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Preliminary Round Robin Test(RRT) for Program for the Inspection of Nickel Alloy Components(PINC) - Reactor Vessel Head Penetration (RVHP) -

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Abstract After several PWSCCs were found in Bugey(France), Ringhals(Sweden), Tihange(Belgium), Oconee, Arkansas, Crystal Fever, Davis-Basse, VC Summer(U.S.A.), Thuruga(Japan), USNRC and PNNL started the research on PWSCC, that is, the PINC project. USNRC required KINS to participate in the PINC project in May 2005. KINS organized the Korean consortium at March 2006 and Pre-RRT for RVHP were performed for the preparation of PINC RRT. Through these preliminary RRT, Korea NDE teams can learn and develop the detection and sizing technique for RVHP dissimilar metal weld. These techniques are now being prepared in Korea and need to be utilized for the In-service inspection of the RVHP and BMI of Korea Nuclear Power Plants. PINC RRT mock-ups will be helpful to training.

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

The reactor pressure vessel (RPV) heads of PWRs have penetrations for control rod drive mechanisms and instrumentation systems. Nickel-based alloys (e.g., Alloy 600) are used in the penetration nozzles and related welds. Primary coolant water and the operating conditions of PWR plants can cause cracking of these nickel-based alloys through a process called primary water stress corrosion cracking (PWSCC). The susceptibility of RPV head penetrations to PWSCC appears to be strongly linked to the operating time and temperature of the RPV head. Problems related to PWSCC have, therefore, increased as plants have operated for longer periods of time.

Inspections of the RPV head nozzles at the Oconee nuclear station, units 2 and 3(Oconee), in early 2001 identified circumferential cracking of the nozzles above the J-groove weld, which joins the nozzle to the RPV head. Circumferential cracking above the J-groove weld is a safety concern because of the possibility of a nozzle ejection if the circumferential cracking is not detected and repaired.

In response to the inspection findings at Oconee and because existing requirements in the ASME Code and NRC regulations do not adequately address inspections of RPV head penetrations for degradation due to PWSCC, the NRC issued Bulletin 2001-01, "Circumferential

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cracking of reactor pressure vessel head penetration nozzles," dated August 3, 2001. In response to the Bulletin, PWR licensees provided their plans for inspecting RPV head penetrations and the outside surface of the heads to determine whether any nozzles were leaking (NRC Bulletin, 2001-01).

In early March 2002, while conducting inspections of RPV head penetrations prompted by Bulletin 2001-01, the licensee for the Davis-Besse nuclear power station(Davis-Besse) identified a cavity in the RPV head near the top of the dome. The cavity was next to a leaking nozzle with a through-wall axial crack and was in an area of the RPV head that the licensee had left covered with boric acid deposits for several years (NRC Order EA-03-009 Revision 1, 2004).

Many other PWSCCs in addition to the above described were found around the world as well.(NRC Information Notice 2000-17, 2000, Amzallag, C., Boursier, J. M., Pages, C., and Gimond, C. 2002, Bamford, W. and Hall, J., 2003, Jenssen A, Norrgard K, Jansson C, Lagerstrom J, Embring G and Efsing P., 2002, Buisine, D., Cattant, F., Champredonde, J., Pichon, C., Ben- hamou, C., Gelpi, A., and Vaindirlis, M., 1993, Shah, V.N., Ware, A.G. and Porter, A.M., 1994) 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 quantita- tively 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, which was done for the preparation of PINC RVHP RRT. Three task groups, morphology Atlas(TG-Atlas) group (task group one), NDE technology assessment(TG-NDE) group (task group two) and data analysis(DA) group (task group three), were organized. For the preliminary RVHP RRT, thermally and mechanically cracked-4 mockups were prepared and two teams were involved in the round robin NDT. Two teams utilized TOFD and ECT 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 one) 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 3 BMI (bottom mounted instrumentation) mock-ups and one of the 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 two) 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. Two organizations were involved in the preliminary RRT using 4 mockups.

Data analysis group(DAG) (task group three) 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 PINC BMI RRT schedule.

3. Preliminary RRT Teams and Mockups

Preliminary RVHP RRT (Pre RRT, from now) has been performed using four mockups during 2005.11.17-19(A) and 2006.03.27-3.30(B) and the result of Pre RRT was analyzed during 2005.11.17-19(A) and 2006.03.30-4.30(B) due to that PINC RVHP RRT was supposed to start from the beginning of 2007. In the Pre-RRT, 2 teams(A, B) used the TOFD and ECT method. Pre-RRT objects are 4 mockups which were supported by KPS as in Table 1 and Fig. 2. Table 2-5 shows information for RVHP mockups.

Table 1 Korea Pre DMW RRT mockups and orientation of cracks

	Penetration #	Type	Indication
Mock up #1	28	WH	Axial 3, Thru-wall 1, Cir 2
Mock up #2	37	WH	Cir 3
Mock up #3	40	CE	Cir 3
Mock up #4	73	CE	Axial 3, Thru-wall 1, Cir 2

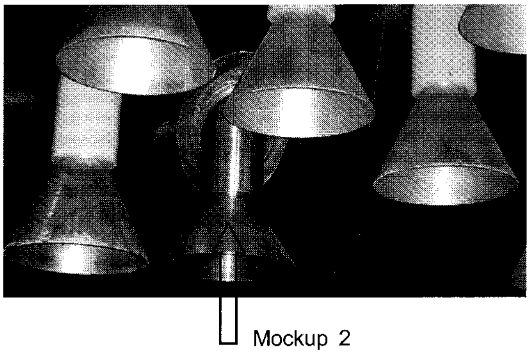


Fig. 2 Photo of Pre RRT mockups

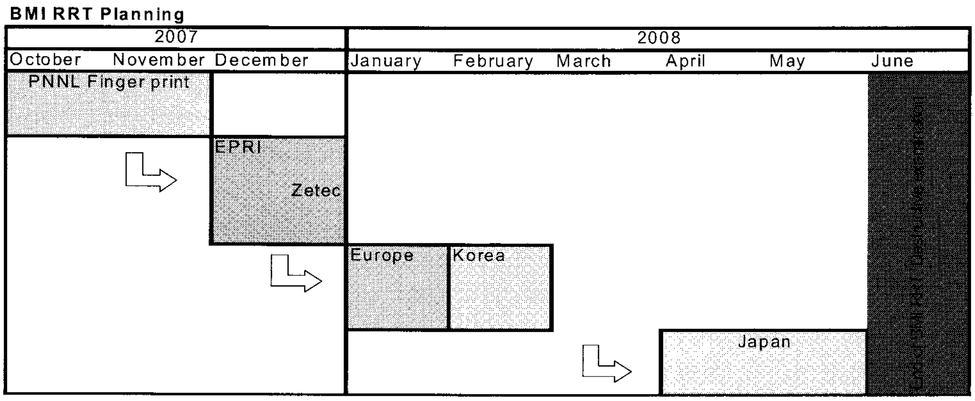


Fig. 1 PINC BMI RRT schedule

Table 2 Crack information of mockup #1

Flaw No.	Orientation	Depth(mm)	Length(mm)	Dist From 0	Tilt	
1	Axial	10.0	11.9	0°	0°	Start from outer toe of J-weld
2	Axial	10.2	9.4	64.3°	0°	Start at buttering interface
3	Axial	9.8	12.7	135°	0°	3.8mm from J-weld & nozzle OD
4	Axial/Circ	Thruwall	N/A	216.5°	0°	Between J-weld & nozzle J-weld surface
5	Circ	3.6	13.2	262.7°	0°	Undercut from J-weld surface
6	Circ	3.8	3.8	302.5°	0°	Grinding mark from top of weld

4. RRT Results

NDE reports of mockup #1 for detection and sizing are summarized in Table 6 and 7. Distance from the flaw #1-4 is 30.1 mm, 15.6 mm, 3.8 mm, and 0 mm. Flaw #4 is between J-weld and nozzle OD interface, flaw #5 is undercut from J-weld surface and flaw #6 is a grind mark from the top of the weld. From Table 6 and 7, no NDE teams found a crack departed more than 3.8mm from OD to J-weld outside. Only one NDE team found the crack departed 3.8 mm from OD to J-weld outside.

NDE reports of mockup #2 for detection and sizing are summarized in Table 8 and 9. Distance from the flaw #1-4 is 3 mm, 29.3 mm, 5.1 mm, and 23.4 mm. From Table 8 and 9, no NDE teams found the crack departed more than 5.1 mm from OD to J-weld outside.

Table 3 Crack information of mockup #2

Flaw No.	Orientation	Depth(mm)	Length(mm)	Dist From 0	Tilt	
1	Circ	5.3	25.7	0°	0°	2.5 or less from interface J-weld and Nozzle OD
2	Circ	4.9	25.1	100°	5°	Start from outer toe of J-weld
3	Circ	4.8	25.8	180°	0°	6.4mm from J-weld & nozzle OD
4	Circ	9.7	26.1	270°	4°	Between J-weld & nozzle OD Interface

Table 4 Crack information of mockup #3

Flaw No.	Orientation	Depth(mm)	Length(mm)	Dist From 0	Tilt	
1	Circ	5.4	25.2	0°	0°	2.5 or less from interface J-weld and Nozzle OD
2	Circ	5.2	25.0	100°	4°	Start from outer toe of J-weld
3	Circ	4.8	25.2	180°	0°	6.4mm from J-weld & nozzle OD
4	Circ	10.1	26.6	271°	0°	Between J-weld & nozzle OD Interface

Table 5 Crack information of mockup #4

Flaw No.	Orientation	Depth(mm)	Length(mm)	Dist From 0	Tilt	
1	Axial	10.2	10.2	0°	0°	Start from outer toe of J-weld
2	Axial	10.0	10.3	64.3°	0°	Start at buttering interface
3	Axial	10.4	12.7	136.5°	0°	3.4mm from J-weld & nozzle OD
4	Axial/Circ	Thruwall	N/A	213.5°	0°	Between J-weld & nozzle OD interface
5	Circ	3.7	12.7	260.8°	0°	Undercut from J-weld surface
6	Circ	3.8	3.8	305.4°	0°	Grinding mark from top of weld

Table 6 NDE report of mockup #1 for detection

Company	L1-L2 (mm)	L3-L4 (mm)	θ1 - θ2	d1	do (mm)	Comments (mm)	Flaw No.
A	129-134	129-142	148°		3.3	Axial(5.1)	#3 (30.5)
A		126-141	214-222°			Leak Path 6.9	#4
A	100	101-103	248-274°		3.1	Circ(L=23)	#5
B	LCG can be seen at 24.4, 74° and 25.4, 108°						#3
B	LOF can be seen at 127, 218°, % of LOF is 82						#4
B	88.4-95.5	95.5-108	255-269°		2.3	PTI	#5

Table 7 NDE report of mockup #1 for sizing

Company	Actual Length (mm)	Measured Length (mm)	Flaw type	Flaw No.
A	9.8	5.1	Axial	#3
A	13.2	23	Circ.	#5
B	13.2	12.4	Circ.	#5

Table 8 NDE report of mockup #2 for detection

Company	L1-L2 (mm)	L3-L4 (mm)	θ1 - θ2	d1	do (mm)	Comments (mm)	Flaw No.
A	60.1	55.9-77.2	346-16°		2.7	Circ(26.4)	#1(Circ)
A	145	137-152	162-194°		5.6	Circ(28.2)	#3(Circ)
B	44.2-61	53.8-77.2	345-14°		2.5	IND	#1(Circ)
B	136-145	134-143	162-192°		4.6	IND	#3(Circ)

Table 9 NDE report of mockup #2 for sizing

Company	Actual Length (mm)	Measured Length (mm)	Flaw No.
A	25.7	28.2	#1(Circ)
A	25.8	31.5	#3(Circ)
B	25.7	34.5	#1(Circ)
B	25.8	29.5	#3(Circ)

Table 10 NDE report of mockup #3 for detection

Company	L1-L2 (mm)	L3-L4 (mm)	θ1 - θ2	d1	do (mm)	Comments (mm)	Flaw No.
A	94.5	87.4-110.7	348-14°		2.3	Circ(27.2)	#1
A	4191	182-199	166-188°		6.9	Circ(23.1)	#3
B	84.2-95.5	89.4-102.6	352-14°		2.3	IND	#1
B	184-195	182-192	168-194°		7.4	IND	#3

Table 11 NDE report of mockup #3 for sizing

Company	Actual Length (mm)	Measured Length (mm)	Flaw No.
A	25.2	24.3	#1(Circ)
A	25.2	21.9	#3(Circ)
B	25.2	22.2	#1(Circ)
B	25.2	26.2	#3(Circ)

Table 12 NDE report of mockup #4 for detection

Company	L1-L2 (mm)	L3-L4 (mm)	θ1 - θ2	d1	do (mm)	Comments (mm)	Flaw No.
A	152-149	150-165	140°		2.8	Axial(WVI)	#3
A		153-168	208-214°			Leak path(6.1)	#4
A	132	127-146	254-278°		3.3	Circ(28.2)	#5
B	149-160	133-140	252-264°		2.5	IND	#3
B	LIF(lack of interference fit) can be seen at 201, 252° and 206, 167°						#4
B	120-131	123-134	254-272°		3.7	PTI	#5

NDE reports of mockup #4 for detection and sizing are summarized in Table 12 and 13. Distance from the flaw #1-3 is 30.8 mm, 12.8 mm and 3.4 mm. Flaw #4 is through wall crack between J-weld and nozzle OD interface, flaw #5 is undercut from J-weld surface and flaw #6 is a grind mark from the top of the weld. From Table 13 and 14, no NDE teams can find the crack departed more than 3.4 mm from OD to J-weld outside. Only one NDE team can find the crack departed 3.4 mm from OD to J-weld outside. A team could find the leak path but B team could not.

4. Discussion

The detection summary of mockup #1 and #2 is given in Table 14.

The detection summary of mockup #3 and #4 is Table 15.

Table 13 NDE report of mockup #4 for sizing

Company	Actual Length (mm)	Measured Length (mm)	Flaw No.
A	10.2	6.1	#3(Axial)
A	12.7	21.3	#5(Axial)
B	12.7	16	#5(Axial)

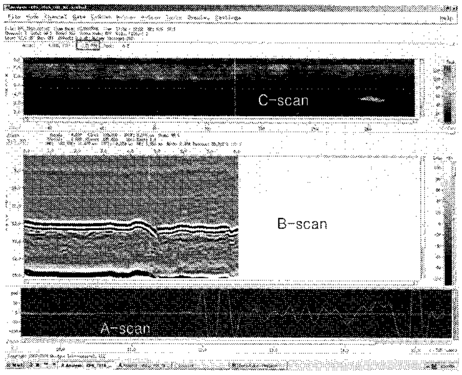
Table 14 The detection summary of mockup #1 and #2

Flaw		Distance from	Company	
#	Type	OD (mm)	A	B
1-1	Axial	30.9	X	X
1-2	Axial	15.6	X	X
1-3	Axial	3.8	O	X
1-4	Leak	0	O	O
1-5	U.C.	-3.6	O	O
1-6	Grind.	3.8	X	X
2-1	Circ.	3	O	O
2-2	Circ.	39.1	X	X
2-3	Circ.	5.6	O	O
2-4	Circ.	23.4	X	X

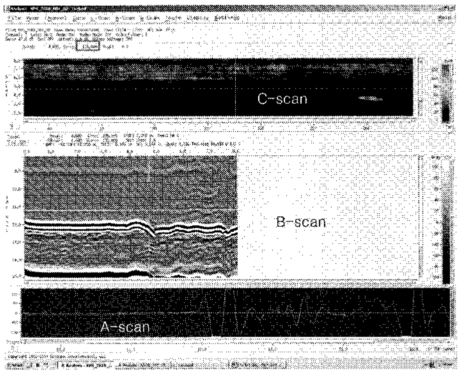
Table 15 The detection summary of mockup #3 and #4

Flaw		Distance from	Company	
#	Type	OD (mm)	A	B
3-1	Circ.	2.9	O	O
3-2	Circ.	32	X	X
3-3	Circ.	7	O	O
3-4	Circ.	22.1	X	X
4-1	Axial	30.8	X	X
4-2	Axial	12.8	X	X
4-3	Axial	3.4	O	X
4-4	Leak	0	O	X
4-5	U.C.	-3.7	O	O
4-6	Grind.	3.8	X	X

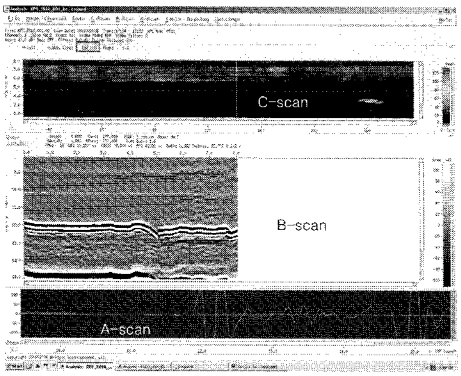
For axial crack departed more than 12.8 mm from OD to J-weld outside, no vender found defects. One vender found axial crack departed less than 3.8 mm or 3.4 mm from OD to J-weld outside. In order to confirm the reason why B team could not find defect #1-3 and #4-3, A, B and C scan were shown according to scanning time in Fig. 3. In A-scan, vertical axis is amplitude and horizontal axis (y-axis of B-scan) is elapsed time. In B-scan, vertical axis is elapsed time and horizontal axis (y-axis of C-scan) is the distance of nozzle axial direction. Therefore, in B-scan, the dashed line in the upper part is lateral wave and the horizontal line near center is back-wall wave. In C-scan, vertical axis is the distance of nozzle axial direction and



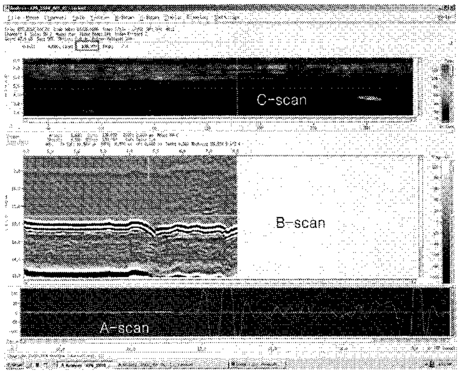
(a) 135th Circumferential frame in the C-scan



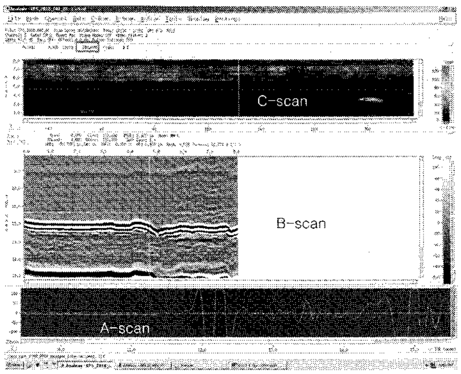
(b) 136th Circumferential frame in the C-scan



(c) 137th Circumferential frame in the C-scan



(d) 138th Circumferential frame in the C-scan

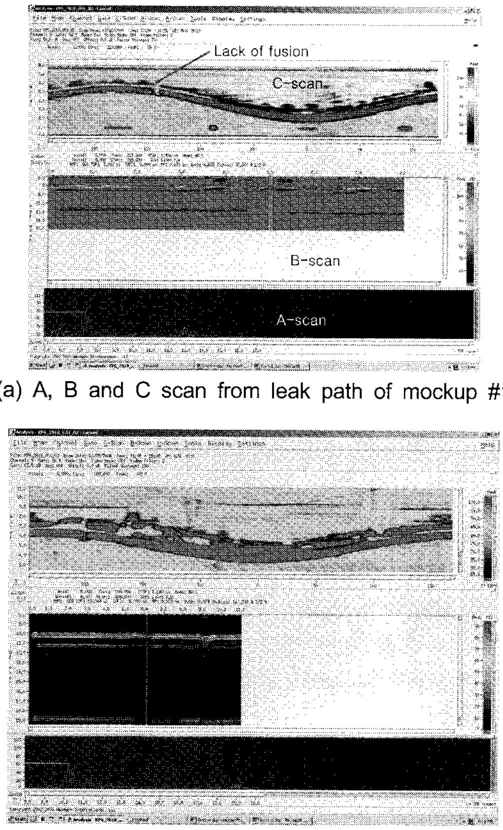


(e) 139th Circumferential frame in the C-scan

Fig. 3 A, B and C scan according to scanning time horizontal axis is the degree of nozzle circumferential direction. The resolution of horizontal axis is 1 degree(frame). In Fig. 3 (a), the rectangle box in B-scan is the location of the defect. If we focus on the rectangle in B-scan from frame 135 degree to 139 degree, the crack becomes bigger gradually and then becomes smaller. False indication near this red rectangle in frame 137 appears suddenly without reason. This defect was not easy to detect.

For circumferential crack departed more than 22.1 from OD to J-weld outside, no vender found defect. Two venders found circumferential crack departed less than 7mm from OD to J-weld outside.

Two venders found the leak path of mockup #1, but one vender found leak path of mockup #4. In order to check why the inspectors missed the leak path, A, B and C scan of two leak paths were compared. Fig. 4 shows the two leak paths.



(a) A, B and C scan from leak path of mockup #1

(b) A, B and C scan from leak path of mockup #4

Fig. 4 Leak path of mockup #1 and 4

If we compare (a) and (b) of Fig. 4, we can confirm that team B did miss leak path of mockup #4.

No venders found two grind marks of mockup #1 and #4.

5. Lesson Learned

From preliminary RRT, we learned the next lesson.

Axial crack more than 2.5 mm from OD to J-weld outside is difficult to detect. Circumferential crack more than 7.6 mm from OD to J-weld outside is difficult to detect. From these results, we can know that axial crack is more difficult to find than circumferential crack. One vender missed one leak path of the two. Grind mark was not found. Inspection technique for defects on weld part needs to be improved in the near future.

6. Conclusions

1) In order to prepare PINC RRT, Korea RRT team performed preliminary RRT successfully.
2) From preliminary RRT, it was shown that the team can find axial crack 2.5 mm from OD to J weld.
3) From preliminary RRT, it was shown that the team can find circumferential crack 7.6 mm from OD to J-weld.
4) Technique for defects on weld part needs to be improved in the near future.
5) From preliminary RRT, several lessons were learned and this lesson will be helpful for training Korea In-service teams.
6) From preliminary RRT, several lessons were learned and this lesson will be helpful for the PINC RRT.

Acknowledgments

We appreciate the participation of RRT teams in the Pre-RRT. RRT Teams: KHNP(NETI), KPS.

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