Boiler RLA

JICA Study Team
Boiler RLA

Target units

- Singrauli Unit 6 (500MW Drum Boiler)
  Cumulative operation hours: 172,000 hours
  (27th October to 1st November, 2009)

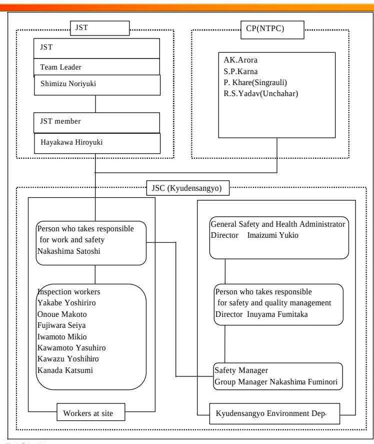
- Unchahar Unit 2 (200MW Drum Boiler)
  Cumulative operation hours: 139,098 hours
  (4th November to 9th November, 2009)

Schedule for Boiler RLA demo

Schedule for Boiler RLA

	Month	October								November											
	Day	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	～January
	Day of the week	Sa	Su	Mo	Tue	We	Th	Fr	Sa	Su	Mo	Tue	We	Th	Fr	Sa	Su	Mo	Tue	We	
Singrauli UNIT6	Boiler Inspection							10/27-11/1													
Unchahar UNIT2	Meeting																				
	Boiler Inspection													11/4-11/9							
	◇Examination in Japan																				

Work organization



Safety working

Following the instruction of power station, keeping Japanese safety management.

✓ Falling
In danger of falling, working at 2m or more high altitude.

✓ Lack of oxygen
In danger of lack of oxygen, working in the boiler furnace.

✓ Dropping
In danger of equipments dropping at hanging in and out
Maximum weight 50 kg.
In danger of manual tools and small parts dropping.

*Check the portion that **asbestos** used.
If asbestos treating work begins, Interrupt working.

*Information sharing to avoid working during upper portion working, γ-ray inspection, etc.

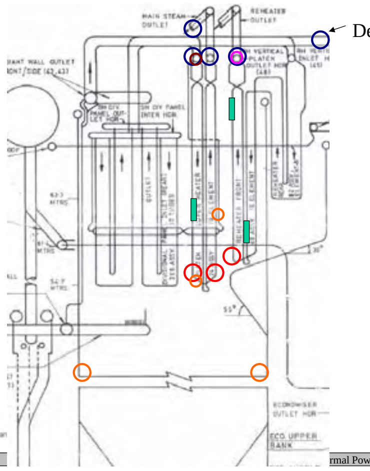
Scope of work (1)

NO.	Parts	INSPECTION	Singrauli #6	Unchahar #2
1	WATER WALL	VT	・Mainly at burner level ・Errosion part	
2		THICKNESS MEASUREMENT	・20 points(5points each from 4corners)	
3	SUPER HEATER	VT	・Mainly Platen super heater	
4		THICKNESS MEASUREMENT	・50 points around soot blower	
5		SAMPLE TUBE INSPECTION *	1 tube with 1m length for Platen SH including weld joint portion	2 tubes with 1m length from Final SH, 1 tubes with 1m length from Platen SH including weld joint portion that is selected by steam oxide scale measurement result.
6		CREEP RUPTURE TEST*	・3 specimens from base metal, 3 specimens from weld joint from the tube identical to above.	・3 specimens from base metal, 3 specimens from weld joint from the tube identical to above.
7		SUS SCALE DEPOSITION INSPECTION	・50 points of bottom bend portion of austenitic steel tubes	・29 ×3 points of bottom bend portion of austenitic steel tubes
8	REHEATER	VT	・Mainly around soot blower.	
9		SAMPLE TUBE INSPECTION *	2 tubes with 1m length for Final RH (one each from furnace inside and penthouse) including weld joint portion.	
10		CREEP RUPTURE TEST*	・3 specimens from base metal, 3 specimens from weld joint from the tube identical to the one of the above sample tubes.	
11		SUS SCALE DEPOSITION INSPECTION	・50 points of bottom bend portion of austenitic steel tubes	

Scope of work (2)

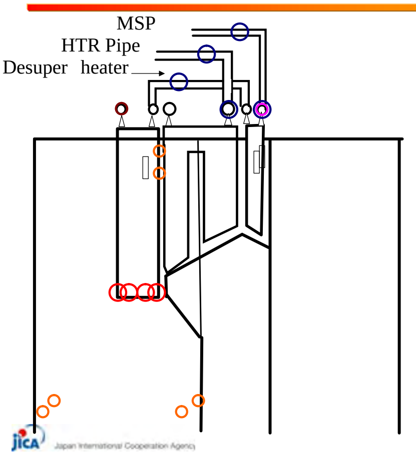
NO.	Parts	INSPECTION	Singrauli #6	Unchahar #2
12	SUPER HEATER HEADER	VT	・Visual inspection in penthouse	
13		PT(DPT)	・4 portions at stub weld of Inlet header .	・4 portions at stub weld of Platten inlet header right side.
14		UT		・1ring of circumferential weld of Final outlet header right side with UT and TOFD identical to the replica portion
15		REPLICA INSPECTION	・1 point on 1ring of circumferential weld of left outlet header. ・1 point on base metal of left outlet header.	・1 point of circumferential weld potion of right side of Final outlet header.
16	DE SUPER HEATER PIPE	REPLICA INSPECTION	・2 points (one each from 1ring of circumferential weld right and left).	
17	REHEATER HEADER	VT	・Visual inspection in penthouse	
18		UT	・1ring of circumferential weld of outlet header with UT and TOFD identical to the replica portion	
19		REPLICA INSPECTION	・2 points (one each from circumferential weld of left and right of out let header.	・3 points of circumferential weld potion of right and left side outlet header.
20	MAIN STEAM PIPE (near the stop valve weld joint)	REPLICA INSPECTION	・2 points on a circumferential weld of left main steam pipe	・2 points on two circumferential welds of right main steam pipe
21	HOT RHEAT PIPE	REPLICA INSPECTION		・1 point on a circumferential weld of right High temperature reheat pipe.

Inspection points (Singrauli #6)



○ :Replica
○ :SUS scale
○ :Thickness measurement
▌ :Tube sampling for inspection and creep rupture test
○ :UT, TOFD
○ :DPT

Inspection points (Unchahar #2)



○ :Replica
○ :SUS scale
○ :Thickness measurement
▯ :Tube sampling for inspection and creep rupture test
○ :UT, TOFD
○ :DPT

Findings (1) (Singrauli #6)

Components	Inspection method	Findings
Water wall tube	Visual check	・Erosion of a number of tubes around short soot blower were found. ・No erosion at any other portions. ・No erosion and decease in thickness around burners.
	Thickness measurement of tubes	Thickness was measured at erosion regions around soot blowerrs near each 4 corner. Min. thickness was 3.7mm(2nd blower in forntwal first from right. f 51* 5.6mm, SA210 Gr.C
Platten SH	Visual check	・Attrition of binding tube #4 and #5 was found.(Min.2.8mm) ・Attrition of cooling spacer tubevwith front tube of #14 panel (Min.5.0mm) ・Disorder of arrangement at lower part of panel with distortion to adjacent panel. ・A number of disjointed slide spac
	Thickness measurement of tubes	・1:Outer tube of rear side portion at sootblower level〔24points〕⇒Min.6.3mm ϕ63.5* 6.3mm SA213 TP347H ・2:Outer bottom tube 〔24points〕⇒Min.9.8mm ϕ54.0* 9.5mm SA213 TP347H ・3:Attrition of coolin
	SUS scale deposition inspection	Nos. exceeding 10% fullness : 7 /50 (magnetized effect of material)
	Tube sampling for sample tube inspection (inspected in Japan).	#12-3(from leftside) f 47.63*8.6-f 47.63*10, SA213 T22
	Creep rupture test (inspected in Japan)	

Findings (2) (Singrauli #6)

Components	Inspection method	Findings
Reheater	Visual check	・Disorder of arrangement at lower part of panel with distortion to adjacent panel.
	SUS scale deposition inspection	No exceeding 10% fullness
	Tube sampling for sample tube inspection (inspected in Japan).	#3-1(from leftside in penthouse) 1m including weld f 54*5.6, SA213 T22 #14-5(from rear side in furnace) (SA213T22 f 54*4.5-SA213T11 f 54*4.0)
	Creep rupture test (inspected in Japan) for 1 tube with 1m length.	
Super heater header	Visual check	・No appearance abnormarity in stubs and other weld portion.
	DPT	#2(1,4,7,12) Indication was found in #2-12 stub at tube side. Indication disaappeared after grindng off the tube in 1mm depth .
	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
De superheater pipe	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
Reheater header	Visual check	・No appearance abnormarity in stubs and other weld portion.
	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
	UT	・No detection of flaw beyond H-detection line. ・4 detected flaw under H-detection line.
	TOFD	・A number of flaw considered as satle blow holes and slag inclusions were detected. ・No considerable crack detected.
Main steam pipe (near the stop valve weld joint)	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.

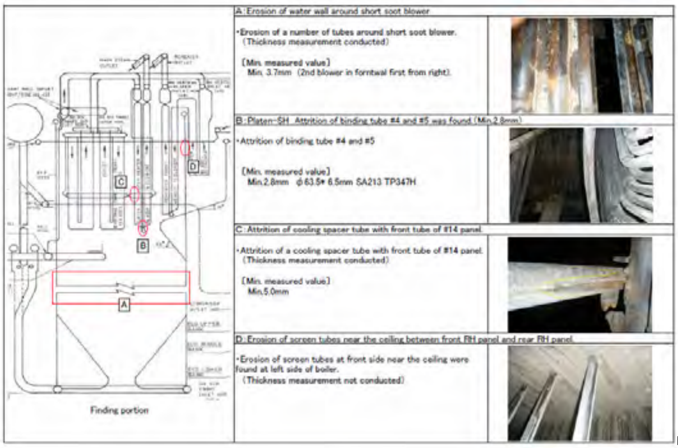
Findings (3) (Unchahar #2)

Components	INSPECTION	Unchahar #2 Brief comment
WATER WALL	VT	Erosion of a number of tubes around short soot blower were found. Erosion of corner tubes at soot blower level.(Thickness measurement 28points (Min.4.2mm)
	THICKNESS MEASUREMENT	Eroded tubes around short soot blower were meareured .(69points measured) Min 5.3mm (2nd short blower rear wall #1 form left)
SUPER HEATER	VT	Disorder of arrangement at lower part of panel with disjointed slide spacers. Slight erosion of rear tubes at the highest level of short soot blower.
	THICKNESS MEASUREMENT	Rear tubes at the highest level of short soot blower.(29points, Min.9.8mm) 2nd tubes from rear tubes at the highest level of short soot blower.(3points, Min.10.0mm) Rear tubes at the second highest level of short soot blower.(29points, Min.9.8mm)
	SAMPLE TUBE INSPECTION *	1 sample tube from Platen-SH in furnace (#3panel- 8th tube from rear) 2 sample tubes from Final-SH in furnace (#1-3rd tube from rear, #119-3rd tube from rear)
	CREEP RUPTURE TEST*	1 sample tube from Platen-SH in furnace (#3panel- 8th tube from rear), 1 sample tubes from Final-SH in furnace (#119-3rd tube from rear)
	SUS SCALE DEPOSITION INSPECTION	3 tubes with 15% fullness and 2 tubes with 10% fullness at front bend portion. 1 tube with 15% fullness and the others with less than 10%.
REHEATER	VT	No abnormality with panel ar r angement Slight erosion of tubes at the highest level of short soot blower.

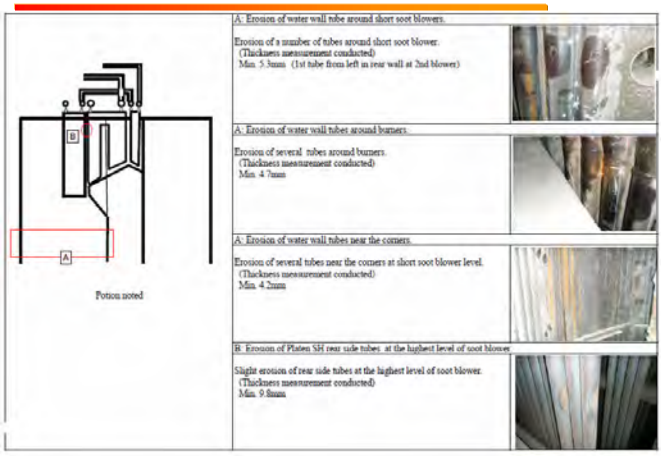
Findings (4) (Unchahar #2)

Components	INSPECTION	Unchahar #2 Brief comment
SUPER HEATER HEADER	VT	No appearance abnormality in stubs and other weld portion.
	PT(DPT)	3 small circular indication patterns by ark strike at 4th tube from front.
	UT	No detection of flaw which echo exceeds L-line by UT. Continuous indication with fine flaws detected at 80mm depth from surface by TOFD.
	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
DE SUPER HEATER PIPE	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
REHEATER HEADER	VT	No appearance abnormality in stubs and other weld portion.
	REPLICA INSPECTION	No crack in Base metal, HAZ (Heat Affected Zone) and weld metal. Abnormal microstructure observed in base metal region of right-hand weld of header, which is considered to be the effect of ark during welding. More detail microstructural observation.
MAIN STEAM PIPE (near the stop valve weld joint)	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
HOT RHEAT PIPE	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo. Some deposit metal by welding attached to base metal near the weld ring.

Visual inspection (Singrauli #6)



Visual inspection (Unchahar #2)



Thickness measurement

Thickness measurement (1)

【Equipment 】

Ultrasonic thickness meter including a probe with a digital display and waveform indicator.

【Couplant 】

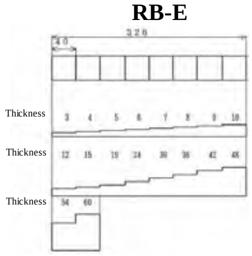
Glycerin paste or glycerin solution with the 75% concentration or more

Thickness measurement (2)

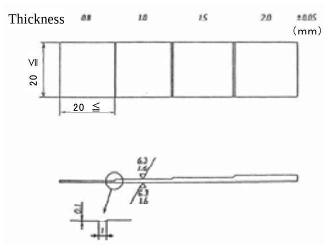
【 Reference block 】

- **Reference block: RB-T and RB-E (for regular interval checking and daily checking)**

RB-E



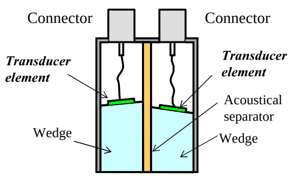
RB-T



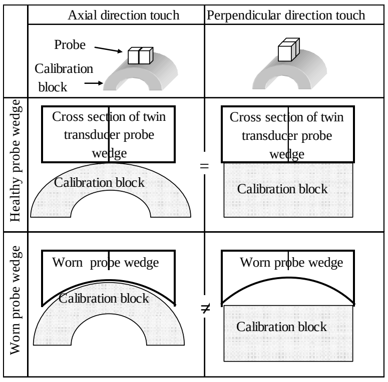
Thickness measurement (3)

【 Original reference block 】

- **Carbon steel**
- **Austenitic steel**



Double transducer normal probe



Thickness measurement (4)

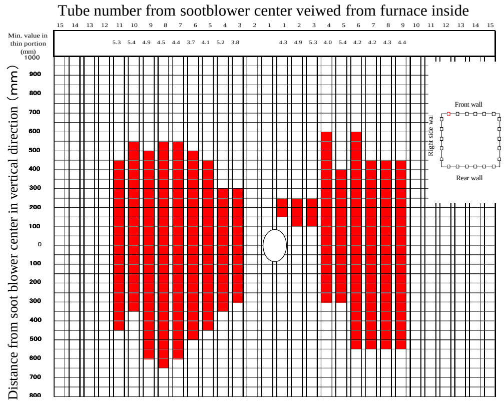
【 Acceptance Criteria 】

Measurement result is judged by the calculated value (tsr: thickness required) based on "Technical standards for thermal power generation facilities" and JIS B 8201 : 2005.

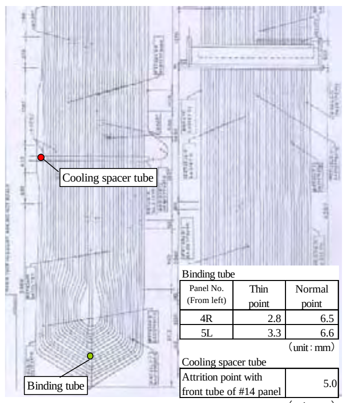
$tsr = (Pd/2\sigma_a + P) + 0.005d$ (JISB8201)

- tsr : Minimum required thickness of tube (mm)
- P : Maximum operating pressure(MPa)
- d : Outside diameter of tube (mm)
- σ_a: Allowable tensile stress of the material (N/mm^2)

Thickness measurement results of WW (Singrauli #6)



Thickness measurement results of Platen SH (Singrauli #6)



Binding tube

Panel No. (From left)	Thin point	Normal point
4R	2.8	6.5
5L	3.3	6.6

(unit : mm)

Cooling spacer tube

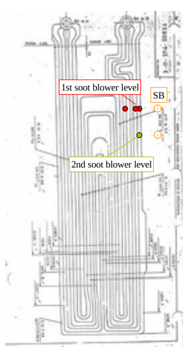
Attrition point with front tube of #14 panel	5.0

(unit : mm)

Thining portion of cooling spacer tube

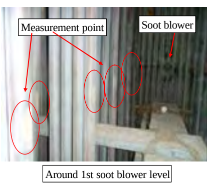
Thining portion of binding tube

Thickness measurement results of Platen SH (Unchahar #2)

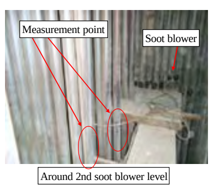


Tube specification: SA213T22 f 51.0×t9.6(tsr9.4mm)

Panel No. (From left)	Soot blower level: 1st soot blower level ● 1st tube from rear	1st soot blower level ● 2nd tube from rear	1st soot blower level ● 5th tube from rear	2nd soot blower level ● 1st tube from rear
1	9.8	-	-	10.0
2	9.9	-	-	10.0
3	10.0	-	-	10.2
4	10.2	-	-	10.4
5	9.9	-	-	10.2
6	10.3	-	-	10.3
7	10.1	-	-	10.2
8	10.1	-	-	10.1
9	9.9	10.1	-	10.1
10	10.1	-	-	10.3
11	10.1	10.0	-	10.2
12	10.1	-	-	10.2
13	10.0	-	-	10.1
14	9.9	-	-	10.0
15	10.1	-	10.2	10.3
16	10.1	-	-	10.3
17	9.9	-	-	9.9
18	10.2	-	-	10.2
19	10.2	-	-	10.1
20	10.1	-	-	10.2
21	10.0	-	-	10.1
22	10.3	-	-	10.3
23	10.3	-	-	10.2
24	10.3	-	-	10.2
25	10.0	-	-	10.1
26	10.2	-	-	10.2
27	10.2	-	-	10.2
28	10.2	-	-	10.3
29	10.2	-	-	10.3



Around 1st soot blower level



Around 2nd soot blower level

Thickness measurement results

Thickness measurement of tubes (Singrauli #6)

Tube	Material	Designed OD (mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temp. (℃)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA210 Gr.C	51.0	5.6	197.3	416	90.1	5.2	3.7	Erosion around short soot blower
PLATEN SH ST-Ⅱ	SA213 TP347H	54.00	9.50	178	540*	92	> 4.9	9.8	
	SA213 TP347H	63.50	6.30	178	540*	92	> 5.8	2.8	Attrition with bind tubes
	SA213 TP347H	63.50	6.30	178	540*	92	> 5.8	6.3	Soot blower level (#1 from rear side)
	SA213 TP347H	54.00	6.00	178	540*	92	> 4.9	6.3	Soot blower level (#2 from rear side)

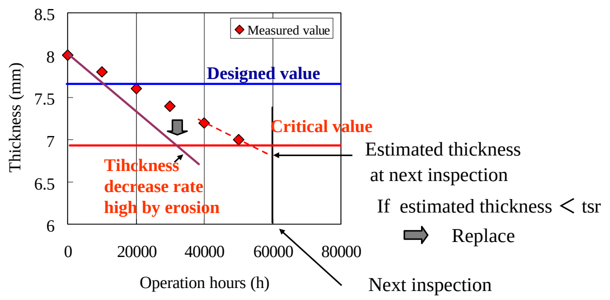
*Designed value of header

Thickness measurement of tubes (Unchahar #2)

Tube	Material	Designed OD (mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temp. (℃)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA-210, GR.A1	63.5	6.3	175.8	404	86.8	6.1	4.2	Erosion around short soot blower
PLATEN SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Highest soot blower level
PLATEN SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Second highest soot blower level
PLATEN SH (ELE 2)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	10.0	Highest soot blower level

t:Thickness $tsr = PD/(2S+P)+0.005D$

Thickness management



【 Critical thickness value 】

Japan : tsr (thiciness shell required) by "Technical standards for thermal power generation facilities"

NTPC : Thckness reduction ratio to designed thickness

Thickness management

How to determine design thickness in Japan ?

Design temperature T, Material ⇒ **Allowable stress S**

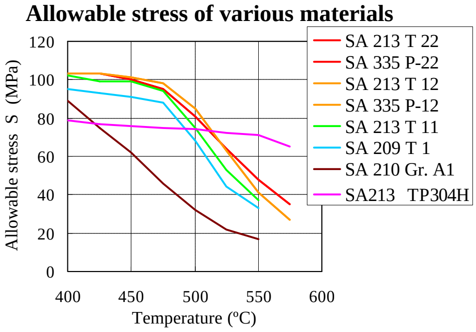
Design pressure P, Design OD D

⇒ **tsr** ⇒ **Designed thickness**

Thickness management

How to determine design thickness in Japan ?

Allowable stress of various materials



by Technical standards for thermal power generation facilities

Thickness management

How to determine design thickness in Japan ?

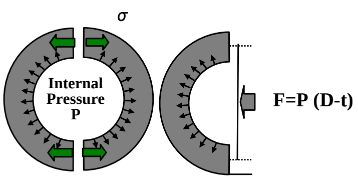
Design temperature T, Material ⇒ **Allowable stress S**

Design pressure P, Design OD D

⇒ **tsr** ⇒ **Designed thickness**

Thickness management

How to determine design thickness in Japan ?



$2t\ \sigma = F$

$\sigma = P(D - t) / 2t$

σ : Hoop stress

t : thickness

$\sigma = P(D-t)/2t \leqq$ Allowable stress S

tsr = PD / (2S+P) +0.005D

Designed thickness ≧ tsr

Thickness management

How to determine design thickness in Japan ?

Design temperature T, Material ⇒ **Allowable stress S**

Design pressure P, Design OD D

⇒ **tsr** ⇒ **Designed thickness**

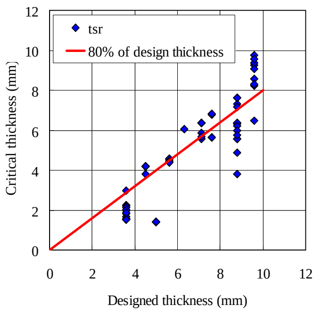
How much mergin to be taken from tsr by OEM ?

Designed thickness = tsr + mergin

If the mergin is small, 80% of designed thickness is not secure.

If the mergin is large, 80% of designed thickness is conservative.

Thickness management criteria



What is to be taken as criteria ?

Where is the origin of designed thickness ?

Integrity calculation documents by OEM is essential.

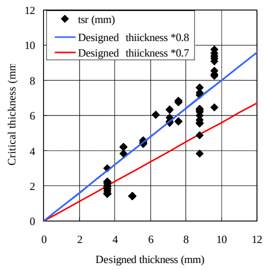
Thickness criterion (Unchahar #2)

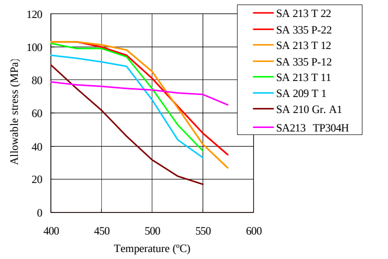
Thickness measurement of tubes

Tube	Material	Designed O.D. D(mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temperature (ºC)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA-210, GR.A1	63.5	6.3	175.8	404	86.8	6.1	4.2	Erosion around short soot blower
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Highest soot blower level
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Second highest soot blower level
Platten SH (ELE 2)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	10.0	Highest soot blower level

O.D.:Outer Diameter
t:Thickness

tsr = PD/(2S+P)+0.005D





Caluculated designed creep life (Unchahar #2)

Creep life calculation of header and pipe based on disigned condition

Header and Pipe	Material	Designed O.D. D(mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temperature (ºC)	Allowable Stress S (MPa)	tsr (mm)	Hoop stress (MPa)	Estimated Life(h) calculated by creep rupture data
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Re-Heater outlet header	SA 335 P-22	558.8	45	44.1	555	45.4	25.0	23.8	9.19E+06
LTSH outlet header	SA 335 P12	323.9	40	167.6	450	101.0	24.7	60.0	4.81E+08
Links to DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
Links from DESH	SA 335 P12	406.4	45	167.6	427	102.8	30.5	67.6	2.25E+09
Platen SH inlet header	SA 335 P12	323.9	40	167.6	427	102.8	24.3	60.0	4.30E+09
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Links to Final SH	SA 335 P-22	406.4	70	163.4	534	58.2	47.0	35.4	8.49E+06
SH Finish inlet header	SA 335 P-22	406.4	65	163.4	534	58.2	47.0	39.0	5.54E+06
SH Finish outlet header	SA 335 P-22	457.2	100	160.6	555	45.4	63.8	25.0	7.76E+06
Main Steam Pipe	SA 335 P-22	355.6	50.3	160.5	540	54.4	42.8	44.6	1.98E+06
Hot Reheat Pipe	SA 335 P-22	508	28	37.6	540	54.4	16.4	30.9	9.91E+06

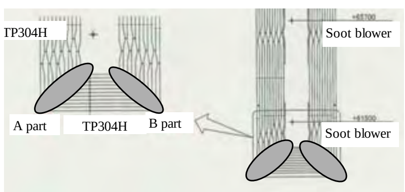
tsr = PD /(2S?+2kP)+a (?=1, a=0)

k	Temperature(ºC) ≦350	480	510	535	565	590	620
Feritic steel	0.4	0.4	0.5	0.7	0.7	0.7	0.7

Detection technique for scale deposition of SUS (Austenite Steel) boiler tube

Detection technique for scale deposition of SUS (Austenitic Steel) boiler tube (1)

(Backgraoud)
Steam oxide scale of austenitic stainless steel (SUS steel) tubes such as TP304, TP321 used for SH and RH, exfoliates and deposits at the bottom inside during long term operation and blocks tube-coolant flow leading to over heat of the tube at down stream side.



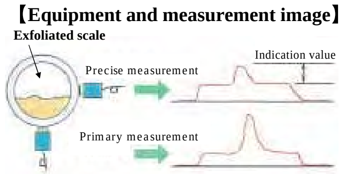
Conventionally γ-ray transmission test method is applied.

From the view point of efficiency and safety

Using the induction principle, the magnetic scale inside of nonmagnetic tube was detected.

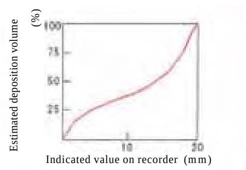
Detection technique for scale deposition of SUS (Austenitic Steel) boiler tube (2)

【Equipment and measurement image】



Measurement technique

Measurement equipment

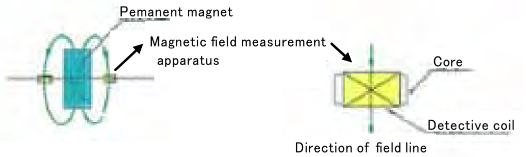


Example of standard curve

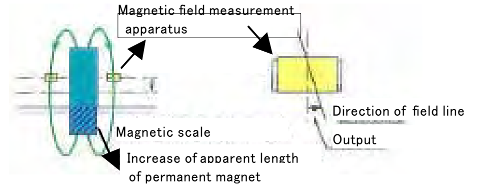
Measurement image

Detection technique for scale deposition of SUS (Austenite Steel) boiler tube (3)

【Detection principle 】

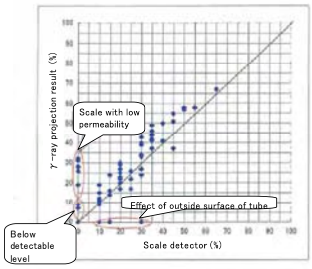


Using the induction principle



Detection technique for scale deposition of SUS (Austenite Steel) boiler tube (4)

【Comparison between γ -ray projection and scale detector results】



【Detectable level】

Detectable level ≧ 10%.

【Effect of outside surface of tube】

The effect of magnetic scale on the tube outside and local magnetization of the tube by long term heat. Suspected signals require to be confirmed by γ -ray detection.

【Scale with low permeability】

The deposit scale with lower permeability than one of reference scale is not detected, such as austenitic stainless steel tips by cutting and limescale etc.

Detection technique for scale deposition of SUS (Austenite Steel) boiler tube (5)

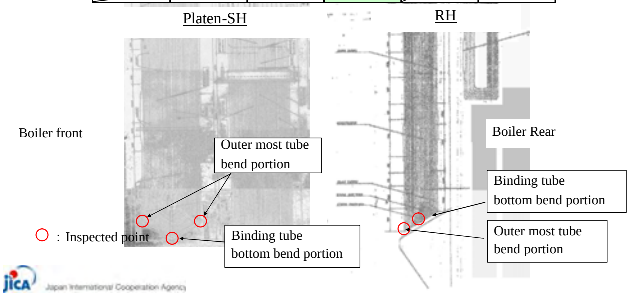
【 Confirmation of scale deposition 】

It is preferable to apply γ -ray detection besides scale detector, in order to recognize the effect of the outside surface of tube and the existence of the scale with low permeability.

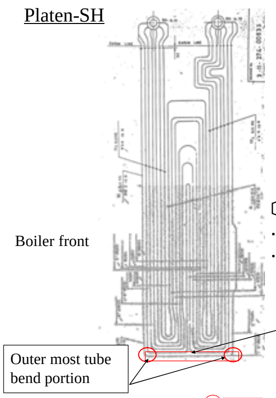
Sampling inspection by γ -ray detection will improve the accuracy of scale deposition estimation.

SUS scale deposition inspection results (Singrauli #6)

Platen SH (outermost tube)				RH (outermost tube)	
Front		Rear		Front	
Panel No.	Fullness (%)	Panel No.	Fullness (%)	Panel No.	Fullness (%)
14	15	6	15	3	15
20	10	13	10		
21	15	18	10		
		21	15		



SUS scale deposition inspection results (Unchahar #2)



Platen Super Heater (Outermost tube bend portion)			
Front		Rear	
Panel No.	Fullness (%)	Panel No.	Fullness (%)
17	10	27	15
18	15		
19	10		
20	15		
22	15		

〔Remarks〕

・Standard curve with φ54.0×t9.5 was used for evaluation of fullness.

・The signal by magnetization of tube material with heat was recognized at front bend, rear bend and horizontal portion.

DPT (Liquid Panetrant Testing)

DPT procedure (Platen SH inlet header 4 stub weld portion)

Process			Content
Pretreatment			Remove oil and dirt on the surface using cleaning agents with the defect opnening, then dry thoroughly.
Osmosis treatment			Penetrant is painted on the surface. Keep for 5 to 60 minutes, so that penetrant penetrates enough into the defect.
Removal / cleaning process			Penetrant on the surface is removed with dry waste cloth. Then wiped up with moisturized cloth.
Development process			Developing powder is coated on the surface with a thin and uniform coating, after stirring developing powder spray sufficiently. Development time is usually 10 to 30 minutes.
Observation			Observe the surface of test material in a bright place. Crack (flaw) appears as red indication on a white background.

More careful surface treatment with wire blush

More carefully

DPT results (Platen SH inlet header 4 stub weld portion)

	After DPT	After grinding off
【Singrauli #6 】 ✓One linear indication in tube side. ✓Disappeared after grinding off 1mm depth from surface.		
【Uncahar #2】 ✓ Two circular indication pattern were detected. ✓ After grinding off, a new circular indication pattern appeared, that was not judged as crack.		

DPT (Liquid Panetrant Testing) (1)

【Classification of penetrant indication 】

Based on JIS Z 2343-1:2005 「Non-destructive testing－Penetrant testing－Part 1 : General principles－Method for liquid penetrant testing and classification of the penetrant indication」

＊Classification of the penetrant indication

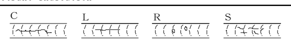
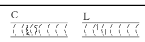
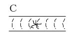
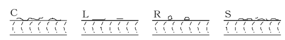
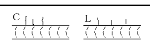
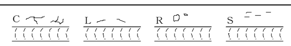
Classification of the penetrant indication		Mark	Definition
Isolated penetrant indication	Indication by cracking	C	Indication by cracking
	Indication with linear pattern	L	Indication in length more than 3 times as width except for cracking
	Indication with circular pattern	R	Non linear indication except for cracking
Continuous penetrant indication		F	A number of indication exisisting on a line
Dispersed penetrant indication		S	A number of indication exisisting in a constant area

DPT (Liquid Panetrant Testing) (2)

【Classification by the position and direction in weld 】

Based on JIS Z 2343-1:2005 「Non-destructive testing－Penetrant testing－Part 1 : General principles－Method for liquid penetrant testing and classification of the penetrant indication」

＊Classification by the position and the direction in weld

Position and direction of penetrant indication	Mark	illustration (C,L,R ,S in figures show classification of the penetrant indication
Longitudinal direction along weld line	A	 C L R S
Horizontal direction perpendicular to weld line	B	 C L
In weld metal	X	 C
Longitudinal direction along HAZ line	C	 C L R S
Horizontal direction perpendicular to HAZ line	D	 C L
In Base metal	E	 C L R S

８x２F ： More than 2 indications with 8mm in length on a line
（０．５） ： 0.5mm depth of flaw

DPT (Liquid Panetrant Testing) (3)

【Criteria for indication by “Technical standards for thermal power generation facilities” 】

Based on JIS Z 2343-1:2005 「Non-destructive testing－Penetrant testing－Part 1 : General principles－Method for liquid penetrant testing and classification of the penetrant indication」

- No penetrant indication by crack
- No linear penetrant indication and indication by linear flaw with longer than 1mm in length.
- No circular penetrant indication and indication by circular flaw with longer than 4mm in length.
- In case of 4 or more circular penetrant indications or circular indications by circular flaw located in a line, the spacing between adjacent indications needs to be longer than 1.5mm.
- No more than 10 or more circular penetrant indications or circular indications by circular flaw are included within the rectangular area of 3750mm^2(short side length is longer than 25mm)

Ultrasonic testing
TOFD (Time of Flight Diffraction)

Ultrasonic testing (1)

Radiographic testing and ultrasonic testing are the typical nondestructive testing that inspects the inside of weld of tubes and pipes. In general, when setting Radiographic film is difficult, the ultrasonic testing is applied.

【Detecting equipment】

- **DSM35 Krautkramer Universal UltrasonicFlaw Detector**

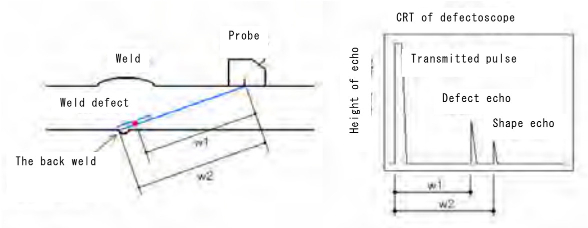
【Couplant】

- **Glycerin paste or glycerin solution with the 75% concentration or more.**

Ultrasonic testing (2)

【Principle of ultrasonic testing (UT) 】

As for the butt-weld joint, "angle beam method" is usually applied because of weld reinforcement.



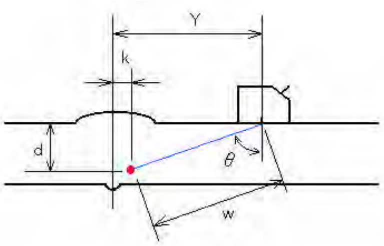
Ultrasonic testing (3)

【Calculation of defect position】

Y can be measured with the scale and W can be read from CRT.
The position of the defect can be calculated by the following formula.

$d = W \times \cos\theta$
$k = Y - W \times \sin\theta$

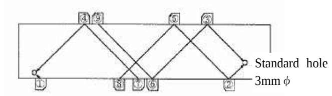
θ (angle of refraction) is measured beforehand, usually using nominal value 40,45,60,65,70.



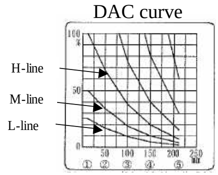
Ultrasonic testing (4)

【Distinction of defect and measurement of echo height】

The echo that appears on CRT is judged whether a defect or not (shape echo) from the reflection source and the echo height. The reflection source is calculated from d and k in equations. If it is located in the weld, the echo is judged to come from a weld defect. The H-line is defined by linking the heights of the echo on CRT that reflects at the drilled hole with 3mm in the diameter of reference test block RB41. M -line is a half of H-line (-6db), L -line is a quarter of the height of H-line (-12db). These lines are called as "Dividing curves of echo height "That is made before flaw detection. The echo that exceeds L line in this echo height area during scanning the probe for flaw detection is judged to be a defect based on L line .



DAC curve



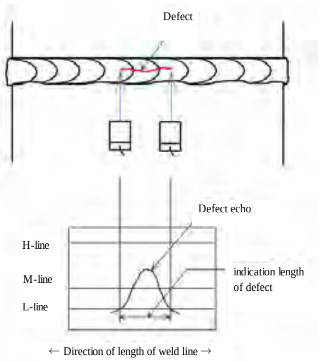
(JIS Z3060:2002)

Ultrasonic testing (5)

【Measurement of length of defect】

The range that exceeds L line during scanning the probe along the direction of the weld line is defined as "the indication length of defect".

(JIS Z3060:2002)



Ultrasonic testing (6)

【Classification of flaw 】

Echo height area and classification of flaw by indication length of flaw						
Area	Ⅲ in case of level M detection Ⅱ and Ⅲ in case of level L detection			Ⅳ		
thickness (t) / Classification	18 ≦t	18 <t≦ 60	60 <t	18 ≦t	18 <t≦ 60	60 <t
The first class	≦ 6	≦ t/3	≦ 20	≦ 4	≦ t/4	≦ 15
The second class	≦ 9	≦ t/2	≦ 30	≦ 6	≦ t/3	≦ 20
The third class	≦ 18	≦ t	≦ 60	≦ 9	≦ t/2	≦ 30
The fourth class	The one exceeding the third class					
JIS Z3060:2002 from appendix 7 of examining ultrasonic wave of welded steel joint						

Ultrasonic testing (7)

【Acceptance Criteria】

To satisfy either of the following (1) or (2).

(1) Height of the reflected wave from the flaw in the weld on CRT must be below the height of reflected wave from the reference hole corrected by the probe to flaw distance.

(2) The length of the flaw from which the height of the reflected wave on CRT beyond the height of reflected wave from the reference hole corrected by probe to flaw distance, must be the value or less as shown below.

Division of thickness of weld(mm)	Length(mm)
t≦18	6
18＜t ≦ 57	1/3 of thickness of weld
57＜ t	19

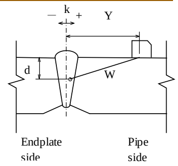
*Technical standards for thermal power generation facilities

TOFD (Time of Flight Diffraction) method (1)

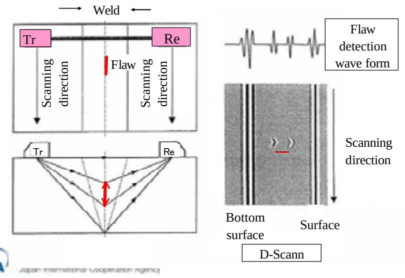
【UT inspection 】

✓ Angle beam probe detection

✓ Angle of refraction 70 °



【TOFD inspection 】



✓ High inspection efficiency

✓ Flaw sizing in depth direction

✓ High sensitivity

TOFD (Time of Flight Diffraction) method (2)

Time of Flight Diffraction (TOFD) method of Ultrasonic inspection is a very sensitive and accurate method for nondestructive testing of welds for defects.

【Detecting equipment】

- **μ-Tomoscan(R/D Tech)**
  Amplitude linearity：within ±3% based on JIS Z 2352 4.1.
  Time base linearity：within ±1% of full scale based on JIS Z 2352 4.2.

【Probes and Wedges】

- **Probes for transmission and receiver are the longitudinal wave angle beam probe with the same performance.**
  Wave frequency: 2～10MHz
  Resonator dimensions: 0.25in～0.5in
  Wedges: the longitudinal wave angle 45° or 60°

【Couplant】

Glycerin paste or glycerin solution with the 75% concentration or more.

TOFD (Time of Flight Diffraction) method (3)

【Test sample】

➢**Test sample with same dimension as inspected part is preferable .**

【An example of selection of transducers and transducers spacing 】

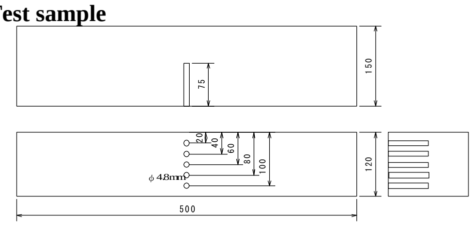
Thickness of sample (mm)	Number of pair of transducers	Center wave frequency (MHz)	Dimension of transducers (mm)	Nominal refractive angle (°)	Transducers spacing (mm)
25	1 pair	5～10	2～6	60	58
90	2 pairs	5～10	2～6	60	69
		2～5	6～12	45	140

TOFD (Time of Flight Diffraction) method (4)

【Sensitivity of detection】

➢**The sensitivity of detector is adjusted at the 80% of echo height from the horizontal cave that is the lowest echo. Also the noise level is kept at lower than 5 to 10%.**

Test sample

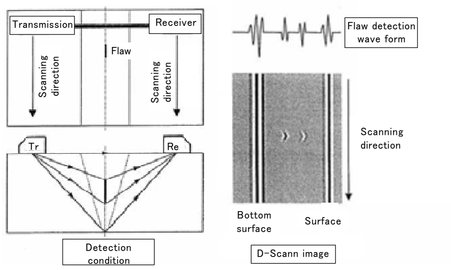


TOFD (Time of Flight Diffraction) method (5)

【Flaw detection 】

➢**The pair of probes across the weld line is manually scanned in the direction parallel to the weld.**

➢**The range of flaw to detect is within the extent to 1 inch (25.4mm) away from weld potion.**

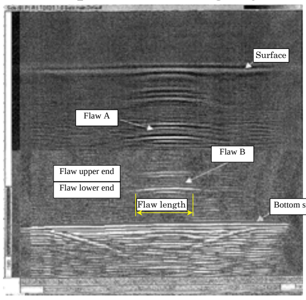


TOFD (Time of Flight Diffraction) method (6)

【Evaluation】

➢**Flaw (depth, length and height) is evaluated by D-scan image.**

An example of flaw image by D-scan

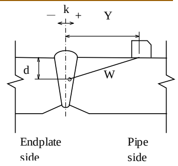


UT& TOFD inspection

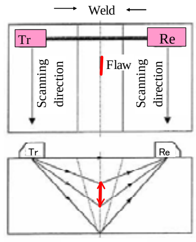
【UT inspection 】

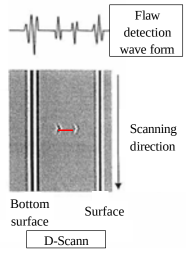
✓ **Angle beam probe detection**

✓ **Angle of refraction 70 °**



【TOFD inspection 】





✓ **High inspection efficiency**

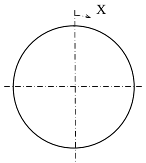
✓ **Flaw sizing in depth direction**

✓ **High sensitivity**

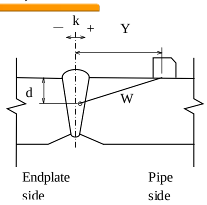
UT inspection results （Singrauli #6)

UT・TOFD inspection location

(RH outlet header)



View from end plate



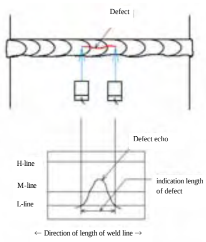
UT detection results

Flaw ?	X	Y	W	d	k	Region of echo height	l	Remarks
1	582	93	104.6	37.5	-4.7	Ⅱ	10	Out of scope of TOFD inspection
2	820	122	129.2	46.3	1.4	Ⅲ	34	
3	940	51	26.8	9.6	26	Ⅱ	6	
4	1110	101	101.3	36.3	6.4	Ⅱ	8	

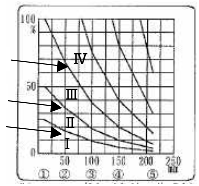
UT inspection results （Singrauli #6)

UT detection results

Flaw ?	X	Y	W	d	k	Region of echo height	l	Remarks
1	582	93	104.6	37.5	-4.7	Ⅱ	10	Out of scope of TOFD inspection
2	820	122	129.2	46.3	1.4	Ⅲ	34	
3	940	51	26.8	9.6	26	Ⅱ	6	
4	1110	101	101.3	36.3	6.4	Ⅱ	8	



Dividing curves of echo height



【Acceptance Criteria】

Region of echo height Ⅳ

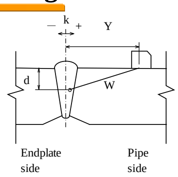
Division of thickness of weld (mm)	Length (mm)
t≦18	6
18＜t ≦ 57	1/3 of thickness of weld
57＜ t	19

*Technical standards for thermal power generation facilities

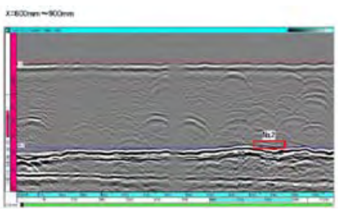
Correspondence between UT and TOFD inspection result (Singrauli 6 unit)

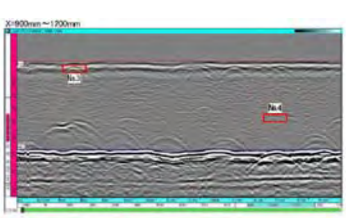
UT detection results

Flaw ?	X	Y	W	d	k	Region of echo height	l	Remarks
1	582	93	104.6	37.5	-4.7	Ⅱ	10	Out of scope of TOFD inspection
2	820	122	129.2	46.3	1.4	Ⅲ	34	
3	940	51	26.8	9.6	26	Ⅱ	6	
4	1110	101	101.3	36.3	6.4	Ⅱ	8	



【 TOFD inspection result 】





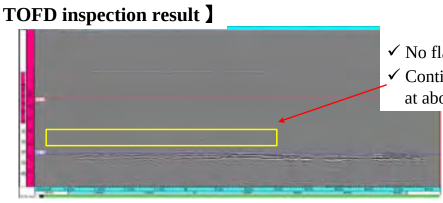
UT inspection results （Unchahar #2)

UT・TOFD inspectio n location

(Final SH outlet header)

✓ No flaw echo exceeding the criteria was detected by UT.

【 TOFD inspection result 】



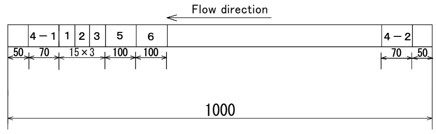
✓ No flaw echo judged as a crack.

✓ Continuous subtle flaw echoes at about 80mm in depth from surface.

Sample tube inspection

Sample tube inspection (1)

【Examination items 】



1： Scale thickness on inner surface of tube・Microstructure
2： Hardness
3： Tube Dimension
4－1： Scale volume on inner surface of tube (upper side)
Observation of scale surface
4－2： Scale volume on inner surface of tube (under side)
5： Scale composition ・Appearance of tube
6： Preservation

Sample tube inspection (2)

【 Tube appearance observation 】

Cutting the tube → Acid cleaning → Observation

100 mm in length

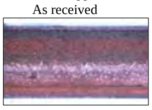
Dissolute in the acid solution
H_2O………77.6 ml
HCl………22.2 ml（8%）
Inhibitor……0.2 ml（2%）
at 60±5℃ for 1～2Hr

or

Dissolute in the ammonia solution
H_2O……58.8 ml
HCl………40 ml（10%）
H_2O_2 …1.2 ml（1.2%）
40 ~ 50 ℃ for 60 to 90 minutes
（until Cu is removed.）

Appearance of fireside of tube outside

As received



After acid cleaning

Appearance of fireside of tube inside

As received

After acid cleaning

Sample tube inspection (3)

【 Tube Dimension 】

Cutting the tube → Acid cleaning → Grinding → Measurement

12～18mm in thickness

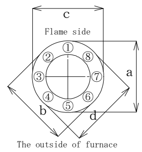
hydrochloric acid ammonia solution
HCL(35%) …29ml
Inhibitor………1ml （60±5℃）

or

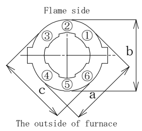
Ammonia（28%）…16ml
Bromine acid soda…… 1 g
Bicarbonate of ammonium 1.2g
（room temperature）

80 → # 600 waterproof SiC paper

- Comparison with designed dimension
- Local thinning
  (High temperature corrosion, local corrosion
- Deformation (Bulging)



a～d:Outside diameter
①～⑧:Thickness



a～c: Outside diameter
①～⑥: Thickness

Sample tube inspection (4)

【 Hardness measurement 】

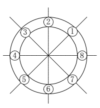
Cutting the tube → Grinding → Measurement

12～18mm in thickness

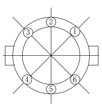
80 → # 600 water proof SiC paper

Vickers hardness test
or
Rockwell hardness test

- Comparison with virgin material data



No fin tube



Fin tube

Average of 3 times measurement for each points

Sample tube inspection (5)

【 Scale composition analysis 】

Cutting the tube → Dissolution of scale on inside surface → Evaporation to dryness → Dissolution in the acid solution for chemical analysis → Atomic Absorption Spectrometry analysis

100 mm in length

Dissolute in the acid solution
H_2O………77.6 ml
HCl………22.2 ml（8%）
Inhibitor……0.2 ml（2%）
at 60±5℃ for 1～2Hr

or

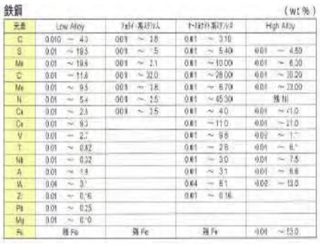
Dissolute in the ammonia solution
H_2O……58.8 ml
HCl………40 ml（10%）
H_2O_2 …1.2 ml（1.2%）
40 ~ 50 ℃ for 60 to 90 minutes
（until Cu is removed.）

Dissolute in the acid solution HCl 10cc， before HNO_3 10cc
for Atomic Absorption Spectrometry analysis

Analysis elements
Fe, Cu, Ni, Mn, Zn, Al
Fe_3O_4 : Fe＝1.38 : 1 ∴ Fe_3O_4＝Fe×1.38
CuO＝Cu×1.25, NiO＝Ni×1.27, MnO＝Mn×1.29,
ZnO=Zn×1.24, Al_2O_3＝Al×1.89

Portable chemical analysis equipment (for information)

Portable chemical composition analysis by spark exitittation

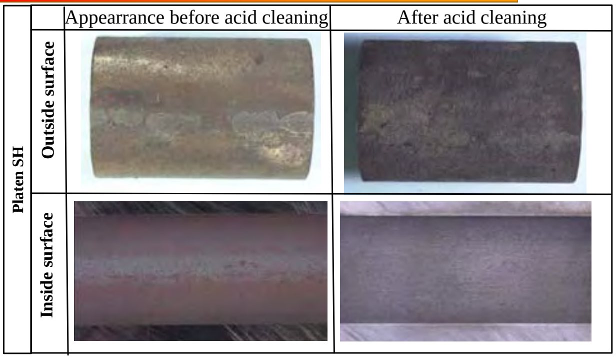


Sample tube inspection items

Singrauli #6 Sample tube	Inspection item						
	1	2	3	4	5	6	7
	Outer surface appearance	Internal surface appearance	Tube dimension・Hardness	Metallography	Scale analysis	RLA by microstructure degradation	Creep rupture test
Platen-SH #12-3	○	○	○	○	○	○	○
RH #3-1 (in penthouse)	○	○	○	○	○	○	—
RH #14-5 (in furnace)	○	○	○	○	○	○	○

Unchahar #2 Sample tube	Inspection item						
	1	2	3	4	5	6	7
	Outer surface appearance	Internal surface appearance	Tube dimension・Hardness	Metallography	Scale analysis	RLA by microstructure degradation	Creep rupture test
Platen-SH	○	○	○	○	○	○	○
Fainal-SH#1	○	○	○	○	○	○	—
Fainal-SH#119	○	○	○	○	○	○	○

Sample tube inspection (Outer surface appearance)

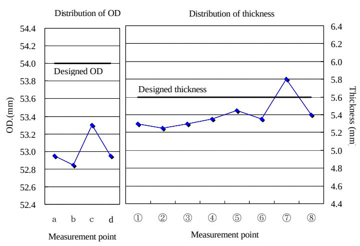


- ✓ Trace of corrosion at outside surface
- ✓ Slightly rough condition at inside surface

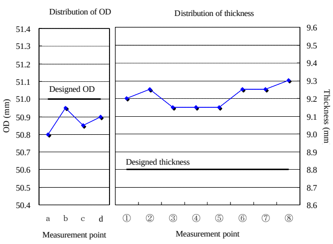
Dissolute in the acid solution
H_2O………77.6 ml
HCl………22.2 ml（8%）
Inhibitor……0.2 ml（2%）
at 60±5℃ for 1～2Hr

Sample tube inspection (Tube dimension)

RH(in penthouse) Singrauli #6

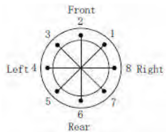


Final-SH #1 Unchahar #2

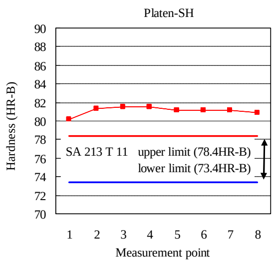


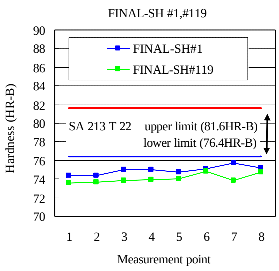
Singrauli #6
- ✓ OD of RH tubes in penthouse and in furnace was less than designed value.
- ✓ Thickness of RH tubes in penthouse was less than designed value.

Unchahar #2
- ✓ OD of each tube was less than designed value.
- ✓ Thickness of each tube was larger than the designed value.

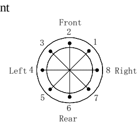


Sample tube inspection (Hardness)

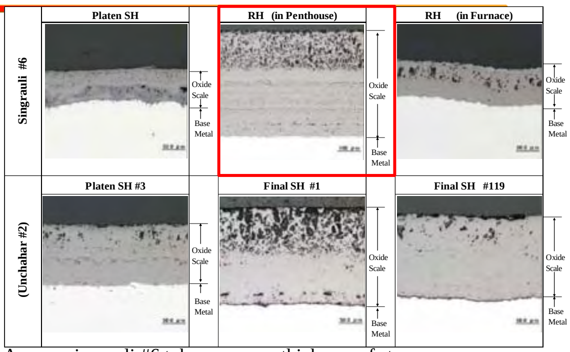




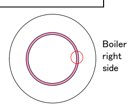
- ✓ Hardness values were stable in circumferential direction.
- ✓ Measured values in SA213T11 were higher than the normal value of virgin material by Japanese steel manufacturer.
- ✓ Measured values in SA213T22 were lower than the normal value of virgin material by Japanese steel manufacturer.



Sample tube inspection (Steam oxide scale adhering condition)



- ✓ Among singrauli #6 tubes, average thickness of steam oxide scale was remarkably large in RH tube(in penthouse) 500μm.



Sample tube inspection (6)

【 Scale adhesion volume】

Cutting the tube — 70 mm in length

↓

Removal of slag on outside surface with grinder

↓

Cutting the tube into furnace inside and outside

↓

Weight measurement with electronic balance

↓

Removal of scale with electrical polishing

↓

Measurement of weight loss with electronic balance

Scale weight of unit area mg/cm2

Electrolyte composition（10%sulfate）
Sulfate(H_2SO_4（98%） 85 ml
Inhibitor……8 ml（2%）
Thiourea (CSN2H4) 30g
Distilled water
Total 1500ml

Sample tube inspection (7)

【 Scale observation】

Cutting the tube — 12～18mm in thickness

↓

Mounting — Cold mounting with epoxy resins or acrylic resins

↓

Grinding — # 80 → # 1500 water proof SiC paper

↓

Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μ m→0.1 μ m.

↓

Scale observation


Scale on water wall tube inside


Scale on SH tube inside

The area at which the scale thickness is measured at fire side is observed with optical microscope ×100～×200 in magnification

Sample tube inspection (8)

【 Scale thickness measurement】

Cutting the tube — 12～18mm in thickness

↓

Mounting — Cold mounting with epoxy resins or acrylic resins

↓

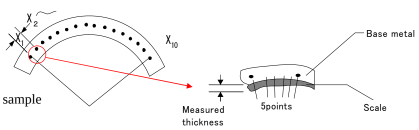
Grinding — # 80 → # 1500 water proof SiC paper

↓

Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μ m→0.1 μ m.

↓

Scale thickness measurement



・ Average thickness in 90°（180°）of sample area
・ Maximum thickness of scale
・ Scale conversion rate（Combined with the results of scale volume）

Scale conversion rate＝μ m／mg・cm²

Sample tube inspection (9)

【 Microstructural observation】

Cutting the tube — 12～18mm in thickness

↓

Mounting — Cold mounting with epoxy resins or acrylic resins

↓

Grinding — # 80 → # 1500 water proof SiC paper

↓

Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μ m→0.1 μ m.

↓

Scale observation

The area at fire side is observed with optical microscope ×100,×400 in magnification

Sample tube inspection （Sample tube specification Singrauli #6 ）

Sample	Material	Designed OD×t(mm)	Designed Temperature(℃)	Designed Pressure (MPa)
Platen-SH #12-3	SA213T11※	ϕ 47.63×t8.6	Not availabl	17.46
	SA213T11	ϕ 47.63×t10.0	Not available	
RH #3-1 (in penthouse)	SA213T22※	ϕ 54.0×t5.6	540	5.27
	SA213T22	ϕ 54.0×t5.6	540	
RH #14-5 (in furnace)	SA213T22	ϕ 54.0×t4.5	Not available	5.27
	SA213T11※	ϕ 54.0×t4.0	Not available	

Chemical composition analysis results by spark discharge optical emission analysis (wt%)

Sample tube	C	Si	Mn	P	S	Cr	Mo
Platen-SH#12-3	0.10	0.53	0.38	0.026	0.012	1.14	0.46
RH #3-1 (in penthouse)	0.10	0.28	0.45	0.013	0.008	2.20	0.95
RH #14-5 (in furnace)	0.10	0.67	0.41	0.006	0.008	1.30	0.58
SA213T11 (JIS-STBA23)	≦0.15	0.50～1.00	0.30～0.60	≦0.030	≦0.030	1.00～1.50	0.45～0.65
SA213T22 (JIS-STBA24)	≦0.15	≦0.50	0.30～0.60	≦0.030	≦0.030	1.90～2.60	0.87～1.13

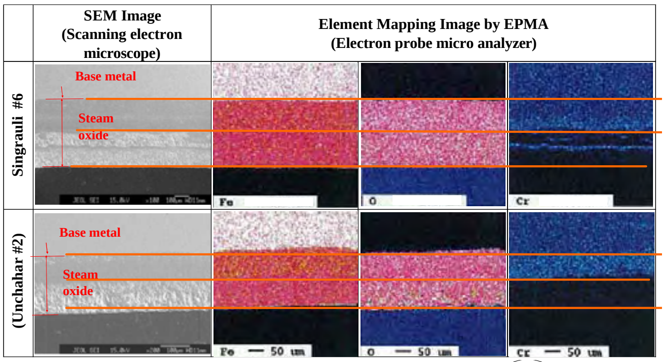
Sample tube inspection （Sample tube specification Unchahar #2 ）

Sample	Material	Designed OD×t(mm)	Designed Temperature (℃)	Designed Pressure (MPa)
Platen-SH #3-8	SA213T22	ϕ51.0×t9.6	553	17.24
	SA213T11※	ϕ51.0×t7.1	503	
Final-SH #1	SA213T22	ϕ51.0×t9.6	554	17.24
	SA213T22※	ϕ51.0×t8.8	545	
Final-SH #119	SA213T22	ϕ51.0×t9.6	545	17.24
	SA213T22※	ϕ51.0×t8.8	534	

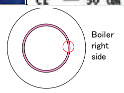
Chemical composition analysis results by spark discharge optical emission analysis (wt%)

Sample tube	C	Si	Mn	P	S	Cr	Mo
Platen-SH #3-8	0.09	0.58	0.44	0.032	0.010	1.12	0.49
Final-SH #1	0.10	0.24	0.42	0.030	0.012	2.20	0.95
Final-SH #119	0.10	0.24	0.42	0.030	0.013	2.22	0.96
SA213T11 (JIS-STBA23)	≦0.15	0.50～1.00	0.30～0.60	≦0.030	≦0.030	1.00～1.50	0.45～0.65
SA213T22 (JIS-STBA24)	≦0.15	≦0.50	0.30～0.60	≦0.030	≦0.030	1.90～2.60	0.87～1.13

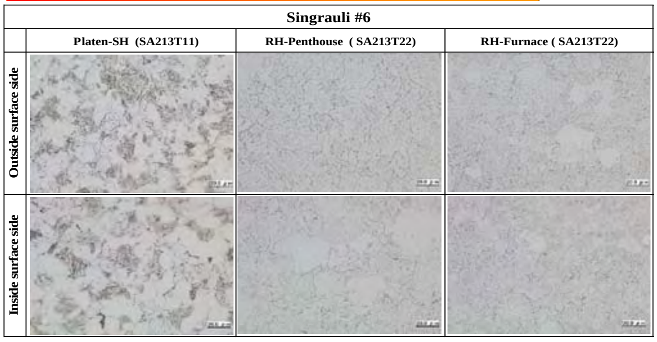
Sample tube inspection (Steam oxide scale composition analysis)



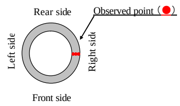
✓ Dual layer comosed of inner layer (Fe, O, Cr) and outer layer (Fe, O).



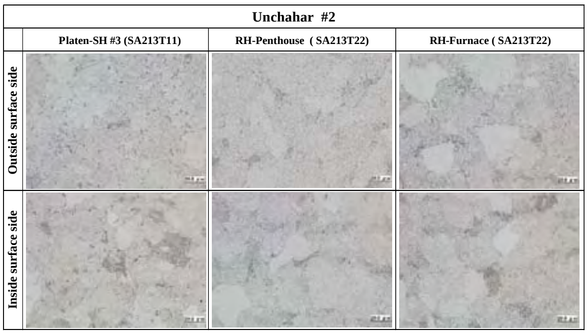
Sample tube inspection (Metallogrphy)



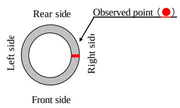
✓ Slight degradation observed in RH-Penthouse (SA213T22).



Sample tube inspection (Metallogrphy)



✓ No remarkable degradation for each tube

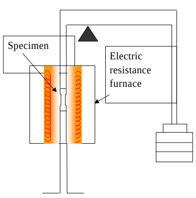


Creep rupture test

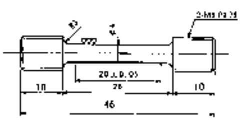
Creep rupture test (1)

Creep rupture test is the most reliable method to evaluate the remaining creep life.

(Test machine)



(Example of specimen for creep rupture test)



➤ **The larger size of specimen is better because of oxidation during the test.**

(Test condition)

➤**Test condition is determined based on the hoop stress under operational condition.**
➤**In order to shorten the test time, test stress or temperature are set at higher than operational condition.**

Creep rupture test (Parameter method) (2)

(Example of test condition and result by parameter method)

➤ **The lowest stress is almost same stress as operational stress .
The temperature is set so that the estimated creep rupture time is within about 3000hrs .**

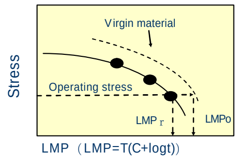
➤ **With the test temperature and rupture time, LMP (Larson-Miller parameter) is obtained.**

Sample	Material	Test condition		Estimated rupture time (h)	Rupture time t (h)	Rupture LMP C=15.8
		Temperature T (℃)	Stress (MPa)			
2nd SH tube	A213 T22	670	30	2,500	1,200	17,806
		670	40	1,500	600	17,522
		670	50	800	400	17,356
		670	60	400	100	16,788

LMP = (273.15+T) (C+log t)

Creep rupture test（Parameter method）(3)

- If the reliable virgin material data is available, the equivalent temperature can be estimated and residual life is evaluated with the equivalent temperature instead of designed temperature.



LMPr by test data at operating stress
LMPo by virgin material data base at operating stress

Assumption :

Initial creep rupture strength = Virgin material data

Residual life “tr” at a temperature T : $tr = 10^{(LMPr/T - C)}$
The whole life “ t “ of the virgin material at a temperature T : $t = 10^{(LMPo/T - C)}$
To hold the assumption that “ $t = tr + to$ (to: operating hour)” ,
appropriate T_E can be determined.
The residual life tr is calculated at temperature T_E
$tr = 10^{(LMPo/(273.15+T_E) - C)}$

Creep rupture test (Isostress method) (4)

(Example of test condition and result)

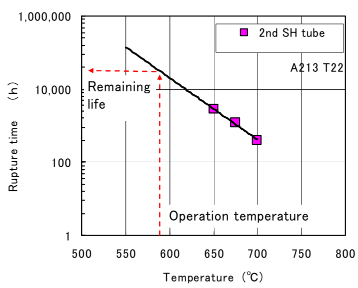
- **The stress is set same as operational stress .**
- **The lowest temperature is set so that the estimated creep rupture time is within about 3000hrs .**

Sample	Material	Test condition		Estimated rupture time	Rupture time
		Temperature T（℃）	Stress (MPa)		t（h）
2nd SH tube	A213 T22	650	30	2,500	2,400
		675	30	1,000	1,200
		700	30	200	400

Creep rupture test (Isostress method) (5)

(Evaluation of test result by Isostress method)

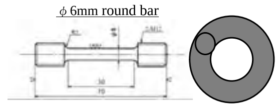
- **The rupture time is extrapolated to operation temperature.**



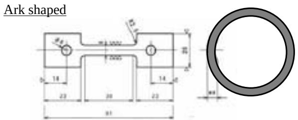
Creep rupture test (condition and test specimens) Singrauli #6

Sample tube	Portion	Material	Test condition		Shape of specimen
			Tem. (℃)	Stress (MPa)	
Platen-SH	Base Metal	SA213T11	665	49.0	f 6mm round bar
			665	63.7	
			700	38.3	
	Weld Metal	SA213T11	665	49.0	
			665	63.7	
			700	38.3	
RH(in furnace)	Base Metal	SA213T11	665	44.1	Arc shaped
			665	58.8	
			700	27.9	
	Weld Metal	SA213T11	665	44.1	
			665	58.8	
			700	27.9	

φ 6mm round bar



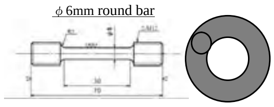
Ark shaped



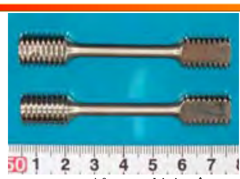
Creep rupture test (condition and test specimens) Unchahar #2

Sample tube	Portion	Material	Test condition		Shape of specimen
			Tem. (℃)	Stress (MPa)	
Platen-SH	Base Metal	SA213T11	635	68.6	φ 6
			635	83.4	
			665	45.9	
	Weld Metal	SA213T11	665	68.6	
			665	83.4	
			700	45.9	
Final-SH #119	Base Metal	SA213T22	665	63.7	φ 6
			665	78.5	
			700	38.3	
	Weld Metal	SA213T22	665	63.7	
			665	78.5	
			700	38.3	

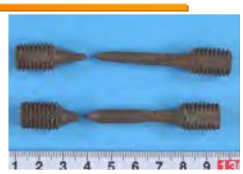
φ 6mm round bar



Creep rupture test specimens before and after testing

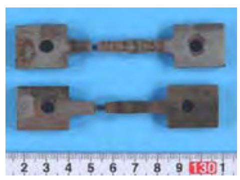


After machining ↑



After creep rupture test ↑

After machining ↑



After creep rupture test ↑

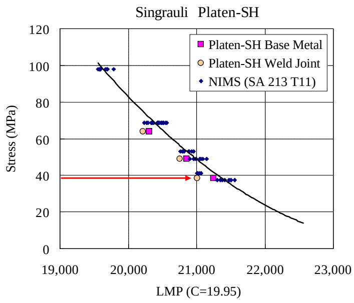
Creep rupture test results Singrauli #6

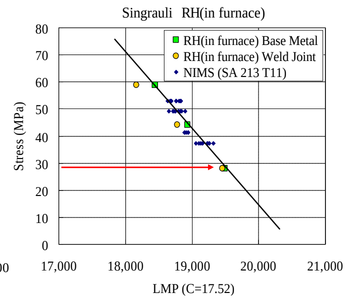
Component		Material	Test condition Temp. T (℃)	Stress (MPa)	Rupture time t (h)	LMP* C=19.95	Fracture elongation (%)	Reduction of area (%)
Platen-SH	Base Metal	SA 213 T11	665	49.0	187.7	20,852	102	97
			665	63.7	48.7	20,302	87	94
			700	38.3	76.1	21,248	88	94
	Weld Metal	SA 213 T11	665	49.0	149.0	20,758	36	92
			665	63.7	39.0	20,212	44	92
			700	38.3	43.5	21,012	35	95

Component		Material	Test condition Temp. T (℃)	Stress (MPa)	Rupture time t (h)	LMP* C=17.52	Fracture elongation (%)	Reduction of area ** (%)
RH(in furnace)	Base Metal	SA 213 T11	665	44.1	457.0	18,933	53	57
			665	58.8	139.2	18,448	62	63
			700	27.9	319.4	19,488	39	55
	Weld Metal	SA 213 T11	665	44.1	310.9	18,776	20	52
			665	58.8	69.3	18,164	13	53
			700	27.9	296.8	19,457	16	56

- LMP=(273.15+T) (C+log t)
- Facture elongation : (L-Lo)/Lo, Lo: Initial gauge length, L: Gauge length after rupture
- Reduction of area : (Ao-A)/Ao, Ao: Initial cross sectional area, A: cross sectional area after rupture

Creep rupture test results Singrauli #6





NIMS : Natinal Institute of Materials Science

✓Creep rupture strength of base metal in Platen-SH is lower than NIMS data.

✓ Creep rupture strength of base metal in RH (in furnace) is almost same as NIMS data.

* LMP=(273.15+T) (C+log t)

Residual life evaluation by creep rupture test Singrauli #6

Parameter method (evaluated at designed temp.)

Component		Material	Hoop Stress σ (MPa)	LMP obtained by creep rupture test C=19.95 (SH) C=17.52 (RH)	Designed temp.T (℃)	Residual life tr (h)	Creep life consumption ratio φc to/(to+tr)	Evaluated residual life tr/2 (h)
Platen-SH	Base Metal	SA 213 T11	38.3	21,248	540(※1)	1,505,000	0.10	750,000
	Weld Joint	SA 213 T11	38.3	21,012	540(※1)	770,000	0.18	380,000
RH(in furnace)	Base Metal	SA 213 T11	27.9	19,488	540(※2)	2,783,000	0.06	1,300,000
	Weld Joint	SA 213 T11	27.9	19,457	540(※2)	2,549,000	0.06	1,200,000

※1; Designed temp. at Platen-SH Outlet Header
※2; Designed temp. at RH Outlet Header
Operation hours to : 172000 h

✓ Hoop stress σ = P (D-t) / 2t

where P : Designed pressure
D : Measured OD of sample tube
t : Measured thickness of sample tube

✓ $tr = 10^{(LMP/(273+T)-C)}$

Residual life evaluation by creep rupture test Singrauli #6

Parameter method (evaluated at equivalent temp.)

Component		Material	Hoop Stress σ (MPa)	LMP obtained by creep rupture test C=19.95 (SH) C=17.52 (RH)	LMPo by NIMS virgin material	Equivalent temperature T_E (℃)	Residual life tr (h)	Creep life consumption ratio φc to/(to+tr)	Evaluated residual life tr/2 (h)
Platen-SH	Base Metal	SA 213 T11	38.3	21,248	21,339	553	598,000	0.22	290,000
	Weld Joint	SA 213 T11	38.3	21,012	21,339	553(※3)	309,000	0.36	150,000
RH(in furnace)	Base Metal	SA 213 T11	27.9	19,488	19,531	551	1,347,000	0.11	670,000
	Weld Joint	SA 213 T11	27.9	19,457	19,531	551(※3)	1,235,000	0.12	610,000

※3; Same equivalent temperature used as base metal
Operation hours to : 172000 h

Assumption : Initial creep rupture strength = NIMS data

$$LMPo = (273.15+T_E) (C+\log (to+tr))$$

$$tr = 10^{(LMP/(273.15+T_E) - C)}$$

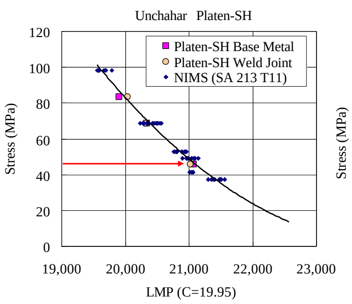
Creep rupture test results Unchahar #2

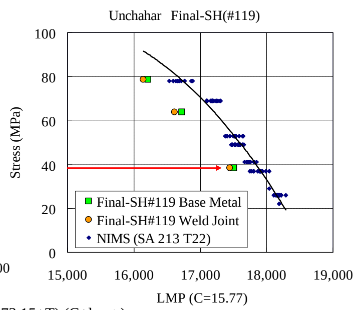
Component		Material	Test condition Temp. T(℃)	Stress (MPa)	Rupture time t (h)	LMP C=19.95	Fracture elongation (%)	Reduction of area (%)	Remark
Platen-SH	Base Metal	SA 213 T11	635	68.6	278.7	20,341	62	94	Ruptured
			635	83.4	90.8	19,899	57	91	Ruptured
			665	45.9	322.4	21,072	86	94	Ruptured
	Weld Metal	SA 213 T11	635	68.6	264.3	20,320	16	81	Ruptured
			635	83.4	127.5	20,033	18	82	Ruptured
			665	45.9	287.5	21,026	13	80	Ruptured

Component		Material	Test condition Temp. T(℃)	Stress (MPa)	Rupture time t (h)	LMP C=15.77	Fracture elongation (%)	Reduction of area (%)	Remark
Final-SH#119	Base Metal	SA 213 T22	665	63.7	113.1	16,725	69	91	Ruptured
			665	78.5	32.1	16,212	55	92	Ruptured
			700	38.3	162.6	17,503	67	94	Ruptured
	Weld Metal	SA 213 T22	665	63.7	86.0	16,614	30	84	Ruptured
			665	78.5	27.3	16,146	31	83	Ruptured
			700	38.3	143.7	17,451	22	81	Ruptured

LMP=(273.15+T) (C+log t)

Creep rupture test results Unchahar #2





* LMP=(273.15+T) (C+log t)

✓Creep rupture strength of SA 213 T22 is lower than NIMS data.

✓ Creep rupture strength of SA213 T11 is almost same as NIMS data.

Creep rupture test results Unchahar #2

Parameter method (evaluated at designed temp.)								
Component		Material	Hoop Stress (MPa)	LMP obtained by creep rupture test C=19.95 (T11) C=15.77 (T22)	Designed temp.T (℃)	Residual life tr (h)	Creep life consumption ratio φc to/(to+tr)	Evaluated residual life tr/2 (h)
Platen-SH	Base Metal	SA 213 T11	45.9	21,072	503	15,726,180	0.01	7,800,000
	Weld Joint	SA 213 T11	45.9	21,026	503	13,692,433	0.01	6,800,000
Final-SH#119	Base Metal	SA 213 T22	38.3	17,503	534	812,994	0.15	400,000
	Weld Joint	SA 213 T22	38.3	17,451	534	700,466	0.17	350,000

Operation hours to: 139098 h

Parameter method (evaluated at equivalent temp.)									
Component		Material	Hoop Stress (MPa)	LMP obtained by creep rupture test	LMPo by NIMS virgin material	Equivalent temperature TE (℃)	Residual life tr (h)	Creep life consumption ratio φc to/(to+tr)	Evaluated residual life tr/2 (h)
				C=19.95 (T11) C=15.77 (T22)					
Platen-SH	Base Metal	SA 213 T11	45.9	21,072	21,072	Non evaluation(※1)			
	Weld Joint	SA 213 T11	45.9	21,026	21,072				
Final-SH#119	Base Metal	SA 213 T22	38.3	17,503	17,865	573	82,798	0.63	41,000
	Weld Joint	SA 213 T22	38.3	17,451	17,865	573(※2)	71,826	0.66	35,000

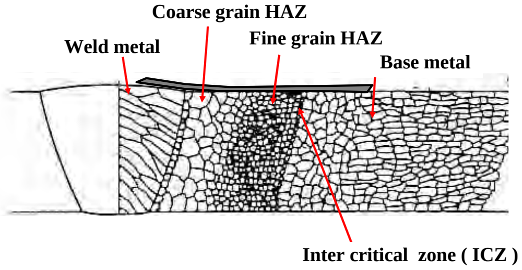
※1; Equivalent temperature could not be evaluated since the test results for base metal in Platen-SH tube indicate higher creep rupture strength than NIMS data.

※2; Same equivalent temperature used as base metal

Sampling of replica and extracted replica

Sampling of replica and extracted replica (1)

Microstructure of weld portion cross section

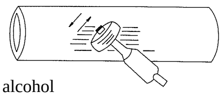


Residual life assessment by microstructural comparison method

Sampling of replica and extracted replica (2)

Grinding

Grinding with handy flexible grinder wheel until #120 roughness



Fine grinding

Grinding with PVA（polyvinyl alcohol (PVA)-based porous elastic grinding wheel until #60 ～#1000 roughness

Polishing

Polishing with 3 μ m ～0.25 μ m diamond particles.

Chemical etching

Etchant

For carbon steel,low alloy steel :

Nital (Ethanol 100ml ＋ 2～5ml HNO_3)

For Austenitic alloy steel：

Villella's solution (Ethanol 94ml+ HCl 5ml + picric acid 1g)

Sampling of replica and extracted replica (3)

Drying

Wash out the etchant with ethanol and dry with air spray.

Replica sampling

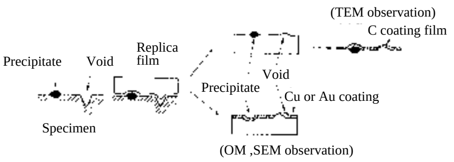
Stick a replica film on dropping the methyl acetate.
Take off the replica film after drying out, paste it on a slide glass.

OM, SEM observation

Polishing

Polishing again with 1 μ m diamond particles.

Chemical etching



Extracted Replica sampling

TEM observation

Boiler remaining life assessment

Japanese Boiler RLA Guidline (1)

To extend periodical inspection interval 2 year to 4year after 100,000 hours operation.

(1) Degradation factor to be evaluated

- Creep rupture remaining life
  (Designed temperature beyond 450℃)

(2) Components to be evaluated

- Furnace evaporation header
- Super heater header or Main steam pipe
- Reheater header or High temperature reheat pipe

Representative points among high heat loaded and high stressed portion in these components

Japanese Boiler RLA Guideline (2)

(3) Method to assess the remaining life

- More than one method used as shown in table below

Method	Guideline		This study	
	Base metal	Weld (HAZ)	Base metal	Weld (HAZ)
Hardness measuring	—	○		
Electrical resisitance	—	○		
Chemical composition of carbide	○	○		
Creep cavity evaluation	—	○		
Microstructural comparison	○	○	○	○
Urtra sonic scattering noise	—	○		
Interparticle spacing	○	—		
Crystal grain deformation	○	—		
Destructive test	○	○		
Analytical method	○	○		

○ : applicable, − : not applicable

(4) Effective (countable) remaining life

- 1/ 2 of remaining life evaluated by above methods

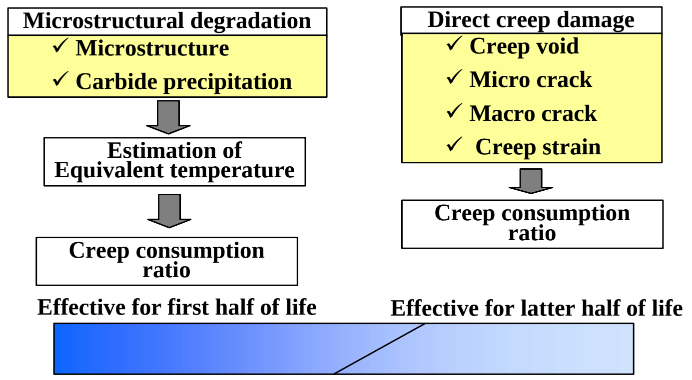
Microstructural comparison method outline

Remaining life synthetically evaluated by three types of damage related to the creep damage ratio as shown below.

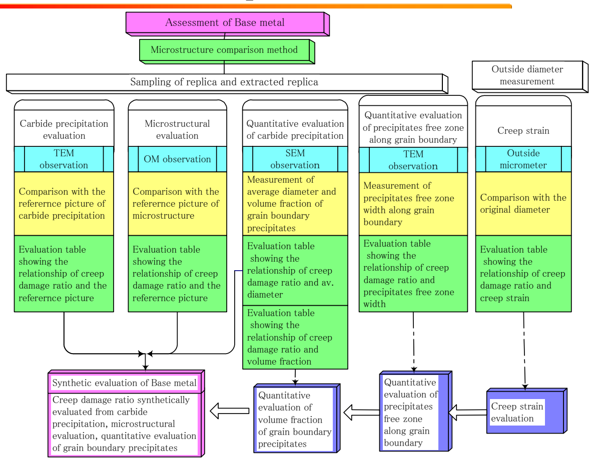
【Base metal】
・Evaluation of average diameter of grain boundary precipitates
・Comparison with the reference picture of microstructure
・Comparison with the reference picture of carbide precipitation

【Weld metal】
・Comparison with the reference picture of creep void and micro crack
・Comparison with the reference picture of microstructure
・Comparison with the reference picture of carbide precipitation

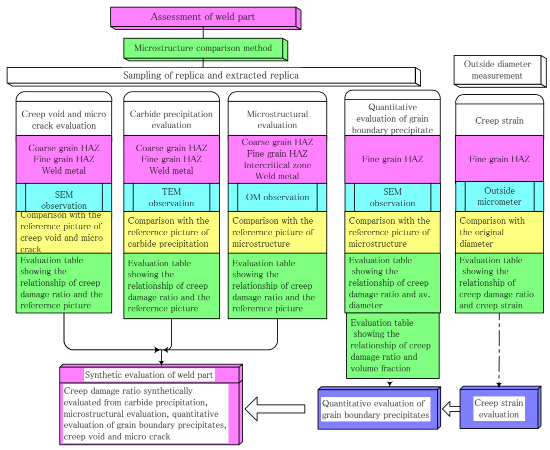
Microstructural comparison method



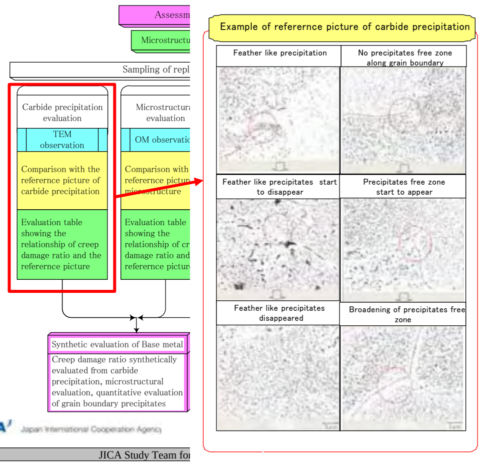
Microstructural comparison method (Base metal)



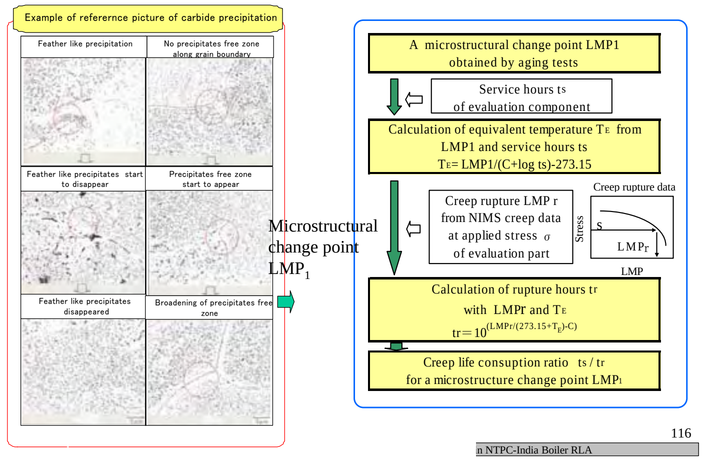
Microstructural comparison method (Weld portion)



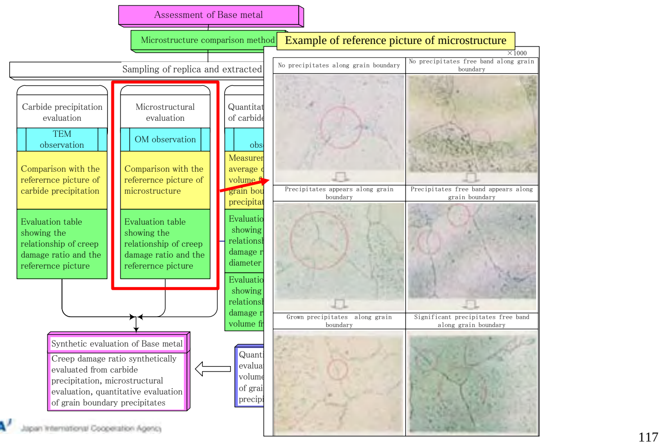
Microstructural comparison method in this study (Base metal)



Microstructural comparison method in this study (Base metal)

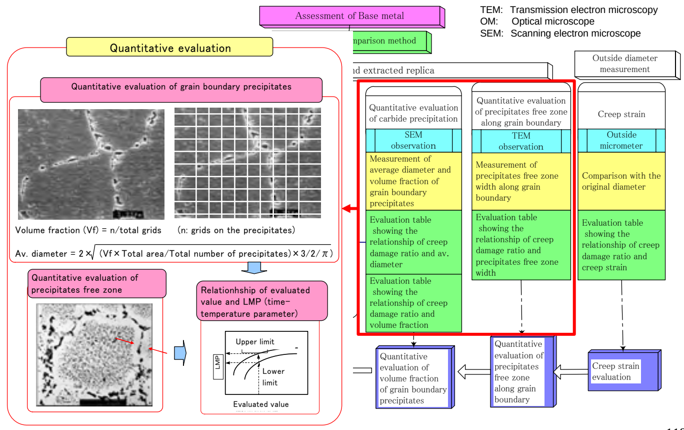


Microstructural comparison method in this study (Base metal)



Microstructural comparison method in this study (Base metal)

TEM: Transmission electron microscopy
OM: Optical microscope
SEM: Scanning electron microscope

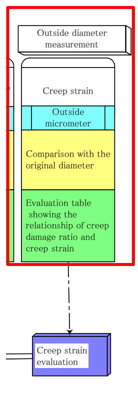


Microstructural comparison method in this study (Base metal)

Creep strain evaluation

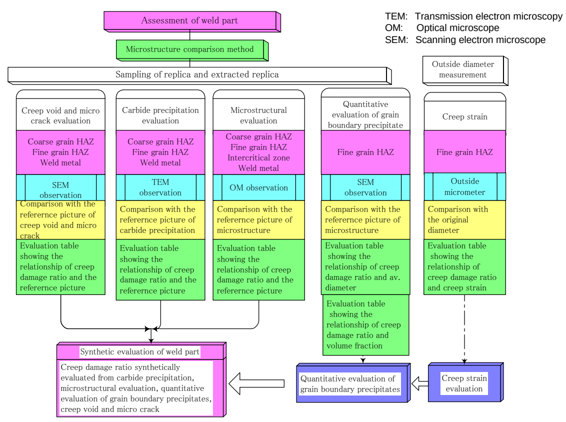
【Example of the relationship between creep damage ratio and creep strain e】

Creep strain e＜1.0%	: 0～70%
Creep strain 1.0%≦ e ≦2.0%	: 50～80%
Creep strain e ≧2.0%	: 70～100%

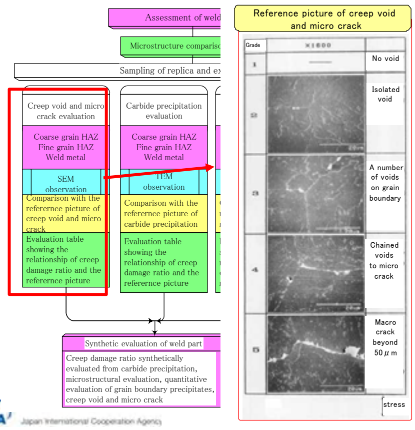


Microstructural comparison method in this study (Weld)

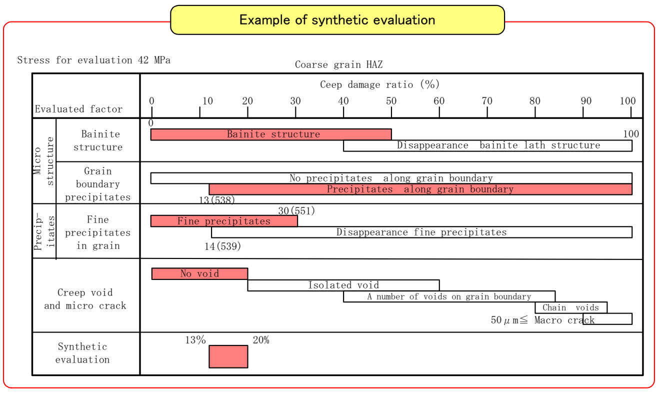
TEM: Transmission electron microscopy
OM: Optical microscope
SEM: Scanning electron microscope



Microstructural comparison method in this study (Weld)



Synthetic evaluation by microstructural comparison method in this study



Replica inspection (Singrauli #6)

Component		Material	Designed OD (mm)	Designed t (mm)	Designed Temp. (℃)	Designed Pressure (MPa)	Hoop Stress (MPa)
Platen SH Outlet Header	Left	SA335P12	508.0	80.0	540	17.46	46.69
De-SH	Left Right	SA335P12	508.0	70.0	406	18.51	57.89
RH Outlet Header	Left Right	SA335P22	558.8	50.0	540	4.26	21.68
Main Steam Pipe	Left	SA335P22	520.0	85.0	540	17.46	44.67

Replica inspection (Unchahar #2)

Component		Material	Designed OD (mm)	Designed t (mm)	Designed Temp. (℃)	Designed Pressure (MPa)	Hoop Stress (MPa)
Final SH Outlet Header		SA335P22	457.2	100.0	555	15.75	28.1
De-SH	Left Right	SA335P12	406.4	45.0	450	16.44	66.0
RH Outlet Header		SA335P22	558.8	45.0	555	4.32	24.7
Main Steam Pipe	Right	SA335P22	355.6	50.3	540	15.74	47.8
Hot Reheat Pipe	Right	SA335P22	508.0	28.0	540	3.69	31.6

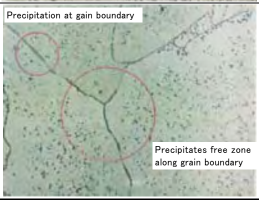
Observation of replica

Observation item	Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method	Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target	Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification	×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area: Base metal	○	○	○		○	○
Observed area: Intercritical zone	○					
Observed area: Fine grain HAZ	○	○			○	○
Observed area: Coarse grain HAZ	○	○		○		
Observed area: Weld metal	○	○				

Microstructure observation results (Singrauli #6)

Components	Location		Observed region	Optical microscope observation – Microstructural features: Precipitation at gain boundary	Precipitates free zone along grain boundary
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Base metal	Appeared	Not appeared
			Intercritical zone	Appeared	Not appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Not appeared	
			Weld metal		
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Appeared
			Intercritical zone	Appeared	Appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Not appeared	
			Weld metal		

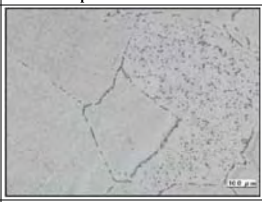
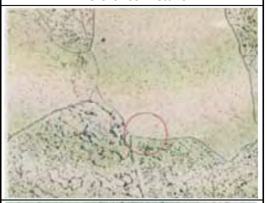
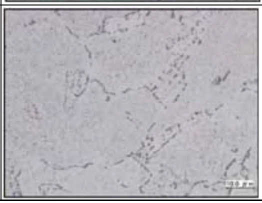
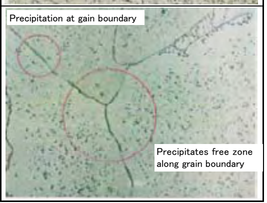
Microstructure observation results (Singrauli #6)

		Replica microstructure	Reference Picture
RH outlet header left (SA 335 P22)	Base metal		
Main steam pipe left (SA 335 P22)	Base metal		

Microstructure observation results (Unchahar #2)

Components	Location		Observed region	OM (Optical microscope observation) Microstructural features: Precipitation at gain boundary	Precipitates free zone along grain boundary
Final SH outlet header (SA 335 P22)	Rightside of header	Circumferential weld	Base metal	Appeared	Not appeared
			Intercritical zone	Not appeared	Not appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Appeared	
			Weld metal		
Main steam pipe (SA 335 P22)	Right	Circumferential weld (near the stop valve)	Base metal	Appeared	Not appeared
			Intercritical zone	Appeared	Not appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Not appeared	
			Weld metal		

Microstructure observation results (Unchahar #2)

		Replica microstructure	Reference Picture
Final SH outlet header (SA 335 P22)	Base metal		
Main steam pipe right (SA 335 P22)	Base metal		

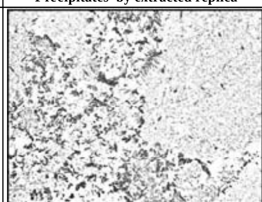
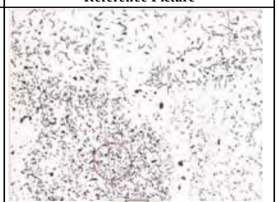
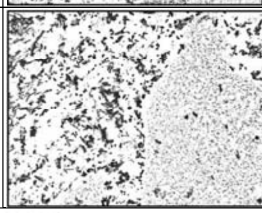
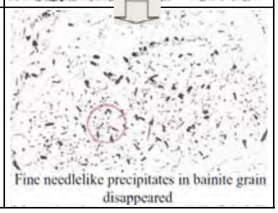
Observation of replica

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				

Precipitates distribution observation results (Singrauli #6)

Components	Location		Observed region	TEM (Transmission Electron Microscope observation) Carbide precipitates features: Precipitates free zone along grain boundary	Featherlike precipitates	Fine needlelike and granular precipitates	Needlelike precipitates	Fine needlelike and granular precipitates in bainite grain
Reheater outlet header (SA 335 P22)	Right	Circumferential weld	Base metal	Not appeared	Remained		No decrease in ferrite grain	Remaining
			Fine grain HAZ				Remaining	
			Coarse grain HAZ			Remaining		
			Weld metal			Remaining		
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared
			Fine grain HAZ				Disappeared	
			Coarse grain HAZ			Disappeared		
			Weld metal			Disappeared		

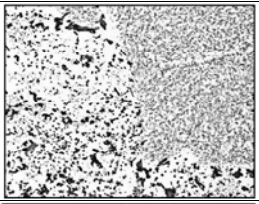
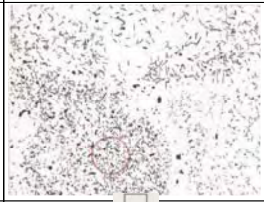
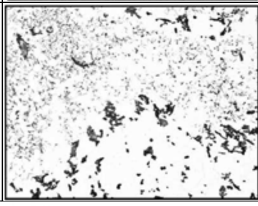
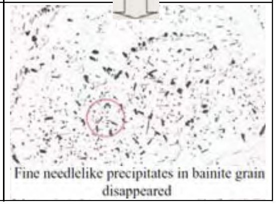
Precipitates distribution observation results Singrauli #6

		Precipitates by extracted replica	Reference Picture
RH outlet header left (SA 335 P22)	Base metal		
Main steam pipe left (SA 335 P22)	Base metal		

Precipitates distribution observation results （Unchahar #2)

Components	Location		Observed region	TEM (Transmission Electron Microscope observation) Precipitates features: Precipitates free zone along grain boundary	Featherlike precipitates	Fine needlelike and granular precipitates	Needlelike precipitates	Fine needlelike and granular precipitates in bainite grain
Final SH outlet header (SA 335 P22)	Left outlet header	Circumferential weld	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared
			Fine grain HAZ				Remaining	
			Coarse grain HAZ			Remaining		
			Weld metal			Remaining		
Main steam pipe (SA 335 P22)	Right	Circumferential weld (near the stop valve)	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Disappeared
			Fine grain HAZ				Spherodized	
			Coarse grain HAZ			Remaining		
			Weld metal			Remaining		

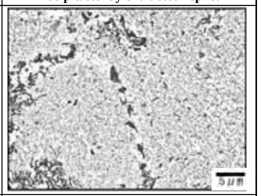
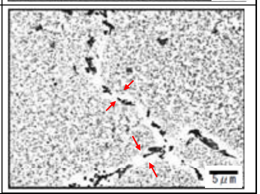
Precipitates distribution observation results Unchahar #2

		Precipitates by extracted replica	Reference Picture
Final SH outlet header (SA 335 P22)	Base metal		
Main steam pipe right (SA 335 P22)	Base metal		

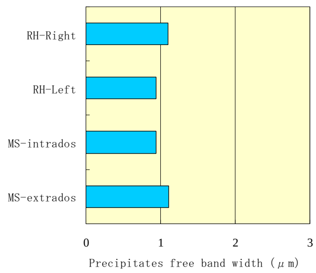
Quantitative evaluation of precipitates free band width

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				

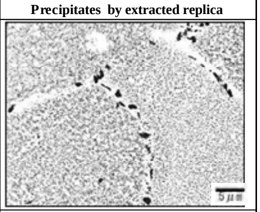
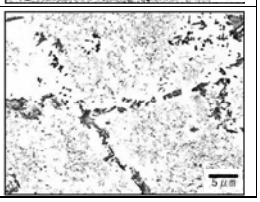
Quantitative evaluation of precipitates free band width

		Precipitates by extracted replica
RH outlet header left (SA 335 P22)	Base metal	
Main steam pipe left (SA 335 P22)	Base metal	

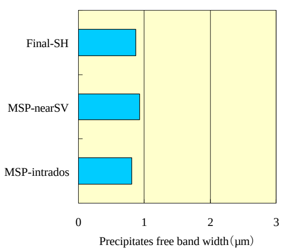
Singrauli #6



Quantitative evaluation of precipitates free band width

		Precipitates by extracted replica
Final SH outlet header (SA 335 P22)	Base metal	
Main steam pipe right (SA 335 P22)	Base metal	

Unchahar #2



Observation of replica

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				

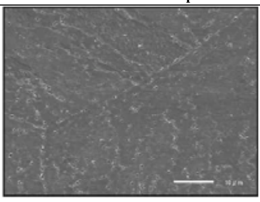
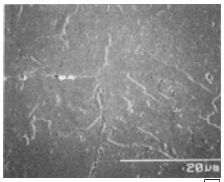
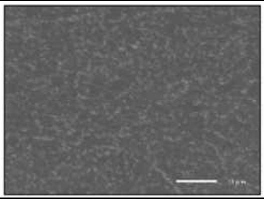
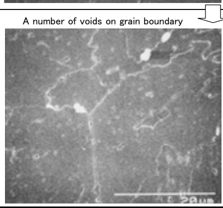
Creep void observation results (Singrauli #6)

Components	Location		Observed region	SEM (Scanning Electron Microscope observation) Creep void damage
RH outlet header	Right	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
Main steam pipe	Left	Circumferential weld (near the stop valve) extrados side	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void

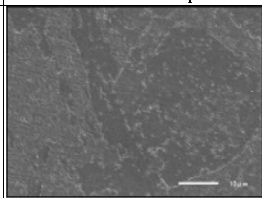
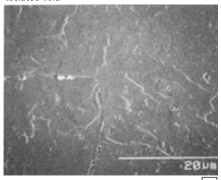
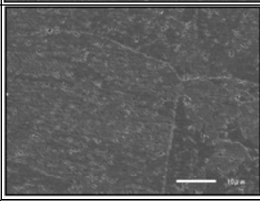
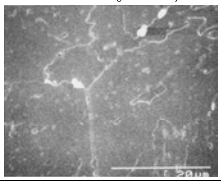
Creep void observation results (Unchahar #2)

Components	Location		Observed region	SEM (Scanning Electron Microscope observation) Ceep void damage
Final SH outlet header	Rightside of header	Circumferential weld	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void
Main steam pipe	Right	Circumferential weld (near the stop valve)	Fine grain HAZ	No void
			Coarse grain HAZ	No void
			Weld metal	No void

Creep void observation results (Singrauli #6)

		SEM observation of replica	Reference Picture
RH outlet header left (SA 335 P22)	Coarse grain HAZ		Isolated void 
Main steam pipe left (SA 335 P22)	Coarse grain HAZ		A number of voids on grain boundary 

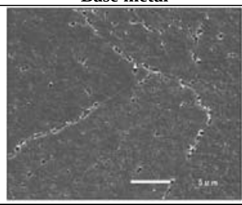
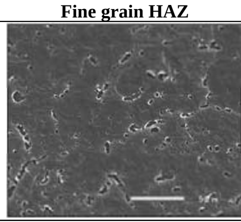
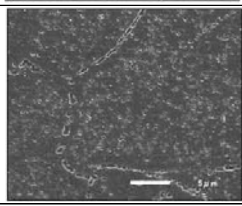
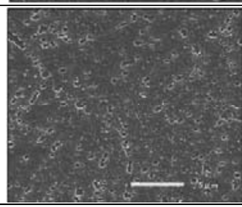
Creep void observation results (Unchahar #2)

		SEM observation of replica	Reference Picture
Final SH outlet header (SA 335 P22)	Base metal		Isolated void 
Main steam pipe right (SA 335 P22)	Base metal		A number of voids on grain boundary 

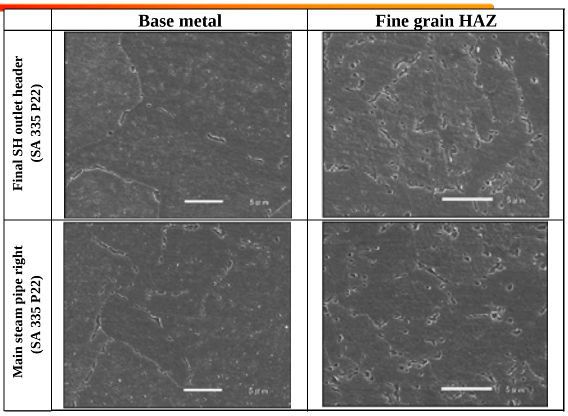
Average diameter and volume fraction of grain boundary precipitates

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				

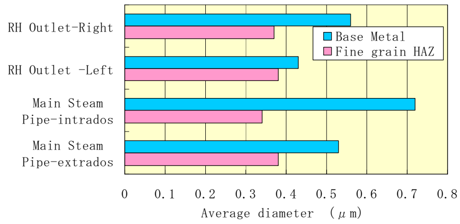
Average diameter and volume fraction of grain boundary precipitates （Singrauli #6)

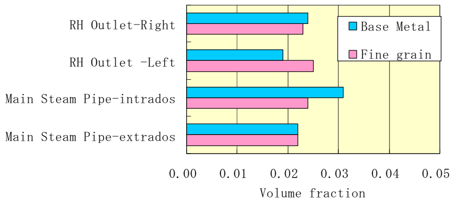
	Base metal	Fine grain HAZ
RH outlet header left (SA 335 P22)		
Main steam pipe left (SA 335 P22)		

Average diameter and volume fraction of grain boundary precipitates (Unchahar #2)

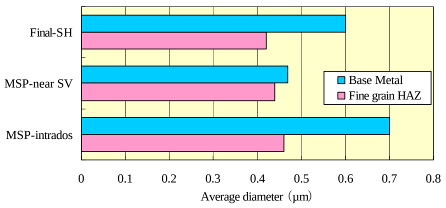


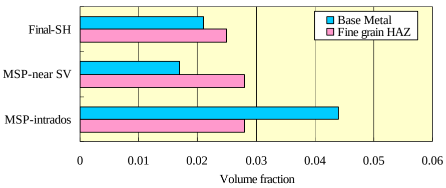
Average diameter and volume fraction of grain boundary precipitates (Singrauli #6)



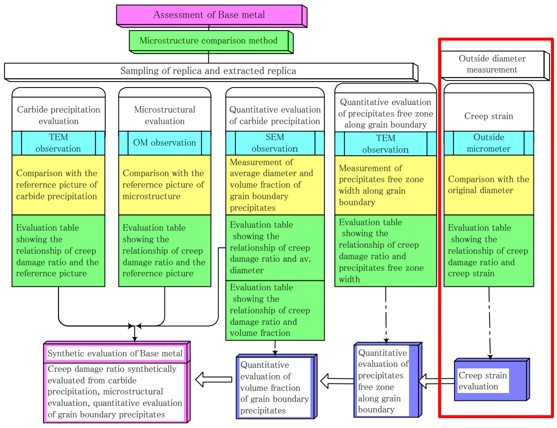


Average diameter and volume fraction of grain boundary precipitates (Unchahara #2)

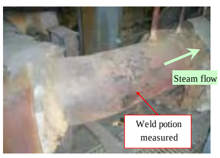




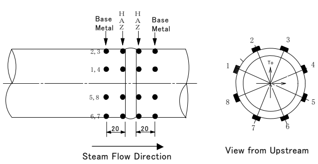
Microstructural comparison method



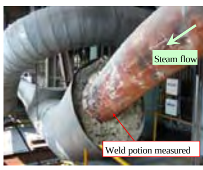
Creep strain evaluation by OD measurement (Singrauli #6)



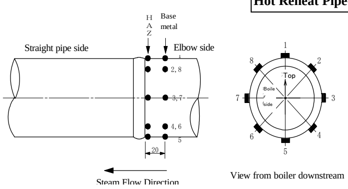
Components	(Averaged measured value-Designed OD) /Designed OD (%)
Platen SH Outlet Header-Left	0.10
De-Superheater-Left	0.94
De-Superheater-Right	0.55
RH Outlet Header-Left	0.37
RH Outlet Header-Right	0.52
Main Steam Pipe-Left	0.08



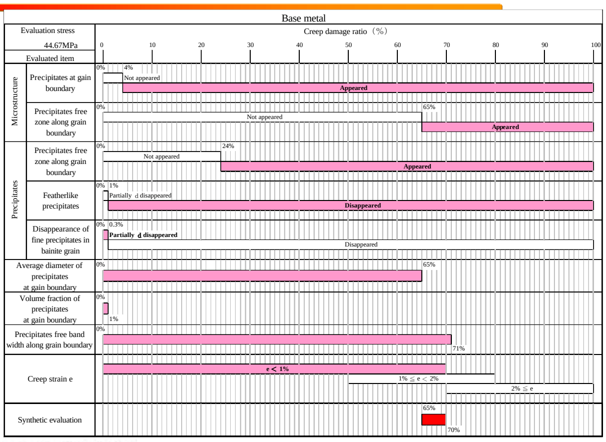
Creep strain evaluation by OD measurement (Unchahar #2)



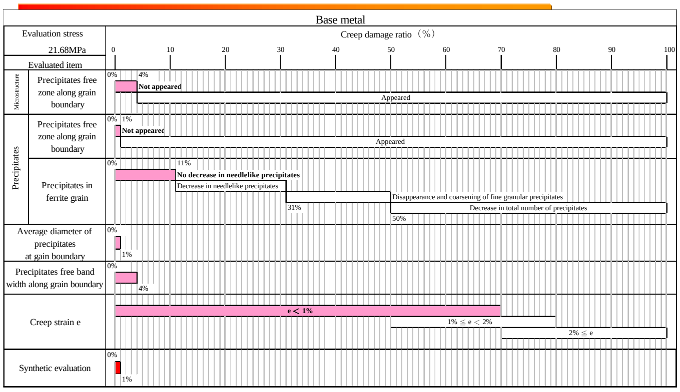
Components	(Averaged measured value-Designed OD) /Designed OD (%)
Final SH Outlet Header	0.74
De-Superheater-Left	0.44
De-Superheater-Right	0.46
RH Outlet Header at left side	0.20
RH Outlet Header at right	0.57
Main Steam Pipe-Right	—
Hot Reheat Pipe-Right	0.01



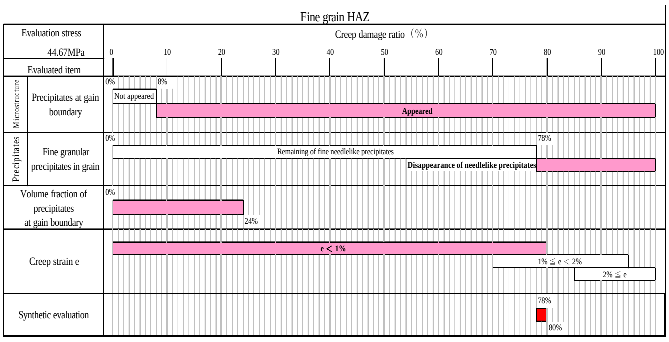
Synthetic evaluation (Base metal of MSP) Singrauli #6



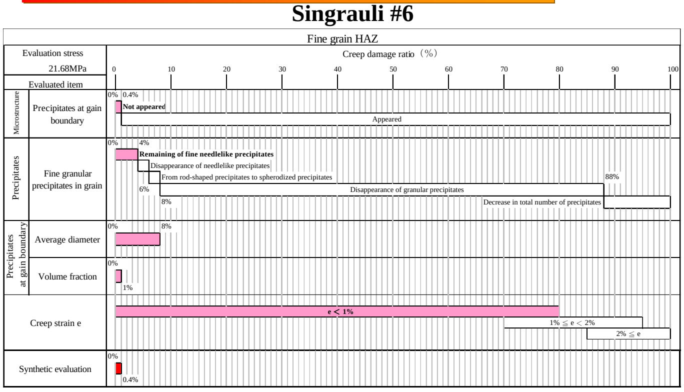
Synthetic evaluation (Base metal of RH header left) Singrauli #6



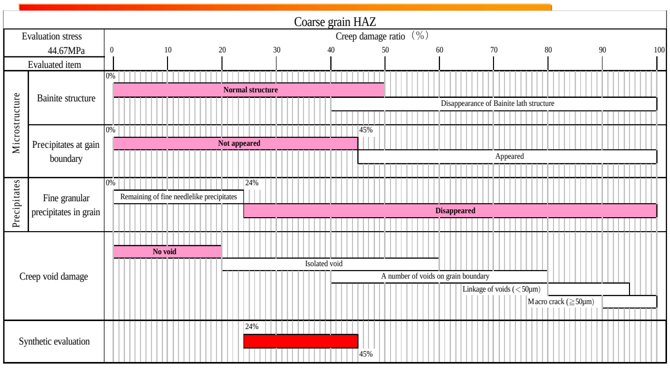
Synthetic evaluation (Fine grain HAZ of MSP) Singrauli #6



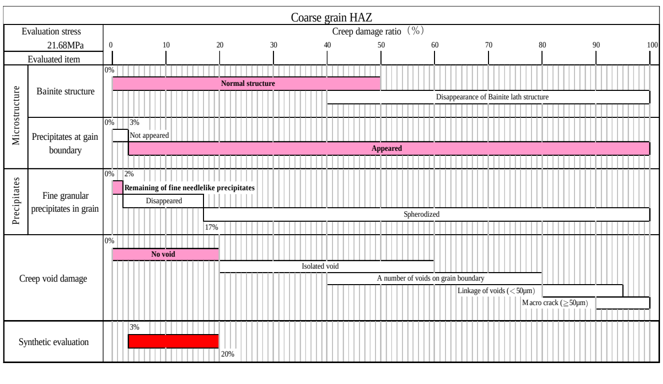
Synthetic evaluation (Fine grain HAZ of RH header left) Singrauli #6



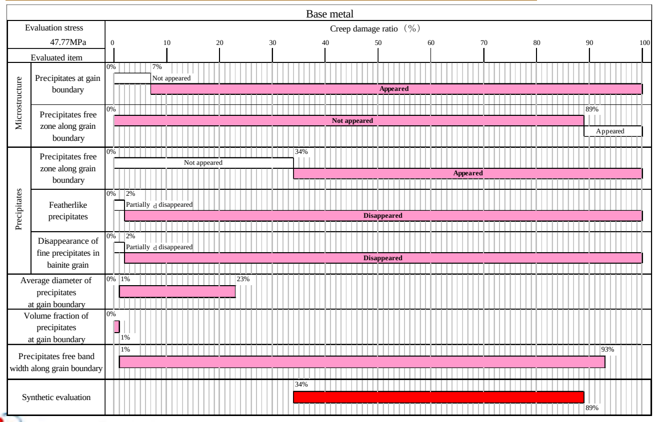
Synthetic evaluation (Coarse grain HAZ of MSP) Singrauli #6



Synthetic evaluation (Coarse grain HAZ of RH header left) Singrauli #6



Synthetic evaluation (Base metal of MSP) Unchahar #2



Residual life assessment results of pipes (Singrauli #6)

Components	Location	Material	Region	Evaluation results: Creep life consumption ratio (%)	Residual life (hr)	Evaluated residual life (h)
Platen-SH OutletHeader-Left	Base Metal at left side	SA 335 P12	Base Metal	9 ～ 16	903,000 ～ 1,739,000	140,000
	circumferential weld at left side		Base Metal	9 ～ 16	903,000 ～ 1,739,000	
			Fine grain HAZ	34 ～ 38	281,000 ～ 334,000	
			Coarse grain HAZ	0 ～ 18	784,000 <	
De-Suerheater-Left	Circumferential weld	SA 335 P12	Base Metal	8 ～ 16	903,000 ～ 1,978,000	100,000
			Fine grain HAZ	0 ～ 19	733,000 <	
			Coarse grain HAZ	19 ～ 45	210,000 ～ 733,000	
De-Suerheater-Right	Circumferential weld	SA 335 P12	Base Metal	0 ～ 1	17,028,000 <	100,000
			Fine grain HAZ	0 ～ 19	733,000 <	
			Coarse grain HAZ	19 ～ 45	210,000 ～ 733,000	
RH Outlet Header-Left	Circumferential weld at left side	SA 335 P22	Base Metal	0 ～ 1	17,028,000 <	340,000
			Fine grain HAZ	0 ～ 0.4	42,828,000 <	
			Coarse grain HAZ	3 ～ 20	688,000 ～ 5,561,000	
RH Outlet Header-Right	Circumferential weld at right side	SA 335 P22	Base Metal	4 ～ 6	2,695,000 ～ 4,128,000	1,300,000
			Fine grain HAZ	0 ～ 0.4	42,828,000 <	
			Coarse grain HAZ	2 ～ 3	5,561,000 ～ 8,428,000	
Main Steam Pipe-Left	Circumferential weld,extrados	SA 335 P22	Base Metal	65 ～ 70	74,000 ～ 93,000	37,000
			Fine grain HAZ	8 ～ 21	647,000 ～ 1,978,000	
			Coarse grain HAZ	0 ～ 20	688,000 <	
Main Steam Pipe-Left	Circumferential weld,intrados	SA 335 P22	Base Metal	65 ～ 70	74,000 ～ 93,000	21,000
			Fine grain HAZ	78 ～ 80	43,000 ～ 49,000	
			Coarse grain HAZ	24 ～ 45	210,000 ～ 545,000	

(Operation hours／Creep life consumption ratio) × 100 − operation hours

Residual life assessment results of pipes (Unchahar #2)

Components	Location	Material	Region	Evaluation results: Creep life consumption ratio (%)	Residual life (hr)	Evaluated residual life (h)
Final SH Outlet Header	Circumferential weld at right side	SA 335 P22	Base Metal	4	3,338,000	270,000
			Fine grain HAZ	1 ～ 4	3,338,000 ～ 13,771,000	
			Coarse grain HAZ	9 ～ 20	556,000 ～ 1,406,000	
De-Suerheater-Left	Circumferential weld	SA 335 P12	Base Metal	16 ～ 31	310,000 ～ 730,000	96,000
			Coarse grain HAZ	0 ～ 42	192,000 <	
De-Suerheater-Right	Circumferential weld	SA 335 P12	Base Metal	16 ～ 31	310,000 ～ 730,000	96,000
			Coarse grain HAZ	0 ～ 42	192,000 <	
RH Outlet Header	Circumferential weld at left side	SA 335 P22	Base Metal	2 ～ 6	2,179,000 ～ 6,816,000	700,000
			Fine grain HAZ	7 ～ 9	1,406,000 ～ 1,848,000	
			Coarse grain HAZ	3 ～ 6	2,179,000 ～ 4,498,000	
	Circumferential weld at right side,top	SA 335 P22	Base Metal	2 ～ 6	2,179,000 ～ 6,816,000	270,000
			Fine grain HAZ	9 ～ 14	854,000 ～ 1,406,000	
			Coarse grain HAZ	6 ～ 20	556,000 ～ 2,179,000	
	Circumferential weld at right side,front	SA 335 P22	Base Metal	2	6,816,000	270,000
			Fine grain HAZ	9 ～ 14	854,000 ～ 1,406,000	
			Coarse grain HAZ	6 ～ 20	556,000 < 2,179,000	
Main Steam Pipe-Right	Circumferential weld,intrados	SA 335 P22	(Base Metal)※	(34) ～ (74)	(49,000) ～ (270,000)	69,000
			(Fine grain HAZ)※	(13) ～ (42)	(192,000) ～ (931,000)	
			Coarse grain HAZ	32 ～ 50	139,000 ～ 296,000	
	Circumferential weld,near the stop valve	SA 335 P22	(Base Metal)※	(34) ～ (89)	(17,000) ～ (270,000)	270,000
			(Fine grain HAZ)※	(13) ～ (42)	(192,000) ～ (931,000)	
			Coarse grain HAZ	0 ～ 20	556,000 <	
Hot Reheat Pipe-Right	Circumferential weld	SA 335 P22	Base Metal	6 ～ 16	730,000 ～ 2,179,000	240,000
			Fine grain HAZ	19 ～ 22	493,000 ～ 593,000	
			Coarse grain HAZ	14 ～ 20	556,000 ～ 854,000	

※: : Regarded as reference for OD measurement was not carried out.

Summary of inspection results

Inspection item	Inspection results
VT	・Water wall, SH, RH panel was visually inspected from the view point of erosion, attrition and distortion of panel arrangement.
THICKNESS MEASUREMENT	・Thickness of tubes was measured mainly at erosion area for water wall, SH, RH. ・Measured thickness was discussed in terms of thickness management criteria.
SUS SCALE DEPOSITION INSPECTION	・SUS scale deposition was inspected at bottom bend portion ub SH and RH panel. ・On the whole SUS scale deposition was not significant with 15% fullness at most.
SAMPLE TUBE INSPECTION	・SH, RH sample tubes were inspected for the oxide scale adhesion condition microstructure hardness and so on.
CREEP RUPTURE TEST	・As a result of creep rupture test for the base metal and the weld joint of SH and RH, min. evaluated residual life was 35,000 hours for the weld joint for Final SH tube in Unchahar #2.

RECOMMENDATION (Boiler RLA)

1. **Singrauli #6** : Implement RLA of main steam pipes including outer diameter measurement and replica sampling before the estimated residual life of 21,000 hrs. Coarse grain HAZ region is the most critical region indicated no creep damage with no creep void. However, in base metal region the estimated residual life for left MS pipe is 21,000 hrs with a little microstructural degradation.
2. **Unchahar #2**:
   For main steam Pipe, the estimated residual life of coarse grain HAZ region is 69,000 hrs. The estimated residual life in base metal varies from 8,000 to 130,000 hrs due to no OD measurements applied, while microstructure shows a little degradation. For accurate estimation of residual life, creep strain (OD) measurement along with microstructure is recommended to be carried out preferably within 8,000 hrs or practically at the earliest opportunity.

RECOMMENDATION (Boiler RLA)

3. **Criteria for tube replacement**: In Japan alternative thickness criteria for more precise judgment of safety margin, such as tsr (thickness shell required) method is used. NTPC can also consider the use of such criteria in consultation with OEM rather than the method of thickness decrease ratio from design thickness.
4. **Scope of RLA**: Conduct RLA focusing or emphasizing on critical parts considering creep life after identification of critical parts, instead of all high temperature pressure parts, which NTPC focuses on currently.

RECOMMENDATION (Boiler RLA)

5. **New techniques**: Apply new techniques and equipments such as
   - SUS scale detection
   - TOFD
   - Advanced metallurgical observation technique using SEM,TEM
   - Precise surface polishing treatment for replica.
6. **Advanced training**: Conduct advanced training of new techniques for NTPC inspection engineers in Japan.

Manual & Guideline

Boiler RLA

Manual & Guideline related to Boiler RLA

✓ **2-1-3) Boiler RLA Manual**

Boiler RLA Manual	**Thickness measurement**
	SUS scale deposition inspection
	PT(DPT)
	UT
	TOFD (Time of Flight Diffraction)
	Sample tube inspection
	Sampling of replica and extracted replica
	Boiler remaining life assessment
	Creep rupture test

✓ **2-1-4) Data collection of new boiler for future RLA Guideline**

✓ **2-1-2) Techniques for boiler tube cleaning after cutting (before welding) Manual**

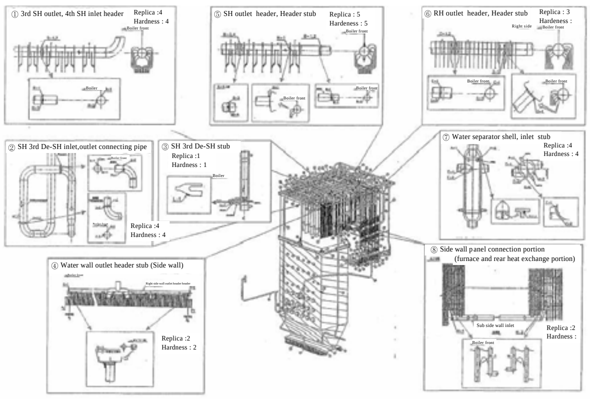
2-1-4) Data collection of new boiler for future RLA Guideline

Example of initial data sampling in new power plants

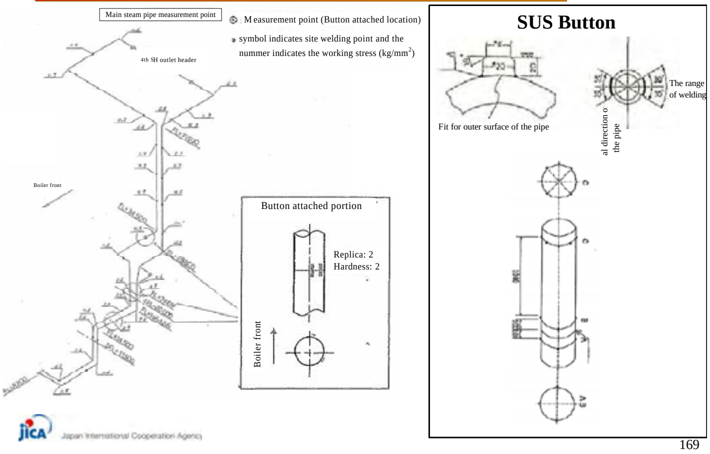
	Componetns	Replica sampling	Haredness measurement	Outside diameter measurement
Shell and header	Water separator	2	2	–
	SH outlet header	4	4	2
	RH outlet header	2	2	1
	3rd SH outlet header	2	2	1
	4th SH inlet header	2	2	1
	Water separator inlet stub	2	2	–
	Water wall outlet header stub (side wall)	2	2	2
	SH outlet header stub	1	1	1
	RH outlet header stub	1	1	1
Main pipe	Main steam pipe	8	8	4
	Hot reheat pipe	8	8	4
	Hot reheat pipe spherical Y piece	4	4	–
	High pressure turbine bypass pipe	1	1	1
Others	3rd SH De-SH outlet connecting pipe	2	2	1
	3rd SH De-SH inlet connecting pipe	2	2	1
	3rd SH De-SH stub	1	1	–
	Side wall panel connection portion (furnace and rear heat exchange portion)	2	2	2

Boiler tube : thickness measurement at constant points, reserved boiler tube for initial creep rupture data and so on.

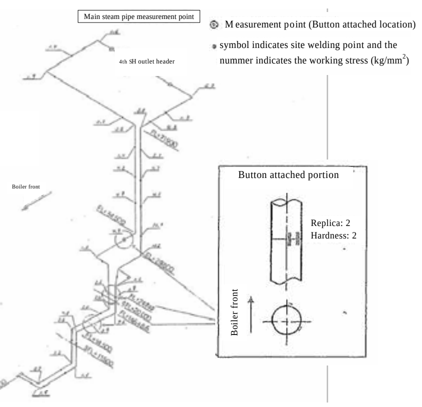
Example of measurement points for initial data



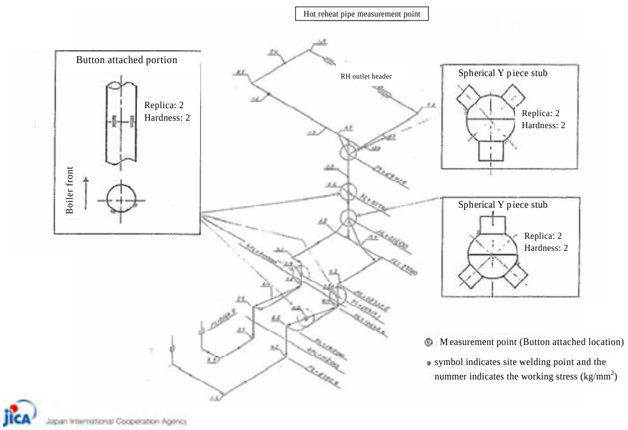
Example of measurement points for Main steam pipe



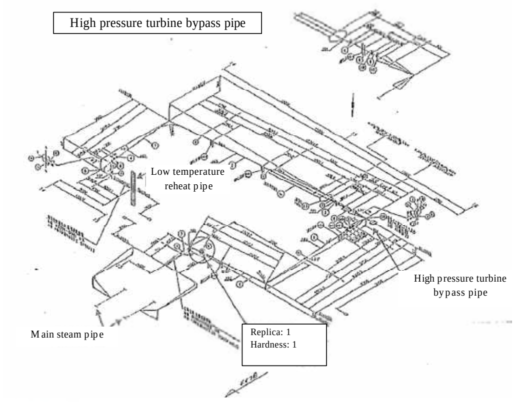
Measurement points for Main steam pipe



Measurement points for Hot reheat pipe

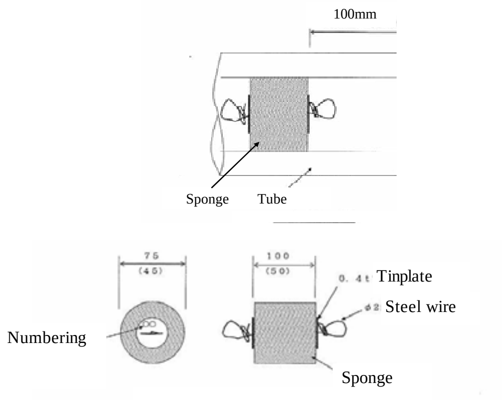


Measurement points for High pressure turbine bypass pipe



2-1-2) Techniques for boiler tube cleaning after cutting (before welding) Manual

Sponge image for prevention against foreign material mixing



5. 3) Kiken Yochi (KY) Meeting Manual

KYM (Kiken Yochi Meeting :danger prediction meeting)

【Scope】

This is applied to the meeting prior to working for workers to have the precaution against danger.

【General】

KYM is one of activities for safety work, predicting danger and setting the preventive measures. In general KYM consists of 4 steps that are grasping the current status, focusing on a few potential hazards by brainstorming, collecting the countermeasures by brainstorming, setting the objective to act focusing one or two countermeasures using KY board.

KYM (Kiken Yochi Meeting :danger prediction meeting)

【Procedure】

1st step :Understanding the current situation
(what kind of danger is hidden?)
Every KYM member talks about what kind of danger is hidden and its reason on KY board.

The person in charge of writing itemizes the each dangerous situation on the KY board.

2nd step :Pursuit of the essence (Identification of danger points)
Focusing on a few danger points which are considered as especially important ones.

KYM (Kiken Yochi Meeting :danger prediction meeting)

3rd step :Establishment of countermeasures
(what do you do in such a situation?)

Collecting the concrete countermeasures for the focused danger points, which are possible to be carried out.

The person in charge of writing itemizes the countermeasures to be collected on the KY board.

4th step :Setting the objective (we do this way)

Focusing on one or two important points from the countermeasures to be collected, determine the objective to act.

Chanting the objective to act with finger pointing by every member for recognition and confirmation.

KYM (Kiken Yochi Meeting :danger prediction meeting)

An example of KYM scene

An example of KY board

Date: Oct. 28		***KY Meeting***	
Work Name: *Boiler RLA*			
Leader Name	*S. Nakashima*	***Number of Workers***	*8*
Contact information	*090-7611-0022(mobile)*	***Health check***	*Good*
What kind of danger is hideen?		***We act the followings***	
Falling from high place		*Wear safety belt*	
Injured with grinding machine		*Check the power switch on/off*	
Falling over		*Watch one' step*	
Sucking dust	*Hitting body*	*Put on dust mask*	*Ensure the safety of the surrounding*
Attention at work :	*Pay attention for congested work !*		
Today's action targets :	*Wear safety belt ! Roger !*		

5. 4) Tool Box Meeting Manual

Tool Box Meeting

【Scope】
This is applied to the meeting prior to working for workers to have the precaution against danger.

【General】
TBM is the meeting held by workers to discuss the safety prior to working in the morning and in the afternoon.
The small unite of group that is 6 members or less discusses about the scope of work, the procedures and the point of safety working.

- ✓Confirming the scope of work and its procedure for the day.
- ✓The leader for the work guides the wok members to make a speech to grasps the work members thought.
- ✓ Summarizing the discussion results, determine the action objective.

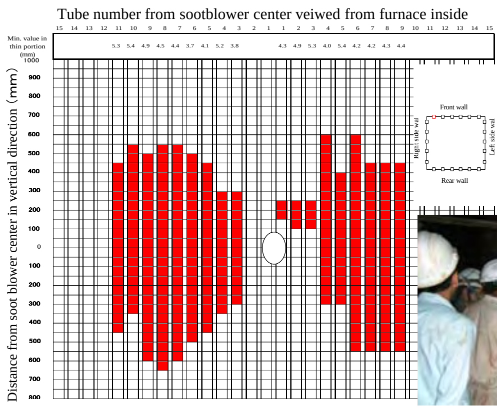
Tool Box Meeting

【Procedure 】
- ✓ Punctual TBM start by all work members
- ✓Discussion about the scope of work, the procedures and the points of safety working
- ✓Grasping the background behind the problems and danger for the work.
- ✓Discussion about the improvement plans for the problems and danger that is carried out with active and sincere participation by every worker. Determination of the objective and the items for action including 5W,1H.

Summary of Boiler RLA Demonstration

Inspection item	Japanese practice / Demo at sites	Recommendation
VT	Erosion and attrition of tubes and disorder of panel arrangement were inspected.	?
Thickness measurement	･Use of the original calibration block ･Acceptance criteria ･Grasping thickness decrease region	Study of alternative standard criteria for tube replacement such as tsr (Thickness Shell Required) was recommended.
SUS scale deposition inspection	The detection technique making use of the principle of induction is applied from the view point of efficiency and safety, besides conventional ?-ray method.	For implementation of new RLA technology, training in Japan was carried out.
Sample tube inspection	･Tube: Appearance, dimension, Hardness, Microstructure ･Scale: Appearance, Volume, Thickness, Composition	?
Creep rupture test	Residual life was evaluated by parameter method with a thousand hours creep rupture tests.	For implementation of precise RLA by creep rupture test, training in Japan was carried out.

Thickness measurement results of WW (Singrauli #6)



Summary of Boiler RLA Demonstration

Inspection item	Japanese practice / Demo at sites	Recommendation
VT	Erosion and attrition of tubes and disorder of panel arrangement were inspected.	?
Thickness measurement	･Use of the original calibration block ･Acceptance criteria ･Grasping thickness decrease region	Study of alternative standard criteria for tube replacement such as tsr (Thickness Shell Required) was recommended.
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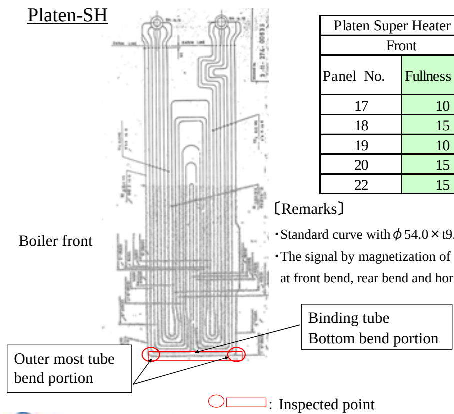
Sample tube inspection	･Tube: Appearance, dimension, Hardness, Microstructure ･Scale: Appearance, Volume, Thickness, Composition	?
Creep rupture test	Residual life was evaluated by parameter method with a thousand hours creep rupture tests.	For implementation of precise RLA by creep rupture test, training in Japan was carried out.

SUS scale deposition inspection results (Unchahar #2)

Platen-SH

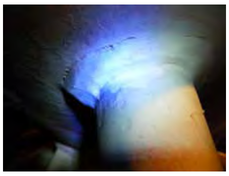


Platen Super Heater (Outermost tube bend portion)			
Front		Rear	
Panel No.	Fullness (%)	Panel No.	Fullness (%)
17	10	27	15
18	15		
19	10		
20	15		
22	15		

〔Remarks〕
･Standard curve with ϕ54.0×t9.5 was used for evaluation of fullness.
･The signal by magnetization of tube material with heat was recognized at front bend, rear bend and horizontal portion.

Summary of Boiler RLA Demonstration

Inspection item	Japanese practice / Demo at sites	Recommendation
DPT	・Same procedure as NTPC	・ More careful surface treatment and wiping out the penetrant



Summary of Boiler RLA Demonstration

Inspection item	Japanese practice / Demo at sites	Recommendation
DPT	・Same procedure as NTPC	・ More careful surface treatment and wiping out the penetrant
UT & TOFD (Time of flight diffraction)	Applied to the crack detection for high temperature header and pipe weld.	For implementation of new RLA technology, training in Japan was carried out.

Summary of Boiler RLA Demonstration

Inspection item	Japanese practice / Demo at sites	Recommendation
DPT	・Same procedure as NTPC	・ More careful surface treatment and wiping out the penetrant
UT & TOFD (Time of flight diffraction)	Applied to the crack detection for high temperature header and pipe weld.	For implementation of new RLA technology, training in Japan was carried out.
Boiler remaining life assessment by replica inspection	Using high magnification electron microscope, residual life was evaluated quantitatively.	・Implement RLA including OD measurement and replica before reaching evaluated life. ・For implementation of new RLA technology, training in Japan was carried out.

Summary of Boiler RLA Demonstration

General matter related to RLA	RLA is carried out focusing on the critical components.	Focusing or emphasizing on critical parts by considering creep design life from the view point of efficient inspection.
Safety	・KY（foreseeing the hazard) meeting was carried out prior to work. ・Safety shoes, safety globes, safety glasses, safety belt, spats and dust proof mask were worn during boiler inspection.	Dissemination of safety activity such as KY meeting, protective suite, indication of unsafe location is essential.

Japanese Boiler Inspection (Water wall, Furnace tube)

Water wall tube / Furnace tube

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	General appearance	Burn out, distortion, swelling, ash cut, steam cut etc.	Periodic inspection (every 2years)
	General appearance building scaffolding by the burner level		Periodic inspection (every 4years)
	General appearance building scaffolding by the top of furnace at the necessary interval set.		Setting necessary interval.
VT(Endoscopy)	Water tube inside	Corrosion	Setting necessary interval.
Chemical analysis of deposit	Outside deposit	Corrosion	Periodic inspection (every 2years)
PT	Representative weld portion of fin edge	Creep-fatigue	In case of elongation of periodic inspection interval (max. 2years).
	Representative attached metal weld portion	Creep-fatigue	After 80,000 hours operation, depending on necessity
Thickness measurement	Fixed points of tube. Representative portion of ash cut and steam cut with no countermeasure	Thinning with aging. Ash cut and steam cut.	Continuous measurement depending on boiler structure and type. Erosion countermeasure necessary, in case of elongation of periodic inspection interval (max. 2years). .
Sampling tube examination	Water wall tube in high heat load portion	Scale deposit	Setting necessary interval.
Residual life assessment	Water wall tube in high heat load portion	Creep	Judge from operation and design condition, depending on necessity.

Japanese Boiler Inspection (SH, RH, Eco tube)

SH, RH, Eco tubes

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	General appearance	Leak, crack, corrosion, erosion	Periodic inspection (every 2years)
Chemical analysis of deposit	Outside deposit	High temperature corrosion	Depending on necessity
Thickness measurement	Representative points of SH, RH, Eco tubes with no countermeasures for erosion.	erosion	Periodic inspection (every 2years)
	High temperature corrosion portion and portion that tends to decrease in thickness	High temperature corrosion	Continuous measurement at constant points.
	Around soot blower	Ash cut and steam cut	Periodic inspection (every 2years)
	Attrition at cross over of tubes		Setting necessary interval.
PT	Representative weld portion of fin edge	Creep fatigue	In case of elongation of periodic inspection interval (max. 2years).
	Representative dissimilar weld portion with no use of Inconel weld metal.	Creep fatigue and creep	Setting necessary interval.
	Representative attached metal weld portion	Creep fatigue	After 80,000 hours operation, depending on necessity
Sampling tube examination	Austenitic steel tube (Austenitic steal used in steam temperature 540℃ or more and metal temperature 620℃ or more).	SUS scale deposition	In case of elongation of periodic inspection interval (max. 2years).
?-ray inspection etc.	Bottom bend potion of austenitic steel tube	SUS scale deposition	Depending on necessity
Residual life assessment	Low alloy steel used in steam temperature 540℃ or more.	Creep	Judge from operation and design condition, depending on necessity.

Japanese Boiler Inspection (Steam drum, water drum)

Steam drum, Water drum

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	・Drum inside with water steam separator equipments detached.	Deposit	Periodic inspection (every 2years)*
		Corrosion	
		Erosion	
Chemical analysis		Deposit	
DPT	・Inner weld line ・Inner corner of stub ・Support and hanging lug	Low cycle fatigue	
MT	・External seam and girth weld line ・Inner weld line of stub	Low cycle fatigue	After 80,000 hours operation

*If the weld of stub inside is smooth finished, periodic inspection every 4years

Desuper

Inspection measure	Portion	Deterioration factors	Inspection interval
Overhaul VT	Nozzle, Mixing chamber	Thermal fatigue, abrasion	Setting necessary interval.

Japanese Boiler Inspection (Header (1))

Header (Water wall header, Evaporator header, Economizer header, SH header, RH header)

Inspection measure	Portion	Deterioration factors	Inspection interval
VT	General appearance	Erosion	Periodic inspection
		Corrosion	
		Cracking	
		Leak from weld part	
VT (Endoscope)	Ligament of Furnace header, Economizer header, SH header and RH header inside (including drain and bent tube portion).	Low cycle fatigue	Include in the periodic inspection plan systematically
	Inside of Furnace header, SH header and RH header inside	Corrosion by deteriorated water condition and dead drain during outage	
	Bottom inside of Furnace headers, Economizer headers	Deposition of sludge and initiation of corrosion fatigue crack	
	Final SH header and Final RH header	Exfoliation of steam oxide scale of header inside	
	Representative 2 or more headers inside	Low cycle fatigue Erosion	Periodic inspection (every 4years)
		Deposition	
Chemical analysis of deposit	Bottom inside of Furnace headers, Economizer headers	Deposition of sludge and initiation of corrosion fatigue crack	Include in the periodic inspection plan systematically
VT, Dimension measurement of corrosion	Stub outside of Economizer header	Low temperature corrosion	
Thickness measurement	Stub tubes of Final SH header and Final RH header	Thinning by high temperature corrosion	

Japanese Boiler Inspection (Header (2))

Header (Water wall header, Evaporator header, Economizer header, SH header, RH header)

Inspection measure	Portion	Deterioration factors	Inspection interval
DPT (MPI)	Representative stubs with no flexible structure and no rounding of weld end toe	Low cycle fatigue	Periodic inspection (every 2years)
	Stub weld of furnace headers, SH headers and RH headers.	Low cycle fatigue	Include in the periodic inspection plan systematically
	Support metal weld of furnace headers, SH headers and RH headers.	Low cycle fatigue	
	Representative header stub weld	Low cycle fatigue	After 80,000 hours operation (Precise
MPI	Representative header girth weld and seam weld	Creep	
Remaining life assessment	Most damaged header or pipe beyond 450℃ among furnace headers among SH headers or main steam pipe among RH headers or hot reheat pipe.	Creep	To extend periodical inspection interval 2 year to 4year after 100,000 hours operation
	High temperature Header and pipe	Creep	Include in the periodic inspection plan systematically, taking into consideration of operation hours, start and stop times and designed life.

Thank You !

Rotating Classifiers in Coal Mill

Manufacture in Japan

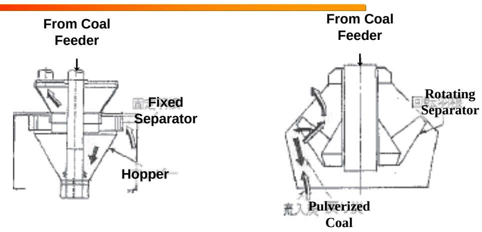
a) **Mitsubishi Heavy Industries, Ltd.: MHI**

b) **Hitachi Ltd.**

c) **IHI Corporation**

Rotating Classifiers in Coal Mill

Fixed and Rotating separator

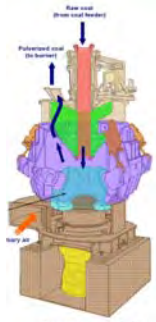


	Fixed Separator	Rotating Separator
Mechanism	- Classification by centrifugal force	- Forced classification by centrifugal force
Future	- Adjustment range of coal particular classification is limited	- Adjustment range of coal particular classification is wide

Rotating Classifiers in Coal Mill

1. MHI Type of Mill

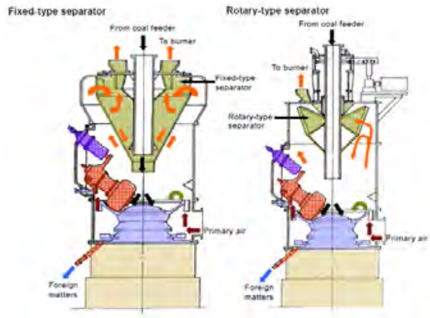
Fixed-type separator system



Rotary-type separator system

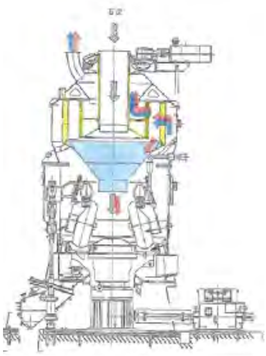
Rotating Classifiers in Coal Mill

MHI Type of Mill



Rotating Classifiers in Coal Mill

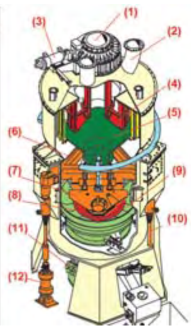
2. HITACH Type of Mill



Rotating Classifiers in Coal Mill

2. HITACH Type of Mill

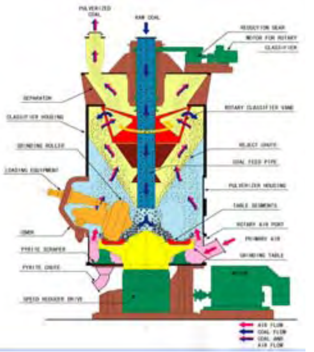
No.	Name of parts
(1)	COAL CHUTE
(2)	PULVERIZED COAL PIPE
(3)	CLASSIFIER MOTOR
(4)	ROTATING CLASSIFIER
(5)	HOPPER
(6)	PRESSURE FRAME
(7)	ROLLER BRAKET
(8)	ROLLER TIRE
(9)	GRINDING RING
(10)	LOADING ROD
(11)	GEAR BOX
(12)	HYDRAURIC CYLINDER
(13)	MAINTENANCE DOOR



Rotating Classifiers in Coal Mill

1. IHI Type of Mill

.



Slit

Air Heater

Heating Element

Type: DU, DUN, DNF, NF, FNC

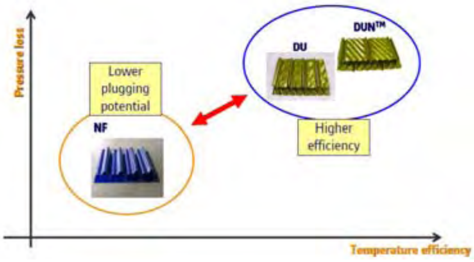
Material: Mild steel , CRLS, enamel coated steel

Thickness: 0.5, 0.6, 0.8, 1.0, 1.2mm

Height: 300 – 1500mm

Air Heater

Heating Element



Air Heater

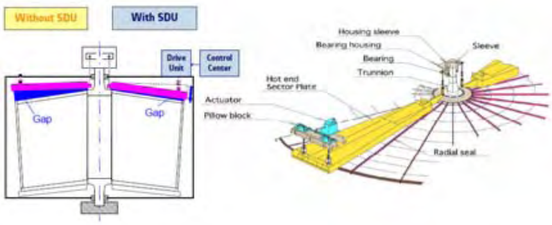
Heating Element

Element replacement record of power utilities in Japan as of 2004

Capacity	Type	Replacement Purpose
600MW	NF => DUN	Improvement of Temp. efficiency (Low temp layer : all)
700MW	DU => DUN	Maintained same efficiency (High temp layer : all)
700MW	DU => DUN	Ditto (High temp layer : all)
700MW	DU => DUN	Ditto (High temp layer : partial)
500MW	DU => DUN	Ditto (High temp layer : all)
700MW	DU => DUN	Ditto (High temp layer : partial)

Air Heater

Sector Plate Drive Unit (Automatic Leakage Control)



Control the gap at hot side radial seal by preset value at hot condition and reduce the leakage

Air Heater

Sensor Drive System track record in Japan

Major track record for Coal fired Power Plants

Capacity	Commercial Operation	Capacity	Commercial Operation
600MW	1985	500MW	1995
700MW	1989	700MW	2000
700MW	1991	700MW	2001
700MW	1992	500MW	2002
700MW	1993	600MW	2008
156MW	1994		

Air Heater

Sensor Drive System

1. One major accident occurred power utilities in Japan Last 10 years
   - Occurrence of an event

     AH trip (over load of AH drive motor)
   - Cause

     Sector Plate lower limit switch did not work

     Rotor tire and sector plate contacted and this caused over load of AH drive motor
   - Countermeasure

     Ammeter of AH drive motor is add at Central Control Room for monitoring purpose.

Condenser Assessment Methodology

Investigation method of cause for deviation of condenser pressure from the desired value

1. Increase in leak in quantity of air

The lowering of the vacuum degree occurs when leak in exceeds the extraction capacity of the vacuum pump.

Condenser Assessment Methodology

2. Decrease of cleanliness of tubes
With no increase in the leak in air amount and with the vacuum pump found to be normal, the cause of lowering of the vacuum degree is often caused by the lowering of cleanliness of the tubes.

3. Decrease of the cooling water volume
When the cooling water volume drops, an increase of temperature rise of cooling water side (ΔT), increase of CWP discharge pressure, decrease of condenser pressure loss and lowering of the condenser water chamber level occur, in case of no pump deterioration.

Condenser Assessment Methodology

4. Abnormality of the vacuum pump
When an abnormality of the vacuum pump is seen, conduct changeover testing with a spare unit and compare the respective air extraction amount and vacuum.

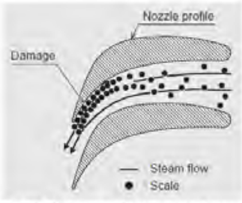
5. Increase of condenser heat load
The condenser pressure is estimated from condenser performance curve. the design heat load, on the condition that cooling water flow, tube cleanliness and heating surface, etc. are nearly design value. If the heat load increases more than the design value at a certain operation point, the condenser pressure increases.

TURBINE BLADE COATING (Boronize)

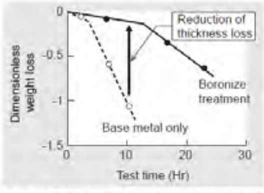
Characteristics of Boronize Treatment

- •Ensures boron alloy layer of hardness Hv 1200-1800
- •High hardness at high temperature and excellent hardwearing properties at high temperature
- •High break away resistance because of penetration intothe base metal
- •Thin layer (approximately 80 u m) of boron alloy

TURBINE BLADE COATING (Boronize)

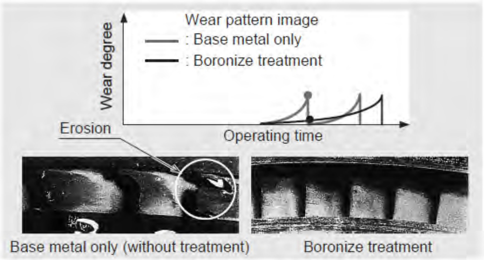


Mechanism of nozzle wear damage



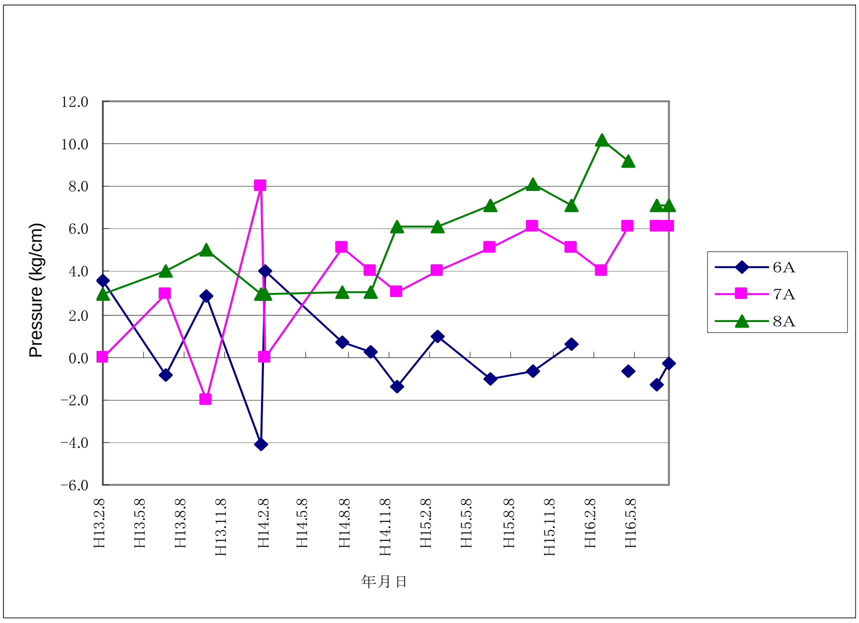
Solid particle erosion test compared

TURBINE BLADE COATING (Boronize)

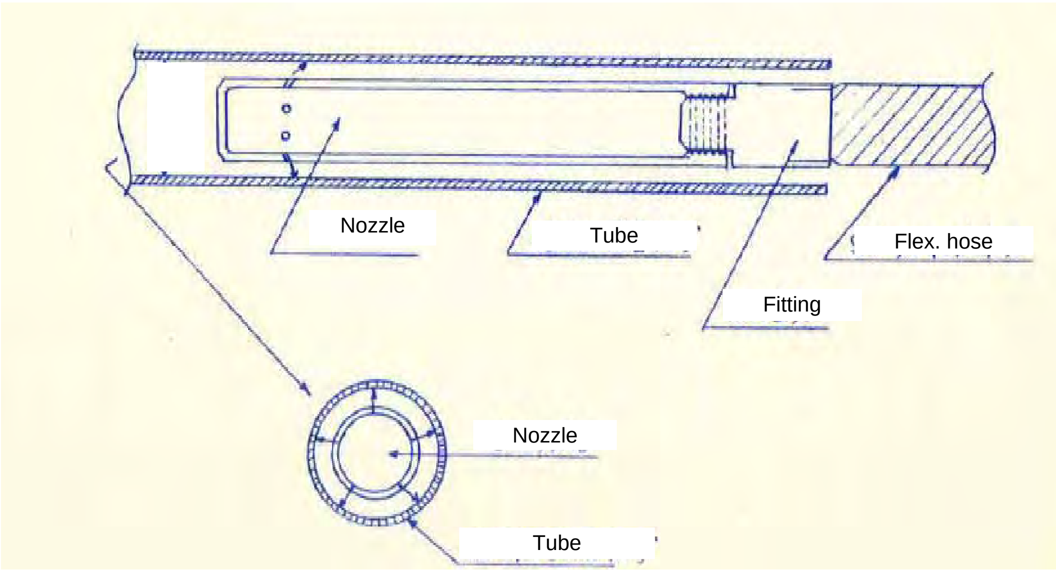


Appearance of speed-control stage nozzle

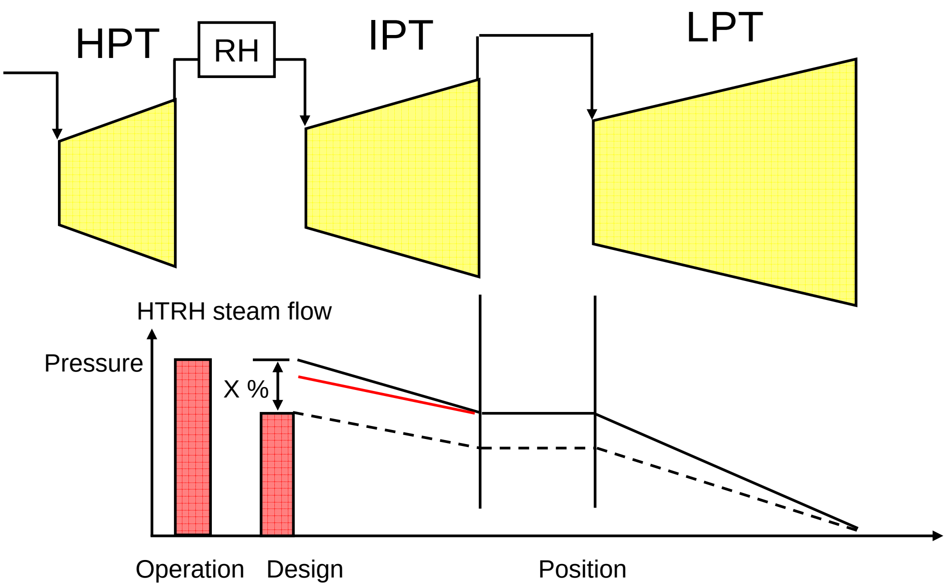
HP HTR PRESSURE LOSS (Example)



HP HTR TUBE CLEANING (Example)



Turbine HTRH flow vs pressure



1. Object Plant

Singrauli #6 unit of NTPC in India.

2. Object of Test

The unit was operated using 2 vacuum pumps (from 4～5 Years), deterioration of the vacuum (by about 10 mmHg) had been observed by operation using 2 vacuum pump. The air leak-in rate at that time under 2 pumps operation was 120 kg/ hour.

From this reason, the leak buster tests were executed for the purpose of identifying the position, which corresponded to the air leaking abnormally into the unit.

3. Test Result

The 130 positions in vacuum line were investigated for this time and resulted in identifying the positions corresponding to about 109 kg/hour of leaks into the unit. Among them, the major position for leak into the unit was the packing gland of BFP-T A & B. (Refer to the attached check list for details.)

No.	Helium test position	Air leak rate [Kg/h]	Detection No.
1	A BFP-T gland sealing portion (Rear)	49.3	Photo No.11
2	B BFP-T gland sealing portion (Rear)	23.5	Photo No.12
3	LP turbine gland sealing portion (Packingland and Bellow flange)	13.3	Photo No.1～5
4	HP Flush tank , Flush box-1 and Drain flush Tank B	12.3	Photo No.6～10
5	Others	14.6	
	Total	**113.0**	

4. Test Period

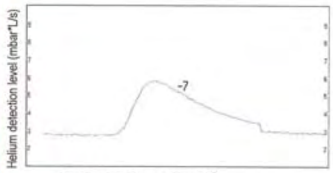
Aug. 6. 2009 – Aug. 10. 2009

	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Aug. 10
1. Preparation for test Equipment	■	■			■
2. Verification of VP air extraction rate				■	
3. Injection test		■	■	■	■
4. Investigation of air-leak points		■	■	■	■
5. Report and Meeting				■	■

Measured by : Kawashima, Sato, Iriki and Hirose

Air leak detection photos at leak buster test

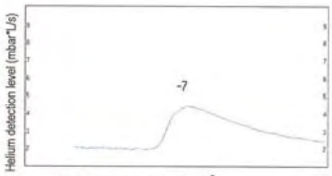
Photo-1: LP turbine packingland Generator side (Lower/Left)

Maximum value: 5.82 x 10^{-7}

Approx. air leak-in rate : 1.5 kg/h

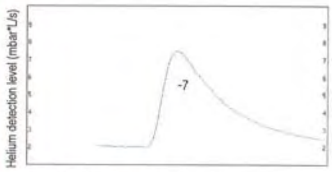
Photo-2: LP turbine packingland Turbine side (Upper/Left)

Maximum value: 4.40 x 10^{-7}

Approx. air leak-in rate : 1.0 kg/h

Photo-3: LP turbine packingland Turbine side (Lower/Left)

Maximum value: 7.46 x 10^{-7}

Approx. air leak-in rate : 2.2 kg/h

Attachment－1

NTPC Singrauli #6

Helium reaction curve

DATE : Aug. 10. 2009

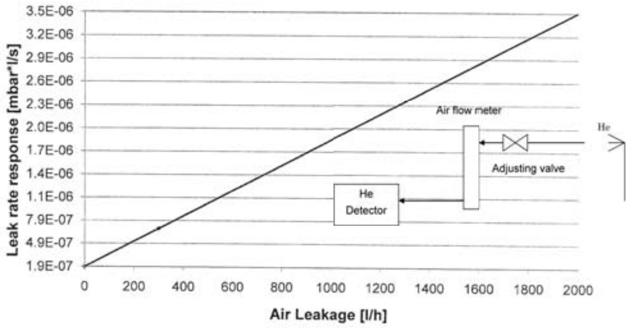
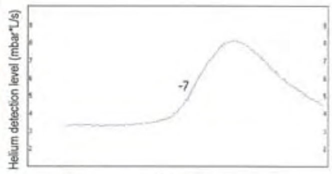


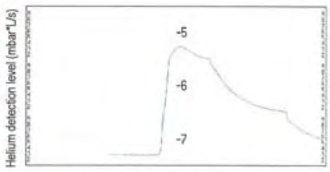
Photo-10: Drain flash tank-B (Connection pipe)

Maximum value: 8.14 x 10^{-7}

Approx. air leak-in rate : 2.9 kg/h

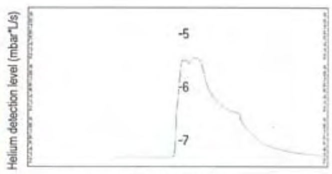
Photo-11: BFPT-A packingland

Maximum value: 3.17 x 10^{-5}

Approx. air leak-in rate : 49.3 kg/h

Photo-12: BFPT-B packingland

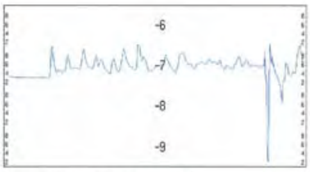
Maximum value: 1.52 x 10^{-5}

Approx. air leak-in rate : 23.5 kg/h

Photo-16: BFPT-B Horizontal flahge of rear casing (Right)

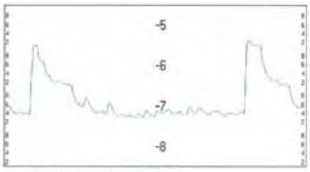
Maximum value: 6.91 x 10^{-7}
Approx. air leak-in rate : 1.8 kg/h

Photo-17: A-Vacuumpump grand seal (coupling side)



Maximum value: 1.27 x 10^{-6}
Approx. air leak-in rate : 0.2 kg/h

Photo-18: A-Vacuumpump grand seal (uncoupling side)



Maximum value: 2.18 x 10^{-5}
Approx. air leak-in rate : 3.5 kg/h

Condenser leak buster (Singrauli #6)

RESULT

1. **Air ingress from gland seal packing of both A-BFPT and B-BFPT were 44% and 21% of total ingress measured respectively.**

RECOMMENDATION

1. **Inspect these area and conduct necessary repair.**
2. **After repair, carry out Helium test again to assure little air ingress.**

Photo-19 Test equipments for helium reaction test

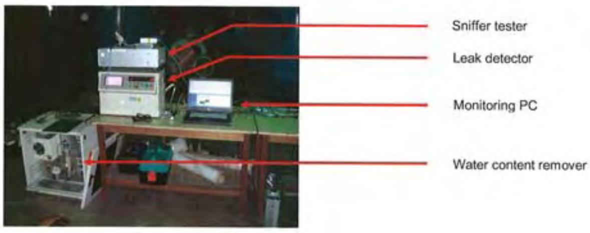


Photo-20 Helium Detection position
(Pressure gauge position for #6B vacuum pump inlet)

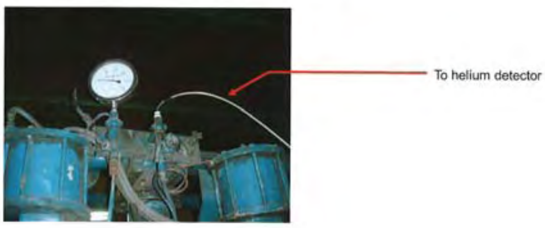


Photo-21 Injection test position
(Drain pipe of Pressure transmitter for #6B vacuum pump inlet)

Pump assessment Korba BFP-6B (T-BFP)

RESULT

1. **Pump efficiency is decreased by approx. 5% from the design value.**

RECOMMENDATION

1. **Refurbish inner parts of the pump after economic evaluation.**
2. **Conduct pump test for the same pump every two years, and to carry out the test for other pumps.**
3. **BFP turbine efficiency can be estimated, when BFP efficiency is known.**

Pump assessment Singrauli CWP I-09

RESULT

1. Pump efficiency is decreased by approx. 11% from the design value.

RECOMMENDATION

1. Refurbish inner parts of the pump after economic evaluation.
2. Conduct pump test for the same pump every two years, and to carry out the test for other pumps.

Pump assessment Rihand BFP-2B (M-BFP)

RESULT

1. Pump efficiency is decreased by approx. 13% from the design value.

RECOMMENDATION

1. Refurbish inner parts of the pump after economic evaluation.
2. Conduct pump test for the same pump every two years, and to carry out the test for other pumps.

Pump assessment Rihand CWP-2B

RESULT

1. Pump is considered to be in acceptable condition while the efficiency is 1.6% lower than the design.

RECOMMENDATION

1. Conduct pump test for the same pump every two years, and to carry out the test for other pumps.