| | |
|---|---|
| Company name | Hokkaido EPCO |
| Date of occurrence | April 9, 2008 |
| Unit name | Tomari 2 |
| Event | Confirmation of Flaws at Welded Part of Primary Coolant Inlet Nozzle of Steam Generator A and B |
| International Nuclear Event Scale (INES) | 0 |
| Status of report | Final report |

## Status when event occurred

During the 13th periodic inspection conducted from March 13, 2008, an eddy current test*1 (hereinafter referred to as "ECT") was conducted based on the NISA document "Inspection of the inner surface of inlet/outlet nozzle welded parts of steam generators" dated on November 16, 2007. As a result, significant signals were indicated at three places with steam generator (hereinafter referred to as "SG") A and 10 places with SG-B at the welded parts of primary coolant inlet nozzle (hereinafter referred to as "inlet nozzle"). No significant signal was indicated at the primary coolant outlet nozzle of both SGs.

Ultrasonic test*2 (hereinafter referred to as "UT") was conducted at areas where significant signals were indicated with ECT and significant signals that can evaluate the depth of the flaw were indicated at one place in SG-A and SG-B respectively.

Depths of the flaws were evaluated as approx. 7 mm and 5 mm in SG-A and SG-B respectively. The plate thicknesses of the two areas which were subtracted the depths of the flaws from the plate thicknesses of the relevant parts of approx. 78 mm, SG-A approx. 71 mm and SG-B approx. 73 mm, were judged below the value of the application for construction plan approval of 75 mm stipulated by the Electricity Utilities Industry Law.

<Time series>

March 31 to April 3: ECT conducted at SG-A and B inlet nozzle

April 3 to April 9: UT conducted at SG-A and B inlet nozzle

April 6 to April 9: ECT conducted at SG-A and B outlet nozzle

*1: Eddy current test (ECT)

A method to detect a flaw by causing an eddy current to an object material, which is done by contacting a coil with high-frequency current to the object material such as a pipe, and a flaw is detected from changes in eddy current that occur around flaws.

*2: Ultrasonic test (UT)

A method to detect a flaw inside an object material using a characteristic of ultrasonic wave which then propagates through the object material and reflects at an area with discontinuity such as flaws.

## Summary of examination of cause

An investigation of flaws at inlet nozzle welded part of SG was conducted based on factor analysis FT diagram. As for flaw observations, a replica examination*3 was conducted on the indicated part No. 1 of SG-A and a replica examination and SUMP observation*4 was conducted on the indicated part No. 5 of SG-B.

*3: Replica examination

Observation to check the surface fabrication status by transcribing the condition of the surface to film.

*4: SUMP observation

Observation of a damaged surface using a film, etc. The damaged surface is polished and a film, etc. is placed on the damaged surface to be transcribed, which is observed using a microscope.

(1) Replica examination result

a. Traces of buff-finishing *6 were observed above grinding work*5 (grinding) at the whole area of the indicated part No. 1 of SG-A, and clear traces of grinding work (grinding) were observed including the cracked part.

b. Traces of buff-finishing were observed above grinding work (grinding) at the whole area of the indicated part No. 5 of SG-B and traces of finishing work other than grinding work (polishing) were observed at the cracked part.

*5: Grinding work

A surface finishing work performed on a welded surface using a grinder (a machine tool to grind or to polish a material or tool by rotating a circular grinding stone in high speed). The finished surface is rougher when compared to that of buffing work.

*6: Buff work

A surface finishing work performed on a welded surface using circular sandpaper, etc. (buff) attached to a tool. The finished surface is finer when compared to that of grinding work.

(2) SUMP observation result

SUMP observation was conducted on the indicated part No. 5 of SG-B.

a. Cracks were found at girth weld area and overlay weld area of 600 type nickel base alloy and were not found at the safe-end of stainless steel and the stainless lining part of the inlet nozzle.

b. Cracks of approx. 1.8 mm to 5.0 mm in axial direction were found, where the whole length was approx. 7.6 mm.

c. Traces of repair welding of approx. 7 mm in diameter were found around the crack area.

d. The cracks have occurred along the dendrite border*7 and a similar facet to that of primary coolant stress corrosion cracking*8 (hereinafter referred to as “PWSCC”) observed both domestically and internationally at welded area using 600 type nickel base alloy was found.

*7: Dendrite border

A pillar-shape crystal (dendrite crystal) is formed at weld areas when melted metal hardens and the border of this crystal texture is called the dendrite border.

*8: Primary coolant stress corrosion cracking (PWCC)

A stress corrosion cracking that occurs with 600 type nickel base alloy in the primary coolant environment that is characteristic of PWR plants (cracking occurs due to overlay of conditions of three elements; material, environment and stress). As a result of SUMP observation, cracks in the indicated part No. 6 of

SG-B were detected, which also had a similar facet to that of PWSCC as in the indicated part No. 5 of SG-B.

(3) Manufacture and operation history investigation result

a. Manufacture history investigation

SG of Unit 2 of Tomari NPP was manufactured during the period of July 1985 to March 1989 and the history of manufacturing was investigated through test inspection records of that time and interviews to persons involved.

(a) Investigation of test inspection record

- The welded part of inlet nozzles of SGs were manufactured according to the procedure stipulated by the manufacturer and no peculiar situation was found in the work procedure and term of weld work in either of the inlet nozzles.
- It was confirmed that the welders had sufficient experience.
- No record of repair welding was found.

(b) Investigation through interviews with persons involved

- Although there is a possibility of various kinds of grinders being used by workers, buffing work (reciprocated three times) was performed after grinding work (grinding) as the standard finishing method.
- It was confirmed that there is a possibility of repair welding performed after buffing work in some cases, such as when a significant signal was indicated through penetrant test (hereinafter referred to a “PT”) by the manufacturer.
- It was confirmed that there is a possibility of grinding work performed (polishing) when repair welding was performed.

*9: Penetrant test (PT)

An observation method used to visually check the flaws open on the surface of a test sample. High penetration liquid with visible dye is penetrated into the surface, which remaining liquid on the surface is wiped off and the indicated pattern by the penetrated liquid is observed using a developer.

b. Operation history investigation

The operation history from commencement of operation (April 12, 1991) to 13th periodic test (parallel off on March 13, 2008) of Tomari NPP Unit 2 was investigated.

(a) Primary coolant temperature/pressure

Two events of manual reactor shut-down were found as events with transient conditions that occurred during the operation of plant. No abnormal transition in temperature/pressure that causes excessive stress was found in said transient conditions.

(b) Water quality control status

The water quality after the commencement of operation has been satisfying the water quality standard stipulated by the safety preservation rules and it was confirmed that hazardous components such as chloride ion were controlled.

(4) Welded part material confirmation result

It was confirmed from the weld record and mill sheet that the components of the material were according to the SG manufacturer’s specifications and was of 600 type nickel base alloy.

(5) Design document confirmation result

It was confirmed from the strength calculation document of the application documents for license of construction plan that considerations to ductile cracking and fatigue cracking were made in the design.

(6) Document investigation result

As a result of document investigation regarding cracking in welded part using 600 type nickel base alloy, damage examples of similar areas were confirmed as described below.

a. Welded part of reactor vessel outlet nozzle

Leakage was reported at V. C. Summer NPP, U.S. (detected in October 2000) and flaw indication was reported at Units 3 and 4 of Ringhals NPP, Sweden (detected in August and September, 2000). The cracks detected at both NPPs were cracking in the axial direction along the dendrite border, wherein the event in V.C.Summer NPP reported that the crack has advanced through the weld metal and almost stopped at the borders of low-alloy steel and safe-end. The cracking was assumed to be caused by PWSCC that occurred due to high tensile residual stress from repair welding work.

b. Pressurizer nozzle welded part

Leakage was reported at Unit 2 of Tsuruga NPP of Japan Atomic Power Company (hereinafter referred to as “Tsuruga NPP Unit 2”) (leakage in pressurizer relief valve nozzle and flaw indication in safety valve nozzle, detected in September 2003). The crack that was detected was cracking in the axial direction along the dendrite border, which was reported that the crack has advanced through the weld metal and almost stopped at the borders of low-alloy steel and safe-end. The cracking was assumed to be caused by PWSCC that occurred due to high tensile residual stress from repair welding work.

c. Welded part of SG inlet nozzle

Flaw indications were reported at Unit 2 of Mihama NPP of Kansai Electric Power Company (hereinafter referred to as “Mihama NPP Unit 2”) (detected in September 2007) and Tsuruga NPP Unit 2 (detected in October 2007), respectively. Cracks detected in both NPP were cracking in the axial direction along the dendrite border. Cracking in the case of Mihama NPP Unit 2 was assumed to be caused by PWSCC that occurred due to high tensile residual stress in the inner top surface area caused by machining work performed during the manufacturing process. Also as for the case of Tsuruga NPP Unit 2, cracking was assumed to be caused by PWSCC that occurred due to high tensile residual stress in the inner top surface area caused by grinding work (polishing), etc. after repair welding performed during the manufacturing process. Furthermore, a confirmation test of surface treatment status (hereinafter referred to as “mockup test”) and a sampling investigation on actual equipment were conducted in the investigation of Tsuruga NPP Unit 2 and surface residual stress was estimated.

- Results of surface observation and X-ray residual stress measurement with 10 kinds of test samples according to the assumed surface treatment procedure were reported.
- As for the residual stress (circumferential direction) of the surface area of welded part of Tsuruga NPP Unit 2 SG-C inlet nozzle caused by finishing work such as grinding, the surface residual stress at floors of grinder grooves is estimated as approx. 90 MPa to 420 MPa when the correction value obtained from the mockup test result (approx. 680 MPa) is added to the residual stress value of the boat sample measured in a hot laboratory (- 591 MPa to - 263 MPa). The surface residual stress of test sample No. 6 is measured as approx. 470 MPa on average.

d. Stress in occurrence of PWSCC

As for the occurrence of PWSCC at the welded part using 600 type nickel base alloy, a constant load stress corrosion cracking (SCC) test is conducted and PWSCC occurred at the stress of approx. 300 MPa or more in the primary coolant environment.

(7) Estimation of surface residual stress of Tomari NPP Unit 2 SG inlet nozzle

Comparisons were made with inner surface conditions that were checked through replica examination and stress measurement results of the mockup test and sampling investigation on actual equipment conducted with Tsuruga NPP Unit 2 in order to estimate the surface residual stress of Tomari NPP Unit 2.

- Clear traces of grinding work (grinding) were observed including the cracked part at the indicated part No. 1 of SG-A, where the surface was in a similar condition as to that of the boat sample of the actual equipment of Tsuruga NPP Unit 2 SG-C. Also, finishing traces that are assumed to be of grinding work (polishing) after repair welding were observed at the cracked part of the indicated part No. 5 of SG-B, where the surface was in a similar condition as to that of the mockup test piece No. 6.
- From the conditions above, the surface residual stress of the welded part in concern of the Tomari NPP Unit 2 is assumed to have exceeded 300 MPa, which is the stress that causes PWSCC.

(8) Other damage investigation result

The possibility of ductile cracking and fatigue cracking was investigated but no abnormality was observed in the use environment condition, used material, etc. hence, these are not the causes of the event in concern. Moreover, no evidence of cause was found from the records and actual equipment investigation results regarding improper welding or welding defect during the manufacturing phase.

(9) Summary of investigation results

a. Through the SUMP observation results, cracks were observed along the dendrite border that have a similar facet to that of PWSCC observed both domestically and internationally at welded areas using 600 type nickel base alloy.

b. Through the replica examination results, traces of grinding work (grinding and polishing) were observed where cracks were detected.

c. It was confirmed that there is a possibility of grinding work performed (polishing) when repair welding was performed after buffing work.

d. Through the replica examination and document investigation results, a tensile residual stress exceeding approx. 300 MPa that is considered susceptible to the occurrence of PWSCC was assumed to have occurred at the welded part in concern of Tomari NPP Unit 2.

e. From the results above, as similar to that of Tsuruga NPP Unit 2, there is a possibility that PWSCC have occurred at Tomari NPP Unit 2 also due to high tensile residual stress at the inner surface where traces of grinding work (grinding) and buff finishing grinding work (grinding) were remained and at the inner surface where grinding work (polishing) at the repair welding location was performed.

Cause of event

PWSCC was assumed to have occurred at the manufacturing of SG due to high tensile residual stress at the areas where traces of grinding work (grinding) were remained after the inlet and safe-end were welded using 600 type nickel base alloy and then finishing was performed by grinding work (grinding) and buffing work, or at the areas finished by grinding work (polishing) after finishing was performed by grinding work (grinding) and buffing work and then some repair welding was performed on inner surfaces. Furthermore, it is assumed that the cracking has advanced in the axial direction since the stress at the welded area in concern is larger at the circumferential direction than in axial direction during the operation.

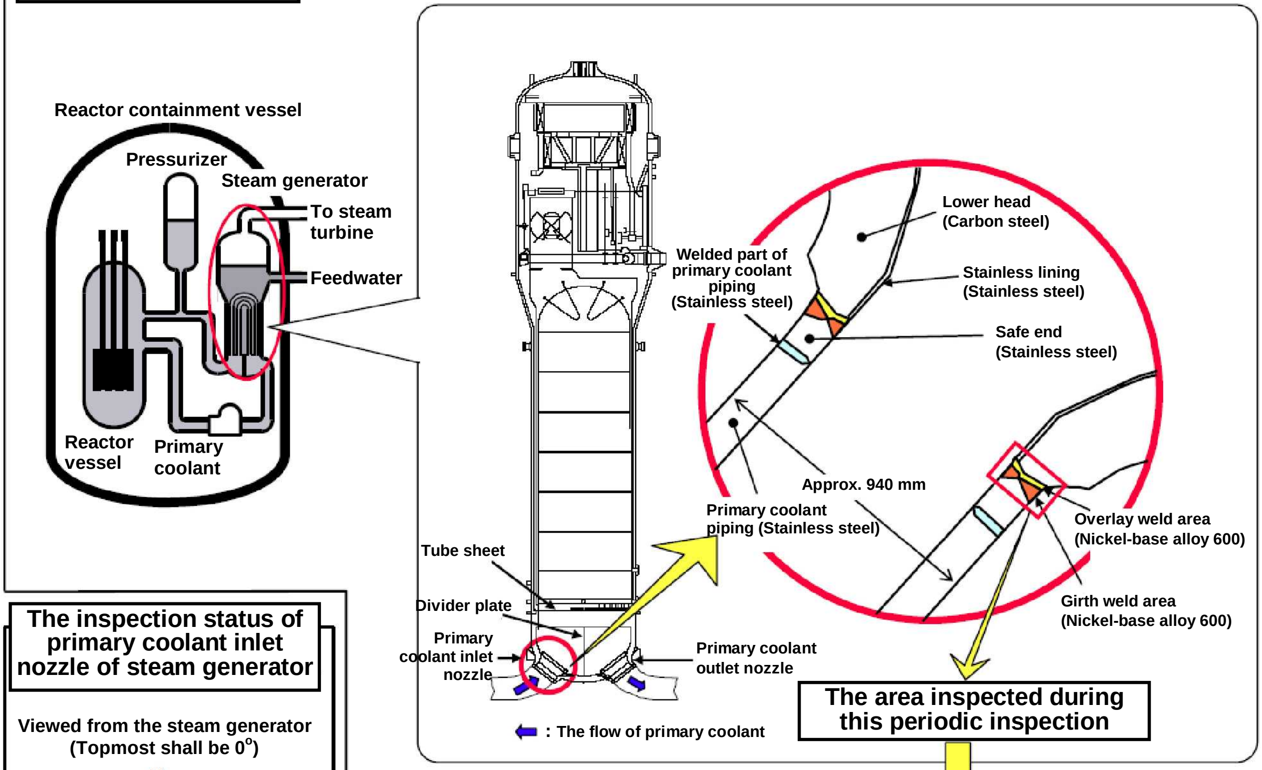
Measures to prevent recurrence

1. The whole circumference of the inner surface of SG inlet nozzle welded part shall be cut by a cutting device and after the shallow cracks are removed, deeper cracks shall be removed partially by grinding work (grinding) as necessary. PT shall be used to confirm the removal of cracks, etc.
2. After the removal, overlay welding shall be performed using 600 type nickel base alloy as for areas where deep cracks are removed and another overlay welding shall be performed throughout the whole circumference of the inner surface of the welded part using 690 type nickel base alloy, which is superior in corrosion resistivity as a recovery measure. As a precautionary measure, buffing work shall be performed on areas in concern to reduce residual stress.

<Attachment>

# The Periodic Inspection Status of Tomari NPP Unit 2
# Cause and Countermeasures for Flaws at Welded Part of Primary Coolant Inlet Nozzle of Steam Generator

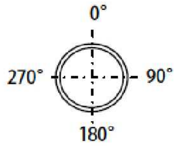
## Place of occurrence




**The area inspected during this periodic inspection**

## The inspection status of primary coolant inlet nozzle of steam generator

Viewed from the steam generator (Topmost shall be 0°)




Cross sectional diagram

**ECT results (Areas of significant indication)**

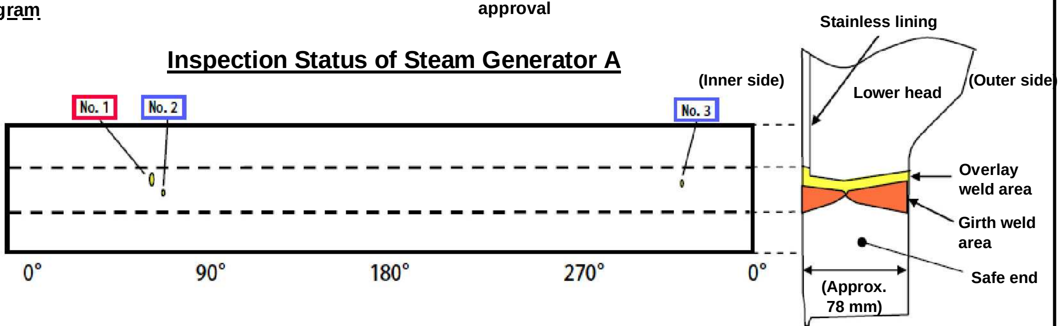
[red box] : Areas where evaluated from the ultrasonic test result to be thinner than the wall thickness registered in the application for construction plan approval

[blue box] : Areas where depths of flaws were not detected by the ultrasonic test

### Inspection Status of Steam Generator A

(Maximum length)
No. 1: Approx. 13 mm*
(Maximum depth)
No. 1: Approx. 7 mm

*: The value was evaluated considering several adjacent ECT signal indications as a continuous flaw.

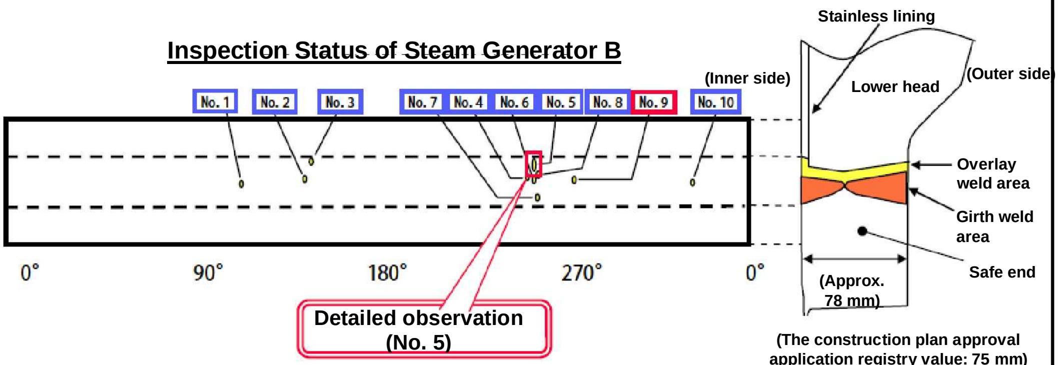



(The construction plan approval application registry value: 75 mm)

### Inspection Status of Steam Generator B

(Maximum length)
No. 5: Approx. 10 mm*
(Maximum depth)
No. 9: Approx. 5 mm

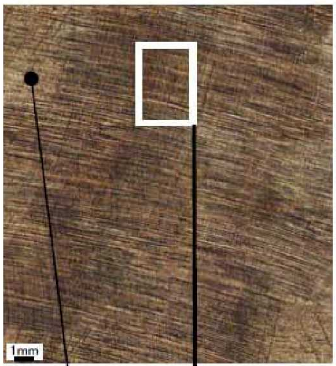
*: The value was evaluated considering several adjacent ECT signal indications as a continuous flaw.




(The construction plan approval application registry value: 75 mm)

# Detailed observation of indicated part No. 5 of welded part of inlet nozzle in steam generator-B

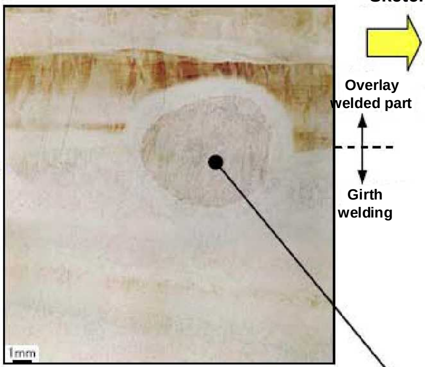
## Replica examination



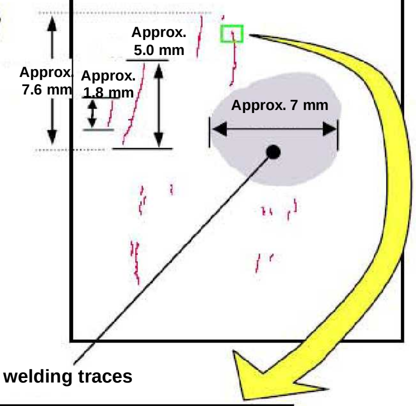
Traces of buffing work

Finishing traces that are assumed to be of grinding work (polishing)

## SUMP observation result




Sketch




Repair welding traces

Cracks have occurred along the dendrite border that has a similar facet to that of stress corrosion cracking in the primary coolant environment.

## Surface treatment status confirmation test

Reproduction test of surface treatment traces in Unit 2 of Tsuruga NPP of Japan Atomic Power Company

[Surface treatment status]
Grinding work (grinding)
+
Buffing work
+
Grinding work (polishing)
(Elastic grinding stone)

- Facet equivalent to replica examination result of Tomari NPP Unit 2.
- Tensile residual stress was confirmed, which has a possibility of causing stress corrosion cracks in the primary coolant environment.

## Assumed cause

Environment: Primary coolant water quality environment in hot temperature

Material: 600 type nickel base alloy susceptible to stress corrosion cracking

Stress: Tensile residual stress by grinding work

It is assumed that three factors have overlaid and the stress corrosion cracking occurred in the primary coolant environment

## Countermeasures

- Cut out the area in concern throughout the whole circumference including cracks with a cutting device.
- Confirm that the cracks are removed through penetrant test (PT).

↓

- If there are any remaining cracks, partially remove the cracks with a grinder.
- Confirm that the cracks are removed through penetrant test (PT).
- Perform overlay repair welding using 600 type nickel base alloy.

↓

- Perform overlay welding throughout the whole circumference using 690 type nickel base alloy, which is superior in corrosion resistivity.
- Perform buffing work as a precautionary measure to reduce residual stress.