regarding sizing performance, although the sizing results performed by two companies were different, the differences became much smaller by making the company-α's original definition of a crack indication closer to the company-β's definition. Following the plan, direct sizing measurement of crack sampling will be performed and reasons to cause the differences will be considered and clarified. Then, if the considerations will be reflected to examination procedure of ex-vessel UT and detail knowhow will be standardized, applicability of ex-vessel UT will be secured and the ex-vessel UT will be able to be applied for the actual UT examination of RPV.

Note that Plant life management inspection or RPV inspection for applying additional long term operation of restarted BWR plants is assumed to be the first timing to detect SCC in H9 weld joint or H11 weld joint. Once size of a crack is measured with in-vessel UT and the result is obtained, the subject such as handling to consider or not to consider a tiny indication observed in corner area of buildup weld is not happened, which is assumed to be one of reasons to cause the differences of the sizing results between two companies.

Although direct sizing measurement of crack sampling is necessary to validate applicability of ex-vessel UT for the actual RPV, based on the UT results and the considerations obtained so far, a positive prospect was obtained to apply ex-vessel UT as continuous inspections after Plant life management inspection or RPV inspection for applying additional long term operation.

Waiting for progresses of Hamaoka unit-1 decommissioning work, direct sizing measurement of crack sampling is planned to be performed in the future.

CONCLUSION

The ex-vessel UT was performed by two Japanese RPV suppliers separately for some cracks found on the nickel based alloy material welds of shroud support plate to RPV and of shroud support plate leg to RPV in Hamaoka unit-1. The differences were confirmed in the results of sizing cracks between two companies. Reasons to cause the differences were considered and assumed, and then counter approaches were established.

Although direct size measurement of crack is necessary to validate applicability of ex-vessel UT for the actual RPV, a positive prospect was obtained to apply ex-vessel UT as a continuous monitoring after size of a crack is measured by in-vessel UT.

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: Hitachi-GE Nuclear Energy, Ltd.

Central Research Institute of Electric Power Industry as a technical cooperation company for Utilities, IHI Corporation and Hitachi, Ltd. as technical cooperation companies for suppliers also join to this program.