RAS M-339

Secondary Piping Rupture Accident at Mihama Power Station, Unit 3, of the Kansai Electric Power Co., Inc. (Final Report)

March 30, 2005
The Nuclear and Industrial Safety Agency

(Translated by JNES, Rev 1 as of May 14, 2005)

Contents

1. Introduction

An accident occurred at Mihama Power Station, Unit 3, of the Kansai Electric Power Co., Inc. (abbreviated to KEPCO hereinafter) on August 9, 2004. A secondary piping ruptured and high temperature secondary cooling water flowed out, so the reactor shut down automatically. An investigation was carried out on the spot and an opening was confirmed in a pipe of the condensate system.

This accident was one of so-called secondary piping rupture accidents of a pressurized water reactor (PWR). When compared to the results of an analysis of the same kind accident in the safety review, no particular problem was recognized in the reactor parameter variations immediately after the accident. However, the accident resulted in a serious consequence that was unprecedented at a nuclear power plant in Japan. That is, of the workers working in the turbine building, 5 were killed and 6 were injured.

Immediately after the occurrence of the accident, the Nuclear and Industrial Safety Agency (abbreviated to NISA hereinafter) dispatched a Deputy Director-General to the scene reprimand for the accident in writing. At the same time, he issued a technical standard conformance order concerning Mihama Power Station, Unit 3, based on Article 40 of the Electric Utilities Industry Law to order a suspension of its use until the conformance to the technical standards was verified.

After that, the Investigation Committee continued surveys and investigations about the matters pointed out in the Interim Summary and also examined the reports submitted by KEPCO and Mitsubishi Heavy Industries, Ltd. (abbreviated to MHI hereinafter) on March 1, 2005. NISA summarized these investigation results into a final report about this accident.

For the investigations of the accident, the Investigation Committee sessions were opened to the public to disclose the deliberation processes transparently. During this period, NISA has made efforts to fulfill its accountability for the accident by explaining directly to Fukui Prefecture, Mihama-cho, and other local municipalities concerning the progress of surveys and investigations.

To help the investigation and discussion at the Nuclear Safety Commission, NISA has appropriately reported the progress of surveys and investigations at the Investigation Committee to the Nuclear Safety Commission.

2. Accident situation and reactions

2.1 Situation at the accident

While Mihama Power Station, Unit 3, was in operation at the rated thermal output, a "Fire Alarm Operation" alarm, etc. was generated in the central control room at 15:22 on August 9, 2004. The operator grasped that the alarm-generated spot was on the second floor of the turbine building and checked the spot to find that the building was filled with steam. Thus, it was judged that there was a high possibility of steam or high temperature water leakage from the secondary piping. The operator started emergency load reduction at 15:26. While those operations took place, a "3A SG Feed water < Steam Flow Inconsistency Trip[1]" alarm was generated at 15:28 and the reactor and then the turbine shut down automatically.

No particular problem was recognized in the major plant parameter variations at the accident and the reactor reached to a cold shutdown at 23:45 on August 10, 2004.

The operator made an inspection in the turbine building and confirmed a ruptured opening in an A-loop condensate pipe at 17:30 on August 9, 2004, which was the feed water line from the 4th feed water heater[2] to the deaerator[3] running near the ceiling on the deaerator side at the 2nd floor of the turbine building. After that, the nuclear safety inspector also confirmed the same situation.

For the unit in question, the 21st periodical inspection was planned to start on August 14, 2004. In the turbine building, a total of 105 workers of KEPCO and affiliated companies were doing preparatory work for the periodical inspection at the time of occurrence of the accident. Of them, the affiliated company's workers working near the ruptured A-loop condensate pipe fell victim to the steam and high temperature water flowed out from the ruptured opening, and 5 were killed and 6 were injured.

The major systems of PWR and the ruptured spot are shown in Figure 1.

According to KEPCO, they examined the operation parameters before and after the occurrence of the accident, but did not find out any variation indicating a symptom of rupture before the occurrence of the rupture. They say they did not perform any special operation that might have induced the accident.

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1 SG Feed water < Steam Flow Inconsistency Trip: An alarm issued when the water level of the steam generator is low and the feed water flow to the steam generator is less than the steam flow.
2 Feed water heater: A heat exchanger to heat feed water by the heat of extraction steam from the turbine.
3 Deaerator: A device to heat feed water by the heat of extraction steam from the turbine to separate and remove noncondensing gases (oxygen and others) in the feed water.

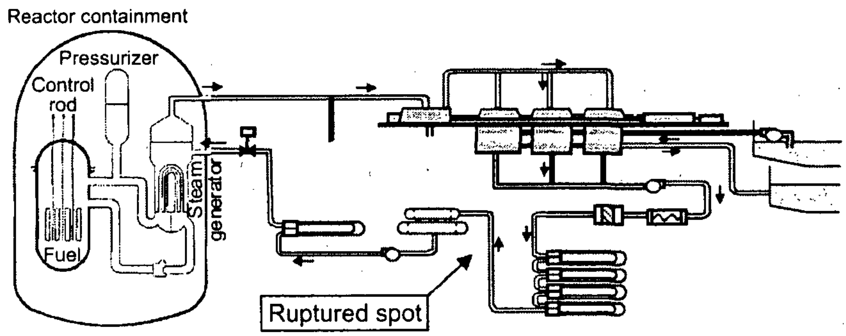

Figure 1. Major systems of PWR and the ruptured spot

(Reference information) Outline of Mihama Power Station, Unit 3

1.	Name:	Mihama Power Station, Unit 3, of KEPCO
2.	Location:	Nyu, Mihama-cho, Mikata County, Fukui Prefecture
3.	Rated thermal output:	2.44 million kW
4.	Rated electric output:	826 thousand kW
5.	Reactor type:	Pressurized water reactor (PWR)
6.	Commissioning:	December 1, 1976
7.	Operating time:	185,700 hours

2.2 Initial reactions of KEPCO and NISA assessment

2.2.1 Notification and communications, rescue activities and NISA assessment

(1) Notification and communications, rescue activities

KEPCO submitted a report named "On the Secondary Piping Rupture Accident of Mihama Power Station, Unit 3" dated on March 1, 2005 (abbreviated to the KEPCO Accident Report hereinafter). According to the KEPCO Accident Report, the actions taken after the occurrence of the accident were as follows. On receipt of a fire alarm, a member of the General Manager's staff immediately instructed evacuation from the turbine building through a public address system. At the same time, the member dialed 119 to call for ambulances. As for the related organs, the Mihama Nuclear Safety Inspector Office of NISA was notified 10 minutes after the occurrence of the accident. As for the local municipalities, Mihama-cho was notified 8 minutes after, and Fukui Prefecture 12 minutes after the occurrence of the accident.

Rescue activities for the victims could not proceed easily at first, because the turbine building was filled with high temperature steam. However, the staffs of the Power Station and the affiliated companies rescued 6 persons and, after arrival of fire brigades, the Power Station staffs and members of fire brigades cooperated in searching and succeeded in rescuing 5 persons. All 11 persons were carried out completely by 16:46, or 1 hour and 24 minutes after the occurrence of the accident.

The series of situations are shown in Appendix 1.

(2) Assessment by NISA

NISA points out in the Interim Summary that the accident should not be taken as a mere accident, but the various lessons learned from the accident should be utilized for enhancing disaster prevention measures by expanding the initial action framework and reinforcing cooperation with the related organs in case of nuclear power station troubles and accidents.

With regard to the initial reactions of KEPCO at the occurrence of the accident, rescue of victims and notification to the related organs were performed appropriately in general. However, inappropriate actions were found in several points. For example, the emergency notification to the fire headquarters did not take place in accordance with the notification path stipulated in the fire defense plan. There was no rule available for the licensee to directly inform the medical agencies of the information whether the radiation contamination such as preparation of an initial response manual that describes a prompt response system in case of an emergency.

2.2.2 Shutdown operations and NISA assessment

(1) Shutdown operations

In the KEPCO Accident Report, the operations performed by the operator at the accident are examined in the divided stages of (a) Judgment of emergency load reduction, (b) Response after the reactor trip, (c) Closing of the deaerator water level control valve, and (d) Transition operations from reactor hot shutdown to cold shutdown. As a result, it is concluded that (a) was performed in accordance with the "Operation Room Job Manual," (b) in accordance with the "Accident Manual" and (d) in accordance with the "Normal Operation Manual" each. For (c), the report says that the operation took place because there was a concern regarding system water boiling due to the opening in the secondary piping.

With regard to a large amount of secondary cooling water flowed out from the opening into the turbine building as described later, KEPCO examined the possibility of reducing the amount of outflow by operator manipulations. As a result, it assessed that there was a possibility of reduction of the outflow amount if the operator had closed the deaerator water level control valve earlier.

(2) Assessment by NISA

NISA assessed the responses of the operators at the accident in view of (a) whether they responded in accordance with the various manuals, and (b) whether the spread of accident damage could be prevented if more appropriate operations were taken.

For (a), the responses and operations of the operators were collated with the respective manuals and, as a result, their conformance to the manuals was confirmed.

For (b), it is important for the licensee to sincerely investigate operation procedures that are effective in reducing the extent of accident damage to be as small as possible. Therefore, it can be appreciated, though being an ex-post measure, that KEPCO made various kinds of case studies concerning how the outflow amount could be reduced.

For this time accident, however, there was a substantial amount of outflow immediately after the pipe rupture, and it can be estimated that the disaster occurred simultaneously. Therefore, even on the assumption that the operator performed the best operations for outflow reduction, it is problematic how much those actions contributed to mitigation of the accident damage.

At the time of the accident, the reactor cooling was maintained by the emergency feedwater system. Therefore, the outflow of cooling water from the secondary system, regardless the amount, did not affect the reactor safety.

2.3 Influences on the reactor and related facilities and NISA assessment

2.3.1 Influences on the reactor

For the influence of the accident on the reactor, as stated in the Interim Summary, the systems related to reactor safety operated normally, and the reactor pressure, primary coolant temperature and other major parameters did not indicate more severe influence than the results assumed in the safety assessment analysis performed at the safety review.

2.3.2 Temporary inoperativeness of auxiliary feed water flow control valve located in turbine-driven auxiliary feed water line

(1) Outline of the event, causes and countermeasures

According to the KEPCO Accident Report, two motor-driven auxiliary feed water pumps automatically started at 15:28 on the day of the accident, followed by an automatic start of one turbine-driven auxiliary feed water pump due to the abnormal low water level of the steam generator. After that, because the necessary flow rate of auxiliary feed water was secured, so the auxiliary feed water flow control valves A, B and C in the turbine-driven auxiliary feed water line were closed at 15:32 to stop lowering the primary coolant temperature excessively.

After that, the water level of the steam generator was recovered and became stable, so the turbine-driven auxiliary feed water pump was stopped at 17:12. To put this pump in an automatic standby condition, the operator tried to open the auxiliary flow control values A, B, and C at 17:13. However, the valves A and C stayed closed and no opening action took place. The operator tried to open the valves A and C again the next day, and both valves opened.

As a result of the cause investigation , it was presumed that the backpressure of the valves in question exceeded the valve opening force while the pump was stopped, and this kind of system condition was not assumed in the design conditions for the valve. That was estimated to be a cause. As a countermeasure, it was decided to replace the valve opening spring with one having a larger spring constant to provide the valve with a larger valve opening force than the maximum back pressure assumed in the design.

(2) Assessment by NISA

As a result of examination of the contents reported by KEPCO, NISA considers these estimated causes to be appropriate .

From the fact that the turbine-driven auxiliary feed water pump fulfilled its function to secure the necessary flow rate of auxiliary feed water and that it was possible to open the valves because the inlet pressure of the valve will increase to exceed the backpressure in case of the turbine-driven auxiliary feed water pump operation, the trouble can be considered in consequence as not affecting the reactor safe shutdown. On the other hand, for the important equipments that are indispensable to secure the reactor safety, it is necessary indeed that they should be designed to keep their functions in any situation in which they are expected to operate. The trouble was caused by the fact that the service conditions appeared during the accident were not sufficiently considered in the design stage. It is appropriate to replace the valve operating spring with one that has a larger spring constant.

2.3.3 Influences of steam and high temperature water on facilities

(1) Evaluation of the amount of leakage and affected zone

In the Interim Summary, the amount of secondary cooling water outflow from the opening was calculated by summing up the amount of makeup water from the secondary makeup water tank, the amount of deaerator water level falling and the amount of water contained in the piping (from the 4th low-pressure feed water heater to the deaerator). As a result, it was evaluated to be about 885 tons.

Table 1. Leakage amount from various parts

(Unit: ton)

Amount of makeup water from the secondary makeup water tank	About 565
Amount of deaerator water level falling	About 307
Amount of water contained in the piping	About 13
Total	About 885

According to the KEPCO Accident Report, it was estimated as a result of the situation survey on the spot that high temperature water flowed out from the opening and then flowed down from the second floor to the 1st floor through the stairs and openings, and finally flowed into the turbine sump. With regard to steam blown out from the opening, it is estimated that the steam rapidly permeated almost all the whole area of the turbine building immediately after the pipe rupture and intruded into some portions of the control building and the intermediate building adjacent to the turbine building.

In the region estimated to have touched high temperature water or steam that blew out from the pipe opening, there were the solenoid valves for main steam isolation valves, the control panels installed in the central control room, the instrument power facilities, the DC power facilities and the turbine-driven auxiliary feedwater pump as safety-related facilities.

Of these, high temperature water intruded into the terminal box of one of the three solenoid valves for the main steam isolation valves, and one-sided grounding formed in the DC circuit; however, it operated normally at the accident.

A trace of steam intrusion was found at the control panels installed in the central control room, the instrument power facilities and the DC power facilities; however, they operated normally at the accident.

For the turbine-driven auxiliary feed water pump, no trace of steam intrusion was found in the pump room, and the pump operated normally at the accident.

In the regions estimated to have touched high temperature water or steam that blew out from the pipe opening, no facilities related to the plant safe shutdown were installed other than these facilities.

(2) Assessment by NISA

According to the KEPCO Accident Report, in the region estimated to have touched high temperature water or steam, there were the solenoid valves for main steam isolation valves, the control panels installed in the central control room, the instrument power facilities, the DC power facilities and the turbine-driven auxiliary feed water pump as safety-related facilities. According to the report, these equipments operated normally during the accident, and there was no trouble in the plant shutdown after the accident; however, the report says that high temperature water or steam intruded into some of the facilities related to the plant safe shutdown at an accident.

In the accident, steam intrusion was observed in the control panels installed in the central control room. The central control room is a place where operators stay even at the time of an accident to perform operations for accident countermeasures, so the room must be designed for ventilation to prevent unnecessary outside air from intruding. According to KEPCO, the steam intrusion this time occurred due to inappropriate sealing work at some of the wall penetrations for cable trays and conduits. Because such inappropriate portions can substantially affect the habitability of the central control room, NISA considers this a serious problem. Therefore, NISA will instruct licensees to check, if necessary, whether construction work has been executed certainly or not at plants other than Mihama Power Station, Unit 3.

2.4 Influences on surrounding environment

As stated in the Interim Summary, no influence of radiation on the surrounding environment due to the leaked secondary cooling water was observed.

3. Technical investigations of pipe rupture

With regard to the pipe rupture mechanism, it was estimated in the Interim Summary based on the results of the investigations of ruptured condition of pipe that the cause for the pipe rupture was so-called erosion/corrosion, which gradually reduced the pipe wall thickness with the lapse of operation time, resulting in insufficient pipe strength and rupture under the load during operation. After that, NISA proceeded with investigations such as metallurgical investigations on the ruptured portion, pipe flow analysis, pipe rupture structural behavior analysis in cooperation with the Japan Nuclear Energy Safety Organization (abbreviated to JNES hereinafter) and the Japan Atomic Energy Research Institute (abbreviated to JAERI hereinafter). This chapter covers the content described in the Interim Summary with an addition of the results of investigations carried out after that and marshals them as a result of technical investigations of pipe rupture .

3.1 Ruptured condition of pipe

The portion where a rupture was confirmed was in a condensate pipe of the A-loop, one of the two loops of condensate piping going from the 4th low-pressure feed water heater to the deaerator near the ceiling on the deaerator side on the 2nd floor of the turbine building, and was near the downstream of the orifice[4] for measuring the condensate flow rate of the A-loop.

A joint team of NISA and JNES conducted an on-the-spot inspection, and as a result confirmed a fracture opening in the ruptured portion, which extended a maximum of about 515 mm in the axial direction and about 930 mm in the circumferential direction of the pipe. KEPCO measured the pipe in the presence of the police authority, and the result was 0.4 mm at the thinnest portion of the pipe, whereas it must be 4.7 mm or over[5] according to the technical standards. As shown in Appendix 2, the thinning was striking in the upper part of the pipe.

The A-loop pipe was cut out, including the ruptured portion, and examined at JAERI. As a result, a portion was found out downstream of the vent hole of the orifice[6] where pipe wall thinning reached to the flange for the orifice support.

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4 Orifice: A throttling mechanism to narrow down the cross section of a pipeline. An orifice installed to measure the flow rate of the fluid flowing in the pipe is called a flow meter orifice, and an orifice installed to reduce the fluid pressure in the pipe is called a pressure reducing orifice.

5 According to the strength calculation for pressure-resistance of pipes attached to a steam turbine, based on the "Ordinance of Establishing Technical Standards on Thermal Power Generation Equipment" applied to the secondary system of PWRs

6 Vent hole of orifice: A hole provided at the top of the orifice to vent air (the diameter is 4 mm for the orifice in question).

The inner surface of the pipe was observed using a digital microscope, and it exhibited a fish scale-like pattern, which is characteristic of so-called erosion/corrosion[7], downstream of the orifice and over the entire surface except the bottom (180°) of the pipe. At the bottom (180°) of the pipe, a portion of almost nominal wall thickness existed where thick surface film (about 0.5 mm) existed, and a fish scale-like pattern was not seen on the inner surface of the pipe.

The insulation material attached to the pipe was scattered around.

The ruptured condition of the pipe is shown in Figure 2.

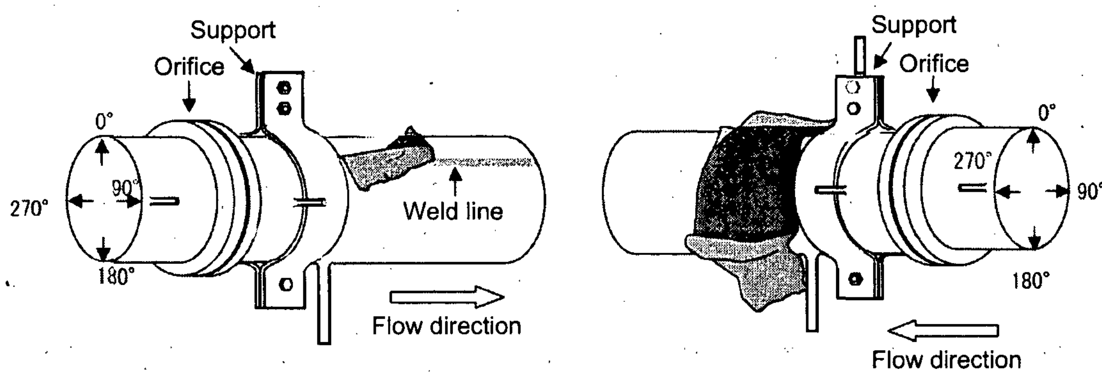

Figure 2. Ruptured condition of pipe

3.2 Investigation of similar portion

The ruptured portion this time is in the A-loop line, one of the two systems (A-loop and B-loop) going from the 4th feed water heater to the deaerator. KEPCO investigated the pipe wall thickness of the same portion of the B-loop (called a similar portion hereinafter) in the presence of the police authority. The B-loop piping was cut out, including the similar portion, and the pipe wall thickness measurement and internal surface observation were performed at JAERI.

As a result, a thinning tendency was observed over almost the entire surface downstream of the orifice as shown in Appendix 2. Pipe wall thinning was observed downstream of the vent hole in the orifice. Upstream of the orifice, however, no significant thinning tendency was observed. At the thinnest portion of the wall, the thickness was 1.8 mm.

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[7] Erosion/corrosion: The thinning phenomenon caused by the mutual action of erosion due to mechanical actions and corrosion due to chemical actions.

The inner surface of the pipe was observed using a digital microscope, and the result was that it exhibited a fish scale-like pattern over almost the entire surface, which is characteristic of so-called erosion/corrosion.

3.3 Investigation of design specifications

According to KEPCO, in case of the design of secondary system piping, material selection and strength calculation of pressure retaining parts were performed in accordance with the "Technical Standards on Thermal Power Generation."

The maximum service pressure of the pipe in question is 1.27 MPa, and the maximum service temperature is 195°C. From among materials having sufficient strength margin, carbon steel (SB42) was chosen, considering its service performance.

Major specifications of the piping in question are shown in Table 2 "Major specifications of the piping in question."

Table 2. Major specifications of the piping in question

Material	Carbon steel (SB42)
Outer diameter (mm)	558.8
Thickness (mm)	10
Maximum service temperature (°C)	195
Maximum service pressure (MPa)	1.27

According to KEPCO, the temperature of the ruptured portion in the state of actual service is about 140°C, the pressure is about 0.93 MPa, and the flow rate is about 1,700 m^3/h.

The design specifications of this piping were decided considering the service environment. The mill sheet[8] was examined concerning the tensile strength, material ingredients, etc. However, no problem was identified by NISA.

3.4 Investigation of installed condition of piping

The roundness deviation of the A-loop pipe in question and B-loop pipe at the similar portion was examined. The result was that the tolerance of the outer diameter exceeded the tolerance of JIS (±0.8%) in parts downstream of the ruptured portion of the A-loop pipe; however, the roundness deviation in other portions was within the tolerance.

8 Mill sheet: When an order of steel with a specified standard is received, this document is attached to the product to certify that the manufactured results of the steel satisfy the requirements, like specified standard, specifications and so on.

The installed condition of the orifice at the ruptured portion was examined, and the result was that the misalignment of the orifice hole center was 0.61 mm in the vertical direction and 0.71 mm in the horizontal direction with respect to the inner diameter center of the pipe.

3.5 Investigation of quality control history of secondary cooling water

According to the KEPCO Accident Report, Mihama Power Station, Unit 3, injects feed water treatment chemicals basically from downstream of the condensate treatment equipment from the standpoint of corrosion inhibition of the whole secondary piping and equipment. All volatile treatment (AVT) using ammonia (pH adjuster) and hydrazine (deoxidizer) ,as the feed water treatment chemicals, has been performed since the commissioning. As an anti-corrosion measure for the steam generator tube, boron injection[9] had been performed from the 10th to the 15th operation periods. From the 17th operation period, ethanolamine has been added as a pH adjuster.

KEPCO investigated the water quality control history since the commissioning of Mihama Power Station, Unit 3; and as a result, it says that both the feed and condensate water quality data have been maintained within the water quality control values and that there was no variation in pH, dissolved oxygen, etc. At Mihama Power Station, Unit 3, condenser tube leaks occurred twice in the past, and seawater flowed into the secondary cooling water. However, these events are considered to have no effect because the copper alloy does not corrode on the side in contact with the condensate water almost free of oxygen.

The effect of boric acid on pipe wall thinning was investigated; however, no significant difference was recognized in the effect on the thinning rate between with and without boron injection.

The control values of secondary system water quality at Mihama Unit 3 are shown in Table 3.

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[9] Boron injection: A substance injected for neutralization to prevent alkali from concentrating in parts of the steam generator tube/support plate and thereby prevent intergranular corrosion in the Inconel 600-alloy tube.

Table 3. Secondary system water quality control values at Mihama, Unit 3

Item		Control value
pH (at 25°C) (Feed water)	AVT	8.8 to 9.3 (9.2)
	AVT + boron injection	8.5 to 9.3
	AVT + ETA injection	8.8 to 9.7
Ethanolamine (at injection of ETA in feed water)		3 ppm
Hydrazine (Feed water)	1	Dissolved oxygen in condensate + 5 ppb
	2 to 7	2 ppb
	8 to 15	5 ppb
	16 to 18	200 ppb
	19 to 21	100 ppb + Dissolved oxygen in condensate × 40
Dissolved oxygen (in feed water)		5 ppb
Dissolved oxygen (in condensate)	1 to 15	50 ppb
	16 to 21	10 ppb
Total iron (in feed water)	1 to 15	20 ppb
	16 to 18	10 ppb
	19 to 21	2 ppb

(Note) Numbers in the "item" column denote operation periods.

3.6 Investigation of operation history

According to the KEPCO Accident Report, plant trips could cause variations in condensate flow rate, temperature and pressure in the piping in question and affect the portion in question. Past plant trips and other transient events having such possibility were investigated. The result was that their influence on feed water flow rate, pressure and temperature was within the limits of the design conditions. And it was confirmed that their number of occurrences was within the limits of the design number of occurrences.

In addition, an interview was held to confirm the plant operation conditions and occurrence of abnormal sound or the like immediately before the rupture of the portion in question. According to the interview result, no transient event or precursor was perceived that might have induced the rupture event.

3.7 Investigation of pipe rupture mechanism

JNES, JAERI and KEPCO carried out the following investigations to estimate the pipe rupture mechanism.

3.7.1 Metallurgical investigations

As metallurgical investigations on cutouts from the ruptured pipe (A-loop piping) and B-loop piping, JAERI performed appearance observation, material investigations (material chemical composition analysis, tensile test, metallographic observation, hardness test, and others), wall thickness measurement, and fractographic observation.

The appearance of the ruptured opening was observed by the naked eye, and there was no traces of external loads, detrimental scratches, cracks that might cause the rupture.

As to the chemical compositions, tensile properties and the like of the pipe material, it was confirmed that the material used for the pipe in question conformed to the mill sheet for both the A-loop and B-loop piping.

On the internal surface of the thinned wall portion, a fish scale-like pattern with a smooth surface was observed. This pattern is formed by so-called erosion/corrosion. The wall thickness near the axial crack in the ruptured opening was 0.3 to 0.4 mm in the thinnest part. On all representative fracture surfaces in the ruptured opening, dimples[10] were observed, which are characteristic of ductile fracture, and fatigue cracks were not observed.

An outline of metallurgical investigations is given in Appendix 3.

3.7.2 Pipe flow analysis

Since flow analysis is apt to exhibit the features of the method employed to make the model and the code used for the analysis, flow analyses were carried out independently using multiple codes owned by JNES and JAERI to evaluate the wall thinning tendency due to flow disturbances.

A prediction analysis to examine the thinning tendency due to turbulent flow was carried out (at JNES and JAERI), and results were compared with actual measurements. They showed a relatively good agreement as to the position of maximum thinning (downstream of the orifice, at a distance of about 1.2 times the pipe diameter).

From a 3-dimensional turbulent flow analysis (at JNES and JAERI), a strong counterclockwise swirling flow, as seen from upstream, was confirmed in the flow velocity distribution at the orifice inlet for the A-loop piping, and a weak clockwise swirling flow, as seen from upstream, was confirmed for the B-loop piping.

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[10] Dimples: Depressions occurring in the fracture surface when a metallic material is ruptured by ductile fracture.

According to a 1-dimensional 2-phase flow analysis using the design values (at JNES), the result obtained was that the possibility of decompressed boiling (cavitation) was low downstream of the orifice.

An outline of pipe flow analysis is given in Appendix 4.

3.7.3 Thinning behavior analysis

Using the thinned wall pipe reliability analysis code (PASCAL-EC) owned by JAERI, so-called erosion/corrosion was assessed in a single-phase water flow.

The maximum amounts of thinning measured on the A-loop and B-loop piping were somewhat larger than the analysis results; however, they were within existing knowledge. Sensitivity analysis with respect to the thinning rate was carried out with the result that pH and dissolved oxygen had a large influence.

In case where the operating pressure and design bending moment were imposed on the A-loop piping, the wall thickness at rupture was 0.5 to 0.6 mm. The result obtained was that the bending moment did not have a large influence on the wall thickness at rupture.

An outline of thinning behavior analysis is given in Appendix 5.

3.7.4 Pipe rupture structural behavior analysis

With a view to grasping the fracture opening behavior of the ruptured portion of the pipe at the accident, the analysis code (AUTODYN-3D) owned by JNES was used to do opening progress analysis at the ruptured opening with a 3-dimensional model. As to pipe wall thickness, the data measured at JAERI after the accident was used.

As a result, it was estimated that, after the occurrence of a crack, the crack propagated in the axial direction first and then in the circumferential direction to attain the final shape in 1/100 second or so.

An outline of pipe rupture structural behavior analysis is given in Appendix 6.

3.7.5 Pipe flow visualization test

KEPCO fabricated a visualization test model to a scale of 1/2.6, including the upstream header to the downstream portion of the orifice of the A-loop and B-loop piping, and measured the flow velocity distribution upstream of the orifice and the pressure variations downstream of the orifice.

As a result of the visualization test, it was confirmed that a stronger swirling flow occurred in the A-loop pipe than in B-loop pipe due to the pipe branching configuration at the header and a relatively large flow disturbance occurred downstream of the orifice.

3.7.6 Investigation results

Findings by the investigations performed so far are summarized as follows:

a. The ruptured pipe is of carbon steel, and the ruptured portion was downstream of the orifice where channeling is apt to occur.

b. The condensate temperature was about 140°C in the neighborhood of the ruptured portion. So-called erosion/corrosion is apt to occur at this temperature.

c. The pH, dissolved oxygen and other water quality data of the feed water and condensate systems have been maintained within the control values.

d. The inner surface of the pipe suffered substantial thinning and exhibited a fish scale-like pattern over almost the entire surface, which is characteristic of so-called erosion/corrosion. On a representative fracture surface at the ruptured opening, dimples were observed, which is characteristic of ductile fracture.

e. At the similar portion of the B-loop, the inner surface of the pipe similarly suffered substantial thinning and exhibited a fish scale-like pattern.

f. From the result of pipe flow analysis, a stronger swirling flow was recognized in the A-loop pipe than in the B-loop pipe. The abrupt thinning tendency seen at the ruptured opening could be reproduced by the analysis relatively well.

Therefore, the cause for the pipe rupture is estimated to be so-called erosion/corrosion, which has gradually reduced the pipe wall thickness with the lapse of operation time. At last, the pipe strength became insufficient and the pipe ruptured under the load during operation.

The maximum amount of wall thinning of the pipe was within existing knowledge, such as past operation experience at various plants and experimental data.

In the portion downstream of the vent hole of the orifice, local wall thinning which reached to the orifice-supporting flange was found; however, it cannot be thought to have affected the wall thinning at the ruptured opening. The wall thinning in this portion is local and the flange acts as a reinforcing member, so it is not thought that this thinning could cause a large opening in the pipe.

4. Investigation of pipe wall thickness control

4.1 Legal positioning of pipe wall thickness control

For the secondary piping of PWR plants, KEPCO established the "Guidelines for Secondary Piping Wall Thickness Control at Nuclear Facilities (PWR)" (abbreviated to PWR Management Guidelines hereinafter) in May 1990, and based on the Guidelines, all licensees operating PWRs had conducted a wall thickness measurement as a self-imposed inspection. With the amendment of the nuclear facility inspection system in October 2003, secondary piping control is now incorporated in the periodic licensee's inspection, and in this scheme, the regulatory authority also checks the appropriateness of the state of fulfillment by the licensee.

The pipe wall thickness control at a thermal power station is given in Appendix 10.

4.2 Verification of control techniques for pipe wall thickness

4.2.1 Control techniques at PWR plants

(1) Background to establishment of PWR Management Guidelines

For PWR, thinning due to erosion/corrosion occurred in some plants in the first half of the 1980s, and investigations were carried out on pipe wall thickness. After that, a secondary piping rupture accident occurred at the Surry Power Station in the US in December 1986. With this accident as a turning point, KEPCO statistically evaluated the data obtained from the results of the secondary pipe wall thinning survey then carried out at KEPCO's PWR plants by commissioning to MHI and examined the control method for that thinning. Based on the examination results, KEPCO established the "PWR Management Guidelines" in May 1990.

In response to the establishment of the PWR Management Guidelines, the licensees operating PWRs reported the establishment of the Guidelines to the then Agency for Natural Resources and Energy, which held jurisdiction over nuclear safety regulations, and appended a note to the effect that they would conduct self-imposed inspections according to the Guidelines.

In response to this report from the licensees, the then Agency for Natural Resources and Energy deliberated in the Advisory Committee on Nuclear Power Generation to confirm the validity of the Guidelines, and after the confirmation, decided to entrust the control to self-imposed safety inspections by the licensees based on the "obligation for conformity with the technical standards" imposed on the licensees by the Electric Utilities Industry Law.

(2) Validity of PWR Management Guidelines

For the PWR Management Guidelines, more than 10 years have passed since the establishment, and a lot of thinning data has been obtained. Nevertheless, no review has been done based on the latest data. Therefore, as shown in Appendix 7, NISA examined this time the validity of the PWR Management Guidelines based on the measured thinning data[11] .

Measured points and thinning tendency of major piping

The PWR Management Guidelines prescribe the initial thinning rate by wetness fraction, flow velocity and temperature differently for "two-phase" and "single-phase water flow," for the systems to be inspected. This time, actual values of the thinning rate based on the data obtained by the inspections so far, described later, at nuclear power plants throughout the country were analyzed, and it was found that these values are less than the initially set value of thinning rate prescribed in the PWR Management Guidelines except for only a few of them. Therefore, the initially set value of thinning rate prescribed in the Guidelines can be assessed to be valid in principle.

Selection of sampling points

For the portions showing no tendency of thinning, the PWR Management Guidelines stipulate inspection of those portions at a rate of about 25% every 10 years. As a result of the investigation this time, the thinning tendency of the sampling points belonging to "other systems" is less than the main checked systems as an overall tendency. That is, the data obtained indicates that control by sampling will cause no problem. However, care must be taken because a thinning tendency of the same degree as the main checked systems was observed at some portions.

Measuring areas and measuring points of thinning

The PWR Management Guidelines stipulate the measuring area of thinning to be, for an orifice for example, from its installed place to 2×D downstream (D is the pipe inside diameter). According to an investigation result, the place of severe thinning is within 2×D. No measuring points are stipulated in the PWR Management Guidelines. In actual practice, however, 8 or 4 measuring points are set up per one cross section. If the wall thickness at a measuring point falls short of a certain criterion of wall thickness,

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[11] Thinning data: The values of thinning rate and other data at the minimum thickness points (21 points for PWR, 27 points for BWR and 38 points at Mihama Power Station, Unit 3), obtained from the licensees according to "Collection of Reports on the Inspection Concerning the Pipe Thinning Phenomenon" (August 11, 2004) based on Paragraph 1, Article 106, of the Electric Utilities Industry Law.

detailed measurement is performed around the measuring point with a finer measuring pitch. As a result, the measuring area and measuring points stipulated in the PWR Management Guidelines are justified as being capable of appropriately keeping track of thinning in combination with the detailed measurement.

(3) Future tasks regarding the PWR Management Guidelines

The major pipes in the PWR secondary piping were checked for thinning. On some pipes, the thinning rate exceeded the initially set thinning rate stipulated in the PWR Management Guidelines. Although it is necessary to conduct a verification by further accumulating data in the future, the actual value of thinning rate is within the value assumed in these Guidelines for most of the pipes. The initially set thinning rate is for use in determining the period to the first wall thickness measurement. Once the thickness measurement is done, a new thinning rate is set based on that measured value. This determines the remaining life and the period to the next measurement. Therefore, the first wall thickness measurement must be performed well in advance, and appropriate thinning rate setting and appropriate remaining life evaluation must be done for the portions to be measured. It is thought that no safety problem will occur as long as repair and replacement are carried out based on these results.

For the "other systems" of PWR under control by sampling, the thinning rate is fairly lower than the main checked systems as a whole. As seen in the case of Mihama Power Station, Unit 3, shown in Appendix 7, and the case of Ohi Power Station, Unit 1, shown in Appendix 8, some portions exhibited the same thinning rate as the main checked systems. For such portions including the similar portions, therefore, it is thought necessary to examine from the actual measurements so far to see whether or not there is a safety problem and to do a wall thickness measurement advancing the inspection date or otherwise if necessary. In addition, it should be examined after this whether or not there is the necessity for doing control of the portion in question as a main checked system.

By practicing measurement at representative measuring points and detailed measurement based on the data from that measurement, it is thought possible to keep track of the shape and size of various kinds of thinning. However, this technique is not specified in the PWR Management Guidelines. In the revising work of the Guidelines after this, current (currently employed) measuring methods should be appropriately reflected in the Guidelines by adding this detailed measuring technique to the Guidelines or otherwise.

4.2.2 Control techniques at BWR plants

(1) Current situation of control techniques

For BWR, thinning due to erosion/corrosion was also recognized at some plants in the initial stage of their operation. Oxygen injection to the feed water and condensate systems is performed as an environmental improvement measure of water quality, and replacement with erosion/corrosion-resistant materials is taking place. For thinning control, the secondary piping rupture accident at the Surry Nuclear Power Station described above acted as a trigger for beginning measurement of thinning at various plants, and each licensee has set down a control technique on its own terms, based on such measurements.

(2) Future tasks regarding BWR control technique

Each licensee operating BWRs has set down control guidelines on its own terms, and there is a great deal of common matter in the contents. Compared to the practices of PWR control based on the PWR Management Guidelines, the inspection frequency (for the portions to be inspected, the ratio of the number of portions actually inspected to the number of portions evaluated or otherwise checked at a representative inspection point instead) for BWR is lower than that for PWR as shown in Appendix 9.

The change of the amount of thinning measured at various BWR plants and the actual values of the thinning rate based on the measurements were surveyed. As a result, the tendency of thinning is different between PWR and BWR, or the thinning rate of BWR is less than that of PWR. This is presumably related to the difference in water quality between PWR and BWR.

After this, the licensees should increase the inspection frequency and obtain sufficient data for analysis of thinning tendencies. In addition, they should mutually utilize the thinning data at different licensees to deepen their scientific analysis further and make their various control guidelines common by joint efforts.

4.3 Implementation state of pipe wall thickness control by licensees

NISA carried out a safety inspection at all nuclear power stations except for the Higashi-Dori Nuclear Power Station of Tohoku Electric Power Company from late August to early October of 2004 (second safety inspection of 2004) and from late November to the middle of December (third safety inspection of the same year) by nuclear safety inspectors and other staffs in residence throughout the country with "implementation policy and implementation state of pipe wall thickness control" taken as a priority inspection item. On that occasion, emphasis was laid on the appropriateness of the licensee's management structure for pipe wall thickness control (selection of the portions to be inspected, determination of an assessing method and assessment of measurements) and decision making criteria. For KEPCO, NISA conducted a special safety inspection after having doubled the inspector numbers and so on.

As a result of the safety inspection, which is described later, it was recognized that the management structure was being developed to be suitable for the licensee's independent control. As to decision-making criteria, there were cases in the past where various inappropriate interpretations specific to the licensee were applied to the evaluation of remaining life, and such cases were recognized also for licensees other than KEPCO.

As a result of the second and third safety inspections of 2004, NISA instructed licensees to improve the items, for example taking concrete shape for inspection plans and evaluation methods regarding pipe wall thickness control, which are necessary to comply appropriately with the Operational Safety Program.

4.3.1 Management structure

Before this accident, every licensee had outsourced the pipe wall thickness control service to affiliated companies. For the selection of portions to be inspected, determination of an assessment method and evaluation of measurement results, the licensees used to confirm and approve the results by the affiliated companies except some licensees. After the accident, the necessary management structure is being built to ensure that the licensee itself exercises the control in a proactive manner.

4.3.2 Decision criteria

It is stipulated that the licensees operating PWRs should make a replacement plan based on the PWR Management Guidelines if the remaining life is 2 years or less.

Actually, however, instances were recognized in which even when the remaining life became 2 years or less, re-assessment was conducted based on the actual operating pressure, or the allowable tensile stress derived from the mill sheet value, or what is more, based on the proviso to Clause 1, Paragraph 1, of Article 4 (Allowable stress of material) of "On the Interpretation of Technical Standards on Thermal Power Generation " (called the "proviso" to the Interpretation of Technical Standards hereinafter) and replacement was postponed.

The instances of inappropriate control recognized at KEPCO will be described in the next chapter, and the instances of inappropriate control recognized at other licensees operating PWRs are shown in Table 4.

Table 4. Instances of inappropriate application of PWR Management Guidelines (Licensees other than KEPCO)

- Tomari Power Station, Unit 2, of Hokkaido Electric Power Company
  In 1999 (6th periodic inspection), re-assessment was performed at two portions with a remaining life of less than 1 year, based on the actual operating pressure. They were replaced at the next periodic inspection.
- Tsuruga Power Station, Unit 2, of the Japan Atomic Power Company
  In 2001 (11th periodic inspection), re-assessment was performed at two portions with a remaining life of less than 1 year, based on the allowable tensile stress derived from the mill sheet value. They were replaced at the next and subsequent periodic inspections.
- Sendai Nuclear Power Station, Units 1 and 2 of Kyushu Electric Power Company

  Unit 1:
  In 1996 (10th periodic inspection), re-assessment was performed at one portion with a remaining life of less than 1 year, based on the actual operating pressure. It was replaced at the next periodic inspection.

  Unit 2:
  In 2000 (12th periodic inspection) and 2002 (13th periodic inspection), re-assessment was performed each time at one portion with a remaining life of less than 1 year, based on the actual operating pressure. They were each replaced at the following inspection.
  In 2003 (14th periodic inspection), re-assessment was performed at one portion with a remaining life of less than 1 year, based on the "proviso" to the Interpretation of Technical Standards. It was replaced at the next periodic inspection.

Among the licensees operating BWRs, no common technique had been established for evaluating the remaining life, and each licensee used to replace at its individual discretion in some planned manner before the necessary minimum wall thickness was reached.

Under the above-mentioned practice prevailing, Tokyo Electric Power Co., Inc. (abbreviated to TEPCO hereinafter) conducted a wall thickness check in the periodic inspection at Fukushima Daiichi Nuclear Power Station, Unit 5 (in May 2003) and found a portion whose remaining life would be calculated to be less than 1 year if evaluated by the control techniques laid down independently by TEPCO. Nevertheless, TEPCO judged that no safety problem would occur if the use of the piping was continued until the next periodic inspection, and continued the operation. NISA recognized this case in September 2004. This suggests a problem in the conventional control methods of the licensees. For this case, NISA suggested laying down a piping control policy as an in-house standard, and TEPCO laid down the "Pipe Wall Thinning Control Guidelines" in November 2004.

4.3.3 Improvement state at each licensee

NISA sent the "Interim Summary" to licensees other than KEPCO as of September 27, 2004, to ask for autonomous improvement activities about pipe wall thickness control. Reports were returned on March 1, 2005, from the licensees about their responses based on the Interim Summary. In the report content, some portions were found to have room for improvement. In general, however, the content was the same as the content confirmed in the safety inspection and the like by NISA. NISA has a policy to monitor the efforts of the licensees, including these points, through nuclear safety inspections and the like after this and to instruct them if necessary.

4.4 Responses of NISA

4.4.1 Establishing rules about pipe wall thickness control

(1) Clarification of objects and inspection methods of a periodical licensee's inspection of nuclear power stations

In response to the Interim Summary, NISA amended the Rules for the Enforcement of the Electricity Utilities Industry Law stipulating the facilities to be inspected and the inspection methods of a periodical licensee's inspection concerning nuclear power stations to clarify the inspection objects, including the piping of steam turbines and the inspection methods (promulgated and enforced on December 28, 2004).

NISA judged that it was necessary to clarify the requirements in the safety regulations for the period until the time when more precise standards are established by the Japan Society of Mechanical Engineers (abbreviated to JSME hereinafter) and issued a notice as of February 18, 2005, stipulating a detailed measuring method of pipe wall thickness, etc. The content is given in Appendix 11.

(2) Request for establishment of standards by JSME

On a request from NISA, JSME is proceeding with work for establishing pipe wall thickness control standards through a transparent process. NISA participated in this establishing work and raised remarks to be considered in the investigation. Based on these requests from NISA, JMSE is proceeding with the work of establishing standards no later than September 2005, making good use of the trouble case data opened to the public after the accident at Mihama Power Station.

4.5 Future tasks

While proceeding in the investigation on the causes of the accident and examination of countermeasures, it was found that the licensees used in-house standards laid down on their own terms for pipe wall thickness control, and inappropriate application of decision criteria had been practiced partly in the past. The concrete control methods have been entrusted to the individual licensees thus far, and this is one of the factors that caused such a situation. Reflecting on the past conduct, NISA considers that the control based on unified guidelines is necessary after this.

Therefore, NISA requested JSME to start the work of examining in a transparent process and establishing more precise standards. It is expected that the standards will be established promptly through cooperation among industry, academy and government. On completion of the establishment of pipe wall thickness standards by JSME, NISA intends to perform technical assessment on those standards over again separately, and position them as decision criteria in administrative procedures. NISA also has a policy to monitor the licensees by safety inspections and the like to check whether they are exercising an appropriate pipe wall thickness control in conformance with those criteria.

To prevent inappropriate application of decision criteria at nuclear power stations and to ensure that the licensees can make efforts to establish and amend related rules for construct an appropriate pipe thinning control structure, NISA has a policy to continue confirmation through routine inspections and nuclear safety inspections by the nuclear safety inspectors.

For KEPCO, NISA has a policy to continue the special safety inspections until the verification of their recurrence prevention measures is completed.

5. Cause determination and recurrence prevention measures

5.1 Actions taken in response to the Interim Summary

In the Interim Summary, NISA judged that the direct cause of the accident was a "mistake in secondary pipe thinning control involving the three companies of KEPCO, MHI and Nihon Arm Co., LTD." and due to this, "the portion to be controlled was missing from the initial control list, and this could not be corrected until the accident." Based on this judgment, NISA pointed out to the licensees that the licensees should conduct investigations, review and also consider mistake prevention measures in the management aspects from the standpoint of the quality assurance, which was introduced in the safety regulations by the amendment of the Nuclear Facility Inspection System last year. Based on the Interim Summary, the Minister of Economy, Trade and Industry gave a strict reprimand to the president of KEPCO, pointing out, as shown in Appendix 12, that the Company's quality assurance system and maintenance management system had been poorly prepared for securing "nuclear safety" in an organized way, which is the direct cause of the accident. In addition, the Minister instructed KEPCO to submit a report on recurrence prevention measures within the current year.

For Mihama Power Station, Unit 3, a technical standard conformance order was issued as of the same date based on Article 40 of the Electricity Utilities Industry Law to suspend its use until the Ministry of Economy, Trade and Industry confirms that the facility, including the ruptured portion, conforms to the technical standards.

In addition, base on Article 55 of the Electric Utilities Industry Law, NISA annulled the rated results of Mihama Power Station, Unit 1, Ohi Power Station, Unit 2, and Takahama Power Station, Unit 3, which JNES had evaluated up to the time of the accident through the periodic safety management review to examine the organizational structure related to a periodic licensee's inspection (organization in charge of execution, inspection methods, process control, management of affiliated companies, and inspection-related education and training) Then NISA sent a notice of the re-rated results to KEPCO on the same day that "rated C. the organization subjected to this review has grave non-conformities regarding the execution of a periodic licensee's inspection, and the quality management system is not functioning."[12]

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[12] The rating criterion was amended as of February 23, 2005, as follows:

A. The execution structure for periodic licensee's inspection of the organization subjected to the review can conduct a periodic licensee's inspection autonomously and appropriately.

B. The execution structure for periodic licensee's inspection of the organization subjected to the review can conduct a periodic licensee's inspection autonomously and appropriately, though room for improvement is recognized partly.

In response to the "immediate actions" and "matters to be examined" described in the "Interim Summary," NISA took the necessary measures for pipe wall thickness control and has conducted an investigation to identify the primary cause of the accident, focusing on the quality assurance system of KEPCO, MHI and Nihon Arm Co., LTD (abbreviated to Nihon Arm hereinafter).

5.2 Investigation by NISA

Based on the indications in the Interim Summary and in the form of a complement to the instructions by the Minister of Economy, Trade and Industry on September 27, 2004, NISA asked KEPCO to search for the causes of these mistakes, or specifically to identify the primary cause for the accident from the standpoint of quality assurance introduced by the amendment of the inspection system for nuclear facilities in 2003 and also to establish effective recurrence prevention measures based on the results.

Based on the indications in the Interim Summary, NISA conducted inspections on the three companies, KEPCO, MHI and Nihon Arm, as follows after October in 2004. The inspection consisted basically of interviews at NISA with the persons concerned, which was held 14 times for KEPCO, 15 times for MHI and 3 times for Nihon Arm by the end of February of this year. The matters inspected were the following three points indicated in the Interim Summary:

(a) Maintenance management, procurement management and other related processes at KEPCO
(b) In-house business process at MHI and Nihon Arm
(c) Business transfer of pipe inspection service from MHI to Nihon Arm and the subsequent actual state of information transmittal

In execution of the examination about the above-stated matters, the following examinations were carried out concurrently to analyze the primary causes clearly from the point of view of grasping the background of the accident.

a. Design concept of PWR secondary piping and appropriate pipe wall thickness control method based on the concept.

C. The execution structure for periodic licensee's inspection of the organization subjected to the review has a plenty of room for improvement to conduct a periodic licensee's inspection autonomously and appropriately.
Because KEPCO's investigation into recurrence prevention measures for this accident was still under way, NISA rated Ohi Power Station, Units 1 and 4, and Takahama Power Station, Unit 4, of the Company to be C as of March 7, 2005.

b. Licensee's maintenance management execution policy for nuclear power stations and the state of development of the policy. Specifically, what transitions has secondary pipe wall thickness control gone through in its exercise up to now?

c. With what structure has maintenance management service been performed at the three companies? Specifically, how have so-called nonconforming events been corrected, including errors occurring by chance in maintenance management service? And how have the knowledge on nonconforming events been linked with prevention measures?

5.3 Reports on cause determination and recurrence prevention measures from KEPCO

5.3.1 Addressing for recurrence prevention after the Interim Summary

KEPCO submitted to NISA a report entitled "Recurrence Prevention Measures of Mihama Power Station, Unit 3 -- Toward business operation for safer nuclear power" (abbreviated to the KEPCO Recurrence Prevention Report hereinafter) on March 1, 2005, as a reply to the above-stated Minister's instructions.

According to the KEPCO Recurrence Prevention Report, the company established various company-wide committees successively under the leadership of the president immediately after the occurrence of the accident to determine the causes for the accident and draw up recurrence prevention measures.

Concretely, a "Mihama Power Station, Unit 3 Accident Countermeasures Committee" was established for investigating the causes for the accident and studying recurrence prevention measures and a "Mihama Power Station, Unit 3 Accident Cause Verification Committee" was established for carrying out investigation and verification of the causes and background from aspects other than technical or physical aspects. In view of maintenance function enhancement, a "Nuclear Maintenance Function Enhancement Examination Committee" was established to indicate the direction of investigation and give necessary instructions to the two Committees, and investigate and establish accident recurrence prevention and proactive measures. It was decided to report at appropriate times to the "Quality and Safety Committee" established in-house beforehand to obtain objective guidance and advice.

5.3.2 Summary of the KEPCO Recurrence Prevention Report

(1) Details of registration omission for the accident portion (portion downstream of the flow meter orifice)

a. After the start of pipe wall thickness control based on the PWR Management Guidelines, which was commissioned to MHI, the numbers of registration omissions from the inspection target portions in the main inspection systems was 3, including the portion of the accident, for Mihama Power Station, Unit 3 and total 42 for 11 units of KEPCO. However, KEPCO was not aware of this fact.

b. The cause for the registration omissions is presumed that the check work at MHI was one person's monotonous work and that the treatment of a flow meter orifice regarding inspection objects was changed before and after the establishment of the PWR Management Guidelines. MHI corrected 10 registration omissions by 1995; however, they did not report it to KEPCO.

(2) Basic attitude toward maintenance management of secondary piping

a. KEPCO commissioned MHI to exercise secondary pipe thinning control based on the PWR Management Guidelines from 1990 to 1995 and Nihon Arm in and after 1996.

b. KEPCO assumed that the both companies extracted and controlled the object portions for in conformity with the PWR Management Guidelines. (KEPCO did not aware of the registration omissions, etc.)

(3) Continuation of inappropriate pipe thinning control

a. In the process of investigation of the inspection records regarding secondary piping , it was found that there were many inspection records indicating that pipes, falling short of the technical standard requirement or having the possibility, were not replaced during the said periodic inspection and continuously used, even though temporarily, in and after 1995. There were 67 such pipes, and of these, 34 fell short of the technical standard requirement.

b. In the background of continuation of such inappropriate pipe thinning control, there was earnest consciousness to conserve the periodic inspection process.

(4) Recurrence prevention measures

Take the following recurrence prevention measures and be sure to follow them:

a. Permeation and fixation of "safety first" management policy and management plan at the first line

b. Organizational restructure of nuclear departments

c. Reallocation of resources (process, personnel, education, investment) to make a nuclear workplace free of pressure

d. Declaration and activity of the safety standard by each person

5.4 Reports on cause determination and recurrence prevention measures from MHI

5.4.1 Addressing for recurrence prevention after the Interim Summary

NISA also made an inspection of MHI to analyze the background of the accident and judged that a report from MHI was also necessary to prevent a recurrence of a similar accident. Thus, NISA requested MHI to summarize and submit the Company's recurrence prevention measures. In response to this, a report on recurrence prevention was also submitted to NISA on March 1, 2005.

5.4.2 Summary of the report

(1) Details of registration omission for the accident portion (portion downstream of the flow meter orifice)

a. KEPCO laid down the PWR Management Guidelines in 1990. Before that, the portion downstream of a flow meter orifice, including the accident portion, was not included in the portions of secondary piping inspection performed by MHI; however, KEPCO laid down the PWR Management Guidelines by adding the portion downstream of a flow meter orifice. After that, MHI was entrusted with the inspection work based on the PWR Management Guidelines. MHI left the work in the charge of an experienced employee alone without confirmation about the change in the treatment of a flow meter orifice before and after the establishment of the PWR Management Guidelines. That resulted in the registration omission for 42 portions to be inspected.

b. It is true that MHI missed inspection portions (registration omission) that should be objects of inspection following the PWR Management Guidelines. MHI sincerely reflects on its past conduct as a plant manufacturer.

(2) Basic attitude toward maintenance management of secondary piping

a. Most secondary piping of PWRs uses carbon steel because of its cost advantage and is designed on the concept of repairing the piping while monitoring its condition. Therefore, secondary piping always has a possibility of wall thinning, and the inspection portions given in the PWR Management Guidelines are merely examples for illustrative purposes based on the knowledge at the time in 1990. On this premise, the knowledge obtained from the inspections after the establishment of the Guidelines should be reflected in enlarging or changing the scope of inspection in due order, and MHI took this kind of reflection as well as periodic inspections for the basis of maintenance management.

b. Therefore, it was general practice to extract and verify the uninspected portions and add them in the inspection list at all times. (The concept of "registration omission" rarely existed.)

(3) Continuation of inappropriate pipe thinning control

At the evaluation of remaining life, MHI applied an inappropriate evaluation method not based on the technical standards and postponed pipe replacement, naming it "real ability evaluation." This is a result of taking priority to the relationship with their customers, and MHI reflects on the fact that the corporate philosophy of legal compliance was not thoroughly permeated.

(4) Recurrence prevention measures

a. Enhancement of document control for skeleton drawings and the like as a countermeasure of "omissions in the list," as well as thoroughly implementation of lateral spread of nonconformance information.

b. Company-wide development of the following three items for proactive preventions :
   - Establishment of a nuclear in-house reform committee.
   - Improvement of the quality management system.
   - Improvement of corporate social responsibility-related (CSR[13]) activities.

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[13] Corporate Social Responsibility: According to the definition by the Ministry of Economy, Trade and Industry, it means the process in which a corporation succeeds in its business by taking a balanced approach not merely to legal compliance, but also to economic, environmental and social issues in the form of benefiting the people, local community and society on its own initiative.

5.5 Results of interview with Nihon Arm

5.5.1 Addressing for recurrence prevention after the Interim Summary

Nihon Arm, a subsidiary of KEPCO, received an order of the "Investigation work of secondary pipe aging deterioration" from KEPCO. This work was performed mainly by those dispatched or transferred from KEPCO.

KEPCO announced its intention to transfer the main management performance of the "investigation work of secondary pipe aging deterioration" from Nihon Arm to KEPCO itself. Therefore, for addressing recurrence prevention after the Interim Summary, Nihon Arm could

Unit 1 and Tsuruga Unit 2, this kind of information was not correctly transferred from NUSEC to Nihon Arm.

(2) Details of registration of the accident portion (portion downstream of the flow meter orifice)

From fiscal 2001 to 2002, Nihon Arm added a function, in commission from KEPCO, to identify and indicate the evaluated remaining life values and the like on skeleton CAD drawings for enhancement of secondary pipe maintenance management services. After the commissioned work, Nihon Arm used this added function to import remaining life evaluation data into the skeleton drawing on its own and found that there were many portions which were registered in the inspection management sheets of the Nuclear Inspection Data Processing System (abbreviated to NIPS hereinafter) but not entered in the skeleton drawings. Nihon Arm executed correction work for this trouble intensively from February to July 2003.

In this intensive work, a registration omission for the ruptured portion in question of Mihama Power Station, Unit 3, was discovered in the NIPS Inspection Management Sheet and the skeleton drawing, and an additional registration was performed. In the same procedure as before, the portion of the additional registration was reflected in the plan of the earliest inspection as an uninspected portion, and the plan was proposed to KEPCO.

(3) Continuation of inappropriate pipe thinning control

In the pipe remaining life evaluation by Nihon Arm, pipe replacement was recommended for the portion, with a pipe remaining life of less than one year, based on the Measurement Result Evaluation Flow Chart attached to the Work Execution Procedure approved by KEPCO, and the evaluated remaining life value with respect to operating pressure was reported as reference information.

For pipes with a remaining life of less than one year, the judgment whether their replacement timing would be postponed to the next periodic inspection or thereafter, was made by KEPCO itself in the end.

(4) Recurrence prevention measures

As a recurrence prevention measure, Nihon Arm revised their in-house rules stipulating a concrete procedure of the "investigation work of secondary pipe aging deterioration" to conform to the PWR Management Guidelines and deleted the provisions for remaining life evaluation with respect to operating pressure.

In response to the Maintenance Service Procedure Guidelines revised by KEPCO after the accident, or on September 17, 2004, Nihon Arm added provisions about "actions to be taken when an unregistered portion is found at a major inspection portion" and "change management of skeleton drawings."

5.6 Assessment of cause determination and recurrence prevention measures

5.6.1 Assessment of investigation system at KEPCO and MHI

For the in-house investigation system reported by KEPCO and MHI, it can be assessed to have become an appropriate system for arranging and coordinating an objective investigation; however, the following problems were found in the process of the investigation by NISA. In constructing an investigation system promptly for cause determination at an accident or the like in the future, these problems are thought to serve as material for reflections.

(1) Investigation system at KEPCO

In its report, KEPCO claims that an investigation system was constructed immediately after the accident under the leadership of the president to conduct investigations; however, it was early December 2004 when the investigation system described in the KEPCO Recurrence Prevention Report was presented in response to the additional investigation by NISA, and even then, the purpose and mutual relationship of the committees were not clear yet.

It is claimed that the in-house investigation at KEPCO was performed while making efforts to know the actual conditions by each committee. However, the investigation focused entirely on the omissions in the inspection list, so it was not necessarily sufficient for accurately grasping the background of the accident. Therefore, NISA instructed KEPCO to clarify the functional sharing among the committees and construct an in-house structure that would allow objective investigation. As a result, in addition to the previous investigations, the Accident Inspection Committee, which is independent of the nuclear business department, conducted an anonymous inspection as to the actual state of on-the-spot maintenance management in February of this year to grasp the causes in a more appropriate way.

(2) Inspection system at MHI

MHI claims that it established the Countermeasure Headquarters immediately after the accident in its Takasago Machinery Works, which has charge of the secondary facilities, to perform cause determination and investigations together with the Nuclear Energy Systems Department and Kobe Shipyard & Machinery Works, which has charge of the primary facilities, in one united body. However, at the beginning of the additional investigation by

NISA, the investigation focused mainly on the omissions in the inspection list in the same way as KEPCO.

By the investigation of NISA, several points to be improved regarding the secondary piping management service were found in MHI's quality assurance activities, for example, the company manual was left unrevised that might cause an inappropriate application of the PWR Management Guidelines. As a result, MHI established the Nuclear Corporate Reform Committee in December 2004 with a president as its chairman in the light of the management policy of fulfilling Corporate Social Responsibility (CSR) and the corporate management department have discussed and examined improvement measures in cooperation with the Nuclear Energy Systems Department.

5.6.2 Assessment of the details of registration omissions for the portions to be inspected

The PWR Management Guidelines were laid down by KEPCO using its plant as a model and commissioning the work to MHI. The flow meter orifice was not included in the report on the commissioned investigation submitted by MHI to KEPCO at that time; however, KEPCO added the flow meter orifice when it laid down the Management Guidelines. Therefore, it is thought that there was some confusion at MHI.

However, because the two companies have mutually been engaged in the process of laying down the management guidelines, they probably assumed that they could share sufficient knowledge. As a result, in the secondary pipe inspection work performed by KEPCO in commission to MHI after the establishment of the Maintenance Guidelines, the inspection was performed in accordance with the established PWR Management Guidelines; however, it was not explicitly required to review the inspection list in accordance with the PWR Management Guidelines.

In the plants of KEPCO, therefore, registration omissions had occurred for several portions downstream of a flow meter orifice, including the portion ruptured by this accident, since the initial stage. So, it is estimated that the recognition of "registration omissions" rarely existed at both companies.

At MHI, an experienced worker who was helped by subcontractors was given charge of planning of secondary piping management service, and the check function for the inspection plan laid down by the worker existed formally, but it did not work sufficiently in reality. An inspection was not performed in the viewpoint of whether or not the work process was executed as stipulated and whether the planned work process itself was appropriate or not.

For the inspection portion's registration omissions that existed at the beginning, MHI has corrected them by expanding the scope of inspection in due order based on the company's PWR secondary piping management policy, and claims that there is no registration omission at present at any licensee other than KEPCO. However, these were corrected merely as a result of expanding the scope of inspection. For the portions discovered that were not inspected due to registration omissions, the company not only inspected them promptly as nonconformance management, but also should have investigated the causes why they were left uninspected and taken appropriate corrective measures for recurrence prevention, such as investigation and inspection of similar portions (so-called lateral spread of registration omission). However, it is hard to say that these corrective measures have been taken appropriately.

As to Nihon Arm, there were defects on the skeleton drawings in addition to the initial registration omissions charged to MHI, so it claims that it had continuously discovered uninspected portions with some frequency since the transfer of the work. The discovered uninspected portions had been reflected in the plan of the earliest periodic inspection, and this procedure presumably took root in the company. As with MHI, however, the company is also far from having investigated into the causes why the discovered uninspected portions due to registration omission had been left uninspected and having taken appropriate corrective measures for recurrence prevention, such as investigation or inspection of similar portions.

Thus, several points to be improved were found in the quality assurance system of the two companies commissioned with secondary piping management service from KEPCO.

5.6.3 Assessment of basic attitude toward maintenance management service and detailed process of registration omissions having remained undiscovered

According to MHI who designed PWR, most secondary piping of PWRs uses carbon steel, because of its cost advantage, and are designed on the concept of repairing them while monitoring their state, on the premise that secondary piping always has a possibility of wall thinning. Therefore, considering that the inspection portions given in the PWR Management Guidelines were merely based on the knowledge at the time of 1990, the company claims that it has exercised secondary pipe thinning control on the basic concept of maintenance management that the knowledge obtained from the inspections after the establishment of the Guidelines should be reflected in expanding or modifying the scope of inspection in due order.

On the other hand, as described in 5.6.2 "Assessment of the details of registration omissions for the portions to be inspected," KEPCO has exercised its secondary pipe thinning control by closing an inspection contract (investigation work of secondary pipe aging deterioration) with

MHI and Nihon Arm for each periodic inspection. In this contract, no provisions were stipulated as to the reporting obligation when registration omissions for the inspection portions were found. Therefore, when uninspected portions were found, the correspondence of the two companies was inadequate as described above. Continuation of the work in such an inadequate state could not be prevented, and this indicates that KEPCO, who ordered the work, could not make procurement control over the suppliers adequately.

KEPCO describes in, for example, the KEPCO Recurrence Prevention Measures Report, "We thought that MHI checked the skeleton drawings of the secondary piping based on the PWR Management Guidelines, and we did not check to prevent omissions of the inspection portions."[14] Outsourcing is indispensable indeed for the maintenance management work; however, outsourcing must be carried out under the appropriate control of KEPCO who ordered the work. This is a matter of course as the responsibility of a licensee and is also stipulated in the ministerial ordinance[15] of the Reactor Regulation Law. The description in the above-stated report indicates KEPCO's insufficient awareness that the responsibility for the occurrence of omissions as a result of outsourcing under such insufficient control lays primarily in the licensee.

The pipe arrangement has possibility of being changed by a repair or remodeling work done at a periodic inspection. Considering such a situation, the planning of secondary piping inspection should be performed based on the renewed skeleton drawings showing the latest pipe arrangement, while accurately keeping track of the portions to be inspected. According to the investigation by NISA, however, it is hard to admit that, when the piping was changed by a repair or reform work, KEPCO made efforts to accurately reflect the actual conditions in the skeleton drawings. It cannot be said that KEPCO, who ordered the maintenance management service, has performed an appropriate control. As described above, considering that the inspection portions given in the PWR Management Guidelines were merely based on the knowledge as of 1990, MHI had a basic concept that it would continue to expand or modify the scope of inspection in due order to reflect the knowledge obtained after the establishment of the Guidelines. However, it is presumed that the basic concept was not recognized clearly by KEPCO because of the self-confidence of having established the PWR Management Guidelines.

In such a situation, a plan of secondary piping inspection to be performed at a periodic inspection was laid down without preparing sufficiently skeleton drawings that reflected the actual state of the plant accurately. That is, KEPCO made MHI and Nihon Arm do work for

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[14] See the last paragraph of Phase I of (2) "Results of survey of facts" in 4. "Investigations and Countermeasures of Secondary Pipe Wall Thickness Control System"

[15] It is stipulated in Clause 3 of Article 7.3.4 and in Clause 2 of Article 7.3.5 in the Rules for Installation, Operation, etc., of Commercial Power Reactors amended in October 2003.

extracting inspection portions and preparing an inspection list and inspection plan using the skeleton drawings that inadequately reflected the actual state of the plant. KEPCO itself mainly checked the inspection list, which is the outcome of the work, but did not check the skeleton drawings adequately. It is presumed that the portions to be inspected, but omitted from the first, had remained unchecked consequently.

5.6.4 Assessment of continuation of inappropriate pipe remaining life management

NISA investigated the actual conditions of the maintenance management work. In the investigation, NISA made the above-mentioned investigation regarding how the licensee had corrected nonconforming events occurring accidentally or necessarily in the maintenance management.

In the process, continuation of nonconformance to the technical standards was found at KEPCO. Namely from 1995 to the present, even when KEPCO found a pipe which thickness fell short of the technical standards' requirements, KEPCO postponed the repair by applying an arbitrary interpretation of the technical standards because of considerations of the lead time for material procurement, which resulted in a delay of resumption of the plant operation.

KEPCO has declared a policy of "Safety First." However, this policy became a dead letter and did not function, and this state had been left uncorrected for a long time. These facts are considered to be a serious problem as a concrete indication of the decay of safety culture. For the inappropriate operation by KEPCO, the plant manufacturer MHI was engaged in an inappropriate pipe remaining life evaluation, naming it "real ability evaluation." This contradicts the corporate social responsibility (CSR) declared by MHI and is also considered to be a serious problem, indicating a decay of safety culture.

KEPCO submitted documents about the cases where, in spite of the fact that the remaining life was less than 1 year, replacement or other appropriate repair was not performed at the relevant periodic inspection. Based on the data, NISA marshaled and analyzed such cases at all of KEPCO's plants.

The number of cases in the past where appropriate repair was not performed at the periodic inspection in spite of the fact that the remaining life fell short of 1 year was counted for all plants of KEPCO. Results are shown in Table 5 "Number of cases where appropriate repair was not performed in spite of the fact that the remaining life fell short of 1 year."

According to the report by KEPCO, there were 67 portions where inappropriate operation of the PWR Management Guidelines was performed, and 34 of them did not conform to the technical standards. On the other hand, according to the counting by NISA, there were 78 cases of inappropriate operation of the PWR Management Guidelines, and 46 of them did not obviously conform to the technical standards.

The difference of counting value is explained as follows. The breakdown of the counting in the KEPCO report and by NISA is shown in Table 6 "Counting of the number of portions having undergone inappropriate pipe remaining life management." In the way of counting by KEPCO, a portion having been subjected to inappropriate treatment as a result of remaining life evaluation was counted as one case.

On the other hand, as a result of NISA investigation, it was discovered that a replacement of repair of several portions, where KEPCO applied the inappropriate remaining life evaluation, was postponed over multiple times of periodic inspections. Thus, NISA took the viewpoint that such an action should be counted as one case, and included the number of times of inappropriate remaining life evaluation in the number of cases.

KEPCO claims that a portion to be counted as a case of falling short of the calculated necessary thickness (Tsr) is a portion with a remaining life of less than 0 year and excludes the case of a remaining life of just 0 year. However, NISA includes such cases, because a portion with a remaining life of 0 year cannot be used for operation after the periodic inspection.

Table 5. Number of cases where appropriate repair was not performed in spite of the fact that the remaining life fell short of 1 year

A: Number of cases of
[remaining life

Table 6. Counting of the number of portions having undergone inappropriate pipe remaining life management

Description in KEPCO report		Portion with a calculated remaining life of less than 1 year (Inappropriate operation of the Management Guidelines)	67 portions
	Breakdown	Portions evaluated based only on the internal pressure criterion	1 portions
		Portions evaluated based on a wrong interpretation of the proviso	6 portions
		Portions evaluated using operating pressure	45 portions
		Portions evaluated on actual yield stress basis	6 portions
		Portions evaluated otherwise	9 portions
		Portions falling short of the calculated necessary thickness (Tsr) (or with a remaining life of less than 0 year) (Nonconformance to the technical standards)	34 portions
Counting by NISA		Number of cases where a calculated remaining life is less than 1 year (Inappropriate operation of the Management Guidelines)	78 cases
	Break-down	Portions with a remaining life of less than 1 year	67 portions
		Portions with a remaining life of less than 1 year whose repair was postponed over multiple times of a periodic inspection	11 cases
		Number of cases where the pipe wall thickness is less than or equal to the calculated necessary thickness (Tsr) (or where a remaining life is 0 or less)(Nonconformance to the technical standards)	46 cases
	Break-down	Portions with a remaining life of less than 0 year	34 portions
		Portions with a remaining life of 0 year	4 portions
		Portions with a remaining life of 0 year or less whose repair was postponed over multiple times of a periodic inspection	8 cases

5.6.5 Assessment of recurrence prevention measures of KEPCO and MHI

(1) Assessment of recurrence prevention measures of KEPCO

For the maintenance and operation management, it is indispensable in the field of the power plant to reflect the changes of plant condition caused by repair or remodeling and also the knowledge obtained by operation experiences. However, it was brought to light by the investigation of the accident that KEPCO had not performed this in an appropriate manner.

KEPCO declares in the KEPCO Recurrence Prevention Report, (a) permeation and fixation of the "safety first" management policy and management plan at the first line, and organizational restructure of nuclear departments, (b) reallocation of resources (process, personnel, education, investment) to make a nuclear workplace free of pressure, and (c) declaration and activity of the safety standard by each person, as recurrence prevention measures.

As KEPCO recognizes this as a lesson learned from the accident, a mere instruction of recurrence prevention measures to the field will not function by itself as instructed. To make these recurrence prevention measures effective, it is necessary to ascertain the current situation as soon as possible, lay down an accurate plan considering its feasibility and implement the plan steadily. It is also indispensable to make an assessment in a timely and appropriate manner to see whether the recurrence prevention measures are executed in line with the initial target and establish a scheme to lead to further improvements based on the assessment results.

Bearing the responsibility of an owner of nuclear plants and a licensee under the Nuclear Regulation Law, KEPCO must clarify its maintenance management policy for its own plants, and then lay down an appropriate maintenance management plan based on the plant life and implement the plan. In addition, licensees are required to always review their maintenance and operation management plan based on the knowledge obtained by maintenance management experiences.

However, it was hard to say that KEPCO presented clearly the maintenance management policy of KEPCO, matters to be done by KEPCO itself and considerations in case of commissioning for the NISA investigations. KEPCO also did not present a concrete plan to continuously conduct the recurrence prevention measures and yield the outcome in line with the initial target.

Therefore, in view of shaping up recurrence prevention measures, NISA gave KEPCO instructions about the "requirements for shaping up recurrence prevention measures" comprising 5 items on March 10, 2005, as shown in Appendix 13. Through the accident investigation, it was recognized that permeation of safety culture and enhancement of the quality assurance system and maintenance management system were necessary over the whole company of KEPCO. Therefore, NISA required that the framework of recurrence prevention measures should be based on the commitment[16] of the top management. On top of that, NISA instructed KEPCO to deploy each measure accurately based on the framework.

As a result, KEPCO presented the framework of recurrence prevention measures in the 9th session of the Accident Investigation Committee on March 14, 2005. Because, for example, the measures concerning maintenance management and procurement management, which were included in the requirements presented by NISA, were not definitive at some points, the necessity to secure consistency with the requirements and enrich the content was pointed out. In response to this, KEPCO submitted its "Action plan for prevention of recurrence, Mihama Unit 3 accident" (abbreviated to the Action Plan hereinafter) to NISA.

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[16] Here, the term "commitment" is used in the sense of "promise." This term is used in ISO 9001 and other international quality assurance standards. Unlike the word "promise" itself, which can mean a mere declaration of an intention, the intrinsic meaning of the English word "commitment" is an obligation to be fulfilled with responsibility, or a pledge of the obligation or manifestation of a determination. Because the word "promise" can be interpreted in either meaning, the word "commitment" is used here deliberately. "Promise" is a mere declaration of intending to do something.

In the Action Plan, the president himself of KEPCO holds up the phrase "Secure safety. It is my mission and our company's mission," as a declaration of the first priority of securing safety. Under the president's declaration, a basic action policy consisting of 5 items is held up: (a) Give top priority to safety, (b) Aggressively invest resources for safety, (c) Continuously improve maintenance management for safety and construct a cooperative structure with manufacturers and affiliated companies, (d) Make efforts to recover the reliance of the local community, and (e) Assess activities for safety objectively and inform the public of the result. Each item of the basic action policy is developed into concrete details to implement it, which in turn are classified into measures already executed, short-term measures and middle-term measures, specifying the term of the measure. These satisfy the requirements presented by NISA previously, and can be assessed to be in line with the indication by the Accident Investigation Committee.

For the accident, however, there were registration omissions for the inspection portions at the beginning and the lateral information spread for their correction was inadequate; no systematic review has been performed on the inspection portions of the secondary piping for many years; and the PWR Management Guidelines have been operated inappropriately. These are serious problems. These problems occurring in the field could not be appropriately kept track of or managed through quality inspections, and it is necessary to review the administrative functions necessary for fulfilling the primary responsibility for outsourcing (procurement) management in conducting maintenance management as a licensee. Therefore, it is premature to judge with the report that all above mentioned items have been solved (corrected) already.

Because KEPCO's Action Plan declares concrete recurrence prevention to the public and society, its appropriate fulfillment should be confirmed. To secure this, the basic action policy's Item (e) "Assess activities for safety objectively and inform the public of the result" should be developed. As such, it is stipulated for sure implementation of the recurrence prevention measures to establish a "Nuclear Quality and Safety Committee (provisional name)" including local intellectuals to assess the state of implementations periodically and announce the results to the public. Therefore, its implementations and content will be observed closely by the whole society.

NISA must confirm that the recurrence prevention measures are surely performed in line with the action plan, so it will continue the special safety inspections and especially strict safety management reviews on KEPCO. Besides this, it has a policy to follow up KEPCO's implementations in a strict way by conducting on-site inspections as needed and otherwise making full use of the current inspection system.

KEPCO is the top PWR owner of Japan, that is, it has 11 PWRs of a total of 23 PWRs in Japan. This company has led the PWR-operating licensees in Japan; for example, it was the first company to assess and analyze data obtained at its own plants to establish the PWR Management Guidelines in 1990. Responses appropriate for the top PWR owner of Japan are expected from the company, so the company should become aware of this fact anew at this occasion. On top of it, the company should sincerely tackle with the recurrence prevention measures stipulated by it and publicize their content so as to serve as a model for other licensees. This is thought to be the social mission imposed on the company.

(2) Assessment of recurrence prevention measures of MHI

MHI submitted its recurrence prevention measures to NISA on March 1, 2005, as described above, and in addition submitted the "Additional Report on the Secondary Pipe Rupture Accident at KEPCO Mihama Power Station, Unit 3" on March 23, presenting concrete recurrence prevention measures.

MHI's recurrence prevention measures include enhancement of making and review process of skeleton drawing for secondary piping inspection and computerization of skeleton drawing management. At the same time, the company establishes a "Mitsubishi Maintenance Examination Committee" in the company to enhance the maintenance management toward aging as the Mitsubishi Group. In addition, it holds recurrence prevention measures, such as newly establishing a "Nuclear Quality and Safety Audit Office," and company reform activities, such as newly establishing a "Nuclear In-House Reform Committee" and enhancing its corporate social responsibility (CSR).

These can be appraised to some degree as conceivable ordinary recurrence prevention measures. However, MHI was involved in the accident concerning the initial registration omissions for the inspection portions and the insufficient lateral information spread for correcting the registration omissions, and these are problems regarding quality control. Particularly, the company had not conducted a systematic review on the state of registration of the inspection portions of the secondary piping for many years, and had been engaged in inappropriate operation of the PWR Management Guidelines. These are serious problems. In addition, these problems occurring in the field could not be appropriately kept track of or managed through quality inspections, and this is a problem also with the quality management system in the organization. Therefore, it cannot be judged with this report that all above-mentioned items have been solved (corrected) already.

MHI was engaged in the inappropriate pipe remaining life evaluation by KEPCO, and this act contradicts the corporate social responsibility (CSR) held up as the management policy of this company. Thus, MHI says that it will perform company reform activities, such as enhancing the corporate social responsibility (CSR).

NISA intends to watch the process of steady implementation of these various measures presented by MHI. NISA will pay particular attention to the statement in the MHI recurrence prevention measures that it will proceed with company reform activities involving the whole company as a unit with awareness of responsibility as the only PWR manufacturer in Japan. The nuclear plant manufacturers, such as MHI, are not subject to nuclear safety regulations (the Reactor Regulation Law) but are participants in operation of nuclear power plants as the contracting party of works commissioned by a licensee. In actuality, however, these manufacturers have comprehensive knowledge and experiences from construction to maintenance of nuclear power plants, and licensees rely not a little on them. For PWR plants in particular, MHI is the only domestic manufacturer, and this situation makes it difficult to introduce competitive principles. MHI should recognize this situation anew and, on top of it, should not take the position as a mere partner of a commission contract for maintenance service, but should be aware of being a major leader of the nuclear industry of Japan. MHI is expected to always try to take an attitude to increase the participation in securing the nuclear safety with that awareness. For example, the recognition of giving top priority to safety should be shared with licensees, and the approach to the targets should be coordinated with them. If there is some new finding in the events or maintenance work of a plant, it is desirable for the company to take the lead in lateral information spreading to the nuclear power plants of other PWR licensees.

6. Responses to tasks found in relation to the accident

6.1 Lessons learned from the accident and its reflection

Japan currently has 53 nuclear power plants in commercial operation, and is a leading country in the field of nuclear power, both in reputation and in reality. Some of these plants have been operated not so long period since the commission for commercial operations, and there is a need to confirm the safety of the new design improvements they employ, meaning that regulations on hardware matters remain important. In general, however, the transition from a construction-oriented age to an operation-oriented age has now been made.

The JCO criticality accident, which occurred in 1999, demonstrates not only the importance of design safety but also the importance of operation safety. It should be understood that nuclear power generation in Japan has made the transition from an age of construction to an age of operation, and that measures to handle aging have become important at many nuclear power plants. Given this, responses focusing on non-hardware factors such as organization operations and maintenance management systems are gaining importance, and dealing with these problems in an appropriate manner has become a task for the regulatory agencies.

6.1.1 Reforming nuclear safety regulations

Japanese nuclear safety regulations have been prepared and operated with the main aim of ensuring the safety of hardware, for example to keep the integrity of equipments and facilities by overcoming troubles at first in the early period of the introduction of nuclear power generation. It is presumed that the traditional regulatory system directed the attention of licensees towards the management of equipments and facilities, which was directly subject to regulations, was one of the factors that caused them to neglect independent dealing with the maintenance management of the whole plant of its own accord.

From the JCO criticality accident which occurred in 1999, the Government learned the lesson that, if the focus was placed on ensuring the safety of hardware alone, as was conventional, it would not be possible in practice to make the appropriate safety regulations effective. Accordingly, the Government changed radically the concept of nuclear safety regulations in Japan by introducing software matters such as the appropriate execution of safety activities by the licensees, in addition to hardware matters as usual, into the targets of safety regulations.

At the same time, the Government introduced nuclear safety inspections in fiscal 2000 newly to check the safety activities of the licensees and, reflecting on the past, decided that additional radical reforms of the inspection system were necessary, and began to conduct studies into a new inspection system for nuclear facilities in fiscal 2001.

As the outcome of the study, the Government decided that it was necessary to check, through inspections by the regulatory agencies, whether quality assurance activities and maintenance management activities, which had been carried out as self-imposed activities by the licensees until then, were being performed appropriately. Accordingly, amendments were made to the related ordinances, the Electricity Utilities Industry Law and the Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors, and then a new inspection system was started in October 2003. The inspection system stipulates appropriate establishments of quality assurance and maintenance management as the legal obligations of the licensees.

One feature of the new inspection system is that enhancement of licensee's capability regarding autonomous maintenance management for a whole plant is a main target, in addition to re-evaluate the role of the regulatory agencies and licensees, to achieve "prevention of nuclear disasters," which is the objective of the Reactor Regulation Law. In addition to conducting inspections of facilities important for safety, the regulatory agencies (NISA and JNES) have borne the role of building a structure for promoting autonomous maintenance management by licensees.

Looking back at the regulations on secondary piping from the point of view of moving forward these reforms of the regulatory system, it seems that there are many points, which need to be reviewed again, in the response of the Japanese Government. On the contrary, the NRC in the United States has actively dealt with reforms of the regulatory system since the Surry Power Station accident in 1989. For example, the licensee's management program for secondary piping was included in the scope of NRC supervisions despite opposition from licensees. NISA considers that it is necessary to take positive action to improve the regulations, including reforms of the system in the future.

6.1.2 Confirming the construction of an effective quality assurance system by licensees

In the process of studies into the new inspection system, an intentional illicit act was found in the records of the self-imposed inspections by TEPCO. These cases, and the Mihama Power Station accident, support the necessity of the new inspection system.

In the period just after the occurrence of the accident, the concern of the investigation focused on the mechanism of the occurrence of erosion and corrosion and the detailed process of registration omissions in the inspection list, because the direct cause was a pipe rupture accident, which was caused by the pipe wall thinning due to the registration omission of a portion to be inspected in the inspection list. In subsequent investigations, however, it was discovered that KEPCO's maintenance management system and quality assurance system did not function sufficiently and that a safety culture had not permeated into the whole company and the registration omissions from the first had not been corrected for many years.

Safety cannot be achieved by the field of power stations alone. Policies for achieving safety must be set up in a practical way in the different layers of the organization and continuously improved. To carry out improvements, it is necessary to assess what is lacking in the organization and re-allocate "management resources" such as personnel, organizations, facilities and money, appropriately. It is therefore indispensable that the top management takes the lead in dealing with these items. This is the reason why the reactor establisher (the president) has been designated as the person (the top management) responsible for the quality management system of the relevant licensee in the quality assurance system introduced by NISA in the amendments to the inspection system in October 2003.

In the scheme for the new inspection system, the secondary piping where the accident occurred is the objective of the periodic licensee's inspection, with the regulatory agencies checking whether the inspection has been carried out appropriately. In the accident, it was discovered that there was no lateral spread of trouble information appropriately. Under the scheme of the new system, however, the licensee should make lateral spread of trouble information, not only at its own power stations but also at other licensees' power stations, as part of legally stipulated quality assurance activities.

Even if a new inspection system is built, however, good results cannot be expected without appropriate operation based on the purpose. NISA will therefore make continued efforts to carry out appropriate inspections. NISA will also follow up appropriately to see whether the licensees have built precise quality assurance systems and are operating them as stipulated, and whether the state of their execution is being assessed in an open scheme, in an objective way, and instruct licensees to open the results to the public.

6.1.3 Responses to aging in nuclear power plants

From the result of the investigation to determine the causes of the accident, the serious problem was found that KEPCO, as a plant owner, had not been carrying out appropriate maintenance management based on the operation history of the plant. As the effect of the operation history becomes larger in proportion to the plant operation period, aging plants occupy the interest of society. For this reason, NISA has established an Investigation Committee for Measures on Aging in the Nuclear Safety and Security Subcommittee of the Advisory Committee on Natural Resources and Energy and started deliberations in December 2004 for the purpose of making effective use of the accumulated technical assessments and the latest technical knowledge and enhancing the activities for measures on aging both at licensees and regulatory agencies.

The Investigation Committee for Measures on Aging will compile an interim report "Basic concepts on improving measures on aging," including a basic policy on controlling deterioration with aging (wall thinning) for the secondary piping by early April this year. In addition, it intends to compile suggestions regarding clarification of the standards and guidelines necessary for measures on aging and also reasonable inspections by the Government by July or August this year.

Since the general pipe wall thinning phenomenon is one of the most important aging deterioration phenomena, licensees are required to position control measures for pipe wall thinning appropriately in the measures on aging for each nuclear plant, lay down the necessary management policies and then implement them. NISA, for its part, intends to make the rational review and inspection system satisfactory to assess the control policy for pipe wall thinning of each licensee effectively, and watch the state of implementation, in line with the policy compiled by the Investigation Committee for Measures on Aging.

6.2 Responses to other tasks

6.2.1 Efforts for industrial safety

(1) Industrial safety in the electric industry

To secure the safety for workers working at nuclear power stations, NISA performs numerous reviews and inspections in the design, installation, operation and decommissioning stages of nuclear plants and other facilities, based on the Reactor Regulation Law and the Electricity Utilities Industry Law, to prevent disasters occurring from the use of nuclear plants or similar facilities, and to ensure public safety.

At the same time, the Ministry of Health, Labour and Welfare is providing the necessary guidance and support, based on the Industrial Safety and Health Law, to secure the implementation of prevention measures for industrial accidents stipulated by law, and promote autonomous efforts as part of activities to prevent industrial accidents performed by licensees, with a view to securing the health and safety of laborers.

In this time accident, the ruptured pipe is an electric facility subject to the Electricity Utilities Industry Law. The relevant safety measures were therefore handled by NISA, which has jurisdiction over safety for the facility. However, as the accident was a serious industrial disaster, with 11 workers suffering fatal accidents or injuries, the Ministry of Health, Labour and Welfare handled the safety management system which the licensee was obliged to establish, and appropriate implementations of safety education for the employees from the viewpoint of industrial safety and sanitation measures, as it has jurisdiction over industrial safety.

(2) Indications from the Government based on the accident

NISA says in the Interim Summary, "It is important for licensees to clearly position not only prevention of radiation hazards but also prevention of industrial accidents at nuclear power plants in their management systems and carry out proper management and administration to respond to every situation." Specifically, NISA pointed out that, to call workers' attention to the potential risks in work environments according to the plant operation conditions, they should carry out preparatory training, and display information on risk in dangerous places.

The Ministry of Health, Labour and Welfare gave instructions in the instruction document "For strict execution of industrial accident prevention measures" on October 25, 2004 addressed to the General Manager of Mihama Power Station from the director of the Fukui Labour Bureau; (a)Thorough measures regarding both "identification and assessment of dangerous places in the workplace and thorough execution of measures based on this" and "secure appropriate equipment maintenance management" based on the "Guidance for urgent measures related to the enhancement of safety management in the large-scale manufacturing industry" (the notice from the Director of the Labour Standards Bureau, the Ministry of Health, Labour and Welfare on March 16, 2004), (b)Securing mutual cooperation between the person in charge of facility safety and the person in charge of occupational safety in the workplace, (c)Carrying out appropriate safety management activities at Mihama Power Station with the general health and safety supervisor playing a central role and (d)thorough execution of general emergency evacuation trainings at the power station, including subcontractors.

(3) Responses of the licensee based on the indications by the Government

In response to the indications and guidance by the Government, KEPCO produced the following recurrence prevention measures related to industrial safety in the KEPCO Accident Report; (a) introducing an industrial health and safety management system, (b)positive execution of safety management activities, (c)improving communication, and (d) administering education to safety managers.

In response to the guidance by the Ministry of Health, Labour and Welfare, KEPCO submitted a response paper (on November 30, 2004) to the Fukui Labour Bureau, describing the introduction of an industrial health and safety management system. The company reported the subsequent state of execution for the guidance concerning Mihama Power Station to the

Fukui Labour Bureau on February 28, 2005 and reported the state of execution of company-wide response to the Ministry of Health, Labour and Welfare on February 24, 2005.

(4) Assessment of the response of the licensee

In response to the guidance by the Government, KEPCO decided to carry out a full-scale introduction of an industrial health and safety management system at Mihama Power Station, the first in any of its nuclear power stations. On January 6, 2005, it laid down 3 station notices and station rules, including the "Station notice on industrial health and safety management at Mihama Power Station (Industrial Safety and Health Manual)" and is dealing positively with preparing systems related to industrial safety.

In terms of specific operations, a manager familiar with the field facilities was appointed as a safety manager for the purpose of integrated execution of safety management and facility management activities. At the same time, the positive execution of safety management activities is now underway with the general safety manager playing the central role, and the education given to the safety manager on the occasion of appointment becomes satisfactory. Dangerous places in the field will be identified and assessed, and measures based on this will be executed thoroughly. KEPCO is required that the above industrial safety activities will be steady and surely put into practice, taking the accident as a turning point.

To make these industrial safety activities by the licensees steady and sure, and for further enhancement of industrial safety in the electricity industry, NISA intends to keep in close contact with the Ministry of Health, Labour and Welfare, which has jurisdiction over industrial safety, to carry out consistent measures and to make familiarize the licensees with the content of these measures.

a. Sharing industrial safety information and nuclear facility safety information and smooth communication among the policy decision makers at the ministries concerned

b. Sharing the above information and smooth communication among Nuclear Safety Inspector Offices, Labour Standards Inspection Offices and the like at the field

c. Familiarizing thoroughly the electric licensees as a whole, including other licensees, with the above information and lateral spread

6.2.2 Social and regional impacts following the accident and responses to the impacts

The accident caused many casualties and physical damages to the power plant facilities. Besides these impacts, the accident also caused social and regional impact like distrust about nuclear safety regulations, an increase of anxiety in the region. The social and regional impact is thought to show up itself in various forms, reflecting the impressions and understanding of the public and residents in the region about the accident. Looking at the impact of the accident from this viewpoint, the following four major factors can be mentioned:

(1) Loss of the sense of security about nuclear power stations among the local residents

With the accident, the residents of Mihama-cho, where the power station is sited, and the surrounding cities, towns and villages and even Fukui Prefecture were anxious about the safety of nuclear power stations and showed distrust about the activities of the licensee and regulatory agents. The sense of trust toward nuclear power was substantially impaired. Concern about health problems and consciousness of the problems regarding means of evacuation at the time of accidents or trouble increased. Many local residents work in the nuclear power station and their anxiety and distrust about their own work place increased.

The contribution of the nuclear power station to the region may be expressed in terms of "coexistence" between the region and the nuclear power station; however, as an impact of the accident, there may be some doubt increasing about the contribution.

(2) Increase in the administrative activities of local municipalities

Local administrative activities concerning the accident increased dramatically to verify and investigate the accident earnestly, to explain and talk with residents with a lot of time, to re-examine the relationship between the licensee and the municipalities. For example, the Nuclear Safety Expert Committee of Fukui Prefecture was held several times. According to comments from municipality officials in the region of the site, the above mentioned activities almost hindered the other administrative services, which could not receive the necessary resources.

(3) Occurrence of damage from bad reputations to economic activities in the region of the site

After the occurrence of the accident, there were cancellations of reservations at accommodation facilities and suspensions of sightseeing trips. The number of tourists and other visitors to the region decreased. This was because judgments were not made based on accurate information and knowledge. Sightseeing and local products were avoided simply because "the region was near the site of the nuclear accident." This would seem to be an instance of damage from bad reputations.

(4) Loss of national confidence in the use of nuclear power

Distrust about the attitude of the licensee toward securing safety at nuclear power stations and about the effectiveness of government safety regulations increased, and as a result, national confidence in the use of nuclear power decreased undeniably.

NISA proceeded investigations to determine the causes of the accident and establish recurrence prevention measures with listening to the comments of municipality officials and also bearing in mind the impact of the accident. NISA has promptly put the matters presented in the Interim Summary into effect. It has also expressed its intention to make efforts to strengthen the system for enforcing safety regulations in the region.

In addition, NISA has made a lot of efforts of information dispatch, like provision of prompt and accurate information about the nature of the accident and recurrence prevention measures via various methods, holding direct explanation meeting to municipalities and local residents and presentation of NISA activities at the national level. NISA has supported road improvements along the route where emergency transport was hindered and has managed the task of improving research into nuclear safety.

On the other hand, for the purpose of effective implementation of these activities, it is pointed out that examinations, analysis and investigations of the countermeasures are necessary from the standpoint of social and regional factors in addition to the cause examinations and investigations of recurrence prevention measures from the engineering points of view. Based on the facts that there were social and regional impacts occurred in case of the past accidents and disasters at nuclear power stations, NISA will make efforts to implement effective countermeasures for future accidents and disasters just in case, by assessing and analyzing the social and regional impacts accurately and establishing a place for investigating the measures necessary based on the results of assessment and analysis.

7. Conclusion

It will soon be eight months since the occurrence of the accident. Under the framework of investigations and deliberations at the Accident Investigation Committee, earnest endeavors from all quarters regarding determination of the accident causes and establishment of recurrence prevention measures have been carried out during this period. Putting together these results, NISA has compiled the final report.

To identify the mechanism of the pipe rupture in the accident, technical research was conducted in cooperation with JNES, JAERI and other related institutions. The results showed that the cause was so-called erosion and corrosion and that the physical phenomenon was within the scope of knowledge obtained from operational experiences at various plants and experimental data up to now.

It is made clear that the reason why the accident could not be avoided finally, even though the accident could have be foreseen or prevented with existing scientific knowledge, was inappropriate management of the nuclear facilities by KEPCO, MHI and Nihon Arm. Namely, the direct cause of the accident was the mistake that had overlooked the pipe wall thinning of the relevant pipe due to the registration omission in the check list. Further, the root cause of the accident was inappropriate maintenance management and quality assurance activities by these companies with background of tear of the "safety culture" in each company. The fact that KEPCO performed inappropriate outsourcing management, which was against the legal and external responsibility as a reactor licensee and also took up management system, which could not grasp and correct the actual conditions of the field was real problem that substantially impaired confidence of nuclear safety. Besides the inappropriate maintenance management at MHI corresponded to the behavior, which lacked self-discipline as a manufacturer playing a main role in the construction and maintenance of nuclear facilities.

The responsibilities of these companies and the assessment of their recurrence prevention measures are as described above. It should not be forgotten that the establishment of licensees' maintenance management and quality assurance systems, which is closely related to the corporate culture and organizational climate concerning nuclear safety, requires persistent efforts. The fair recurrence prevention measures have been submitted by KEPCO and MHI; however, whether or not these measures involve substantial reform of consciousness and efforts for improvement by the top management, leading to reform and fixing of the corporate culture and organizational climate concerning nuclear safety will be the key to their success or failure. The two companies should perform these activities in earnest, and explain their processes and results to the outside of companies. This will be an obligation for them, as they have hurt the national confidence, especially local residents', in nuclear safety. NISA will follow up these actions rigorously with special safety inspections for KEPCO, among other measures.

The accident provides an important lesson for other licensees to promote the maintenance management and quality assurance activities necessary for nuclear safety. It is important for each licensee to incorporate the tasks and measures clarified this time into its maintenance management and quality assurance activities. NISA will make sure that the licensees give thorough lateral spread among them regarding this matter.

On the other hand, NISA took the accident seriously, and made efforts to examine nuclear safety regulations and to extract problems earnestly. As a result, NISA thought over the fact first of all that the detailed methods of the pipe wall thickness control had been entrusted to in-house standards of each licensee and this entrustment was one of the factors that caused the inappropriate application of the decision criteria. Therefore NISA clarified the requirements as national standards regarding objects and inspection methods at the periodic licensee's inspection by amending the Enforcement of the Electricity Utilities Industry Law (December 2004) and issuing the NISA notice (February 2005) for the final purpose of thorough control based on the forthcoming unified guidelines. NISA is participating positively in the JSME workshop to establish the standard regarding pipe wall thickness control. At the same time, NISA will watch and instruct licensees' activities to ensure that they are controlling pipe wall thickness in an appropriate manner through nuclear safety inspections.

The licensee's autonomous maintenance management and quality assurance activities are fundamental in ensuring the safety of nuclear facilities, and NISA has recognized anew the importance of the inspection system (enacted in October 2003) to watch and give instructions for these activities. In that respect, the following matters have come to light as a result of the accident : (a) To establish appropriate maintenance management and quality assurance systems, it is essential to reform consciousness of the top management in real terms and to bring out their efforts for improvement, and (b) The nuclear licensees are required to perform more substantial outsourcing management to fulfill all its comprehensive responsibilities related to maintenance work at nuclear facilities, including the work outsourced to manufacturers and affiliated companies. NISA intends to make use of these pieces of knowledge in future inspections regarding the licensee's maintenance management and quality assurance activities and continue to improve the quality of inspections.

The accident had consequences that were unprecedented at nuclear power plants in Japan. NISA recognizes it as responsibility requested for to keep the accident in mind and to reflect continuously and humbly on how nuclear safety regulation should be. With considering the difficulties with which the residents and municipalities in the region of the site faced at the accident, who are pointing to a coexistence with nuclear energy, to listen to their requests seriously is very important. Based on this recognition, NISA makes a fresh resolve to secure and maintain confidence in nuclear safety by continuous improvements of safety regulations like making inspections satisfactory, enhancing the quality of nuclear safety inspectors in addition to a dialogue with the public and constant examination of safety regulations.

Reference 1. List of members of the Accident Investigation Committee for the Secondary Piping Rupture at Mihama Power Station, Unit 3

Chairman	Yasuhide Asada,	Technical advisor of the Thermal and Nuclear Power Engineering Society
	Yoshinori Iizuka,	Professor of Graduate School of Engineering, the University of Tokyo (from the fourth meeting)
	Hideo Kobayashi,	Professor of Graduate School of Science and Engineering, the Tokyo Institute of Technology
	Katsuyuki Shibata,	Chief of Reactor Safety Engineering Department, Tokai Research Establishment, the Japan Atomic Energy Research Institute
	Shigeo Tsujikawa,	Professor Emeritus of the University of Tokyo
Deputy Chairman	Haruki Madarame,	Professor of Research Center for Nuclear Science and Technology, the University of Tokyo
	Kenzo Miya,	Professor of Graduate School of Science and Technology, Keio University

Reference 2. Progress of deliberation

First session, August 11 (Wednesday), 2004

Outline of the secondary pipe rupture accident at Mihama Power Station, Unit 3
Results of on-the-spot survey
Concepts and situations of inspection of the ruptured pipe portion

Second session, August 19 (Wednesday), 2004

Report on the secondary pipe rupture accident at Mihama Power Station, Unit 3
Outline of on-the-spot inspection
Concept of investigation procedure to determine causes for the secondary pipe rupture accident at Mihama Power station, Unit 3
Results of collected reports on the pipe wall thinning events

Third session, August 27 (Friday), 2004

Concept of investigation procedure at the Investigation Committee on the Secondary Piping Rupture Accident at Mihama Power Station, Unit 3
Clarification of the mechanism of the pipe rupture
Tendencies in pipe wall thinning and control techniques
Appropriateness of maintenance management for pipe wall thickness
Regulations on pipe wall thinning controls in the US
Results of investigation into pipe accident at Shinchi Power Station, Unit 2 of Soma Kyodo Power Company, Ltd.
Examination of conformance state of water and steam piping at thermal power facilities with technical standards

Fourth session, September 6 (Monday), 2004 (held at Fukui City)

Clarification of the mechanism of the pipe rupture
Situation of inspection by KEPCO
Controls of pipe wall thinning
Recurrence prevention measures
Skeleton (draft) of the interim summary

Fifth session, September 17 (Friday), 2004

Background, immediate measures and future tasks of KEPCO
Clarification of the mechanism of the pipe rupture
Situation of inspection
Background of registration omission for inspection
The Interim Summary (draft)

Sixth session, September 27 (Monday), 2004

Situation of the investigation on the mechanism of the pipe rupture

Situation of inspection

The Interim Summary (draft)

Seventh session, December 13 (Monday), 2004

Clarification of the mechanism of the pipe rupture

Subsequent Governmental actions

Eighth session, March 3 (Thursday), 2005

Validity of operations at the accident and problems concerning facilities

Determination of causes of the accident and recurrence prevention measures

Ninth session, March 14 (Monday), 2005 (held at Fukui City)

Recurrence prevention measures

Draft of the final report

Tenth session, March 30 (Wednesday), 2005

Draft of the final report

Appendices

Appendix 1

Initial reactions, notification to the related organs and actions for rescue of victims (in time sequence)

○ August 9, 2004

15:22 A "Fire Alarm Operation" alarm, etc., was generated. An operator promptly announced a "fire breaking out in the turbine building" through a public address system.

15:27 An operator found a victim at the front of an elevator on the second floor of the turbine building.

15:30 A member of the General Manager's staff dialed 119 (the first report). Shortly after that, the member also called for ambulances. Then the local municipality (Mihama-cho) was notified about the occurrence of the accident.

15:30-15:45
A member of the General Manager's staff ordered an evacuation from the turbine building through a public address system.

15:32 The Mihama Nuclear Safety Inspector's Office of NISA was notified about the occurrence of the accident.

15:34 The local municipality (Fukui Prefecture) was notified about the occurrence of the accident.

15:35 On-site rescue personnel (the Power Station staff (including the staff of an affiliated company)) started to rescue victims.

15:58 An ambulance crew (fire-fighting vehicles) arrived. Firefighters and the Power Station staff cooperated in conducting a rescue operation for victims.

16:46 All 11 victims were transported to hospitals.
(The hospitals to which the victims were transported: 8 victims at Tsuruga City Hospital, 3 victims at Fukui National Hospital)

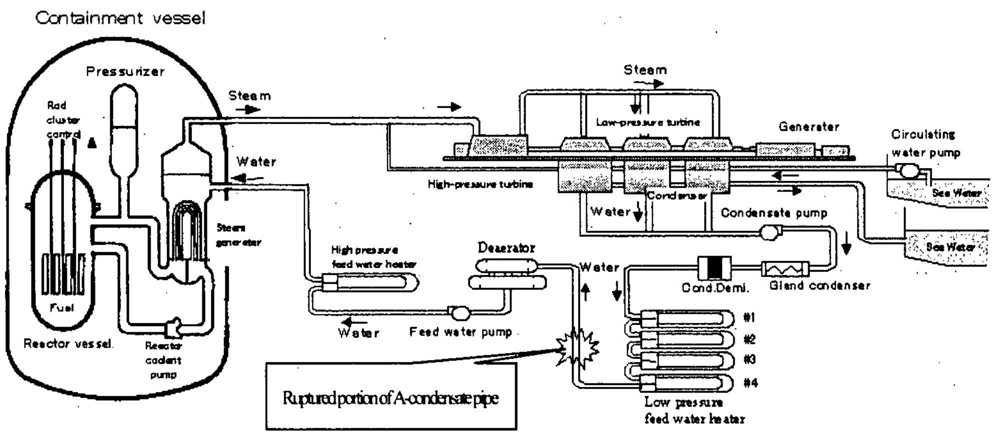
After that, while access to the accident site was restricted, a search-and-rescue operation was continued.

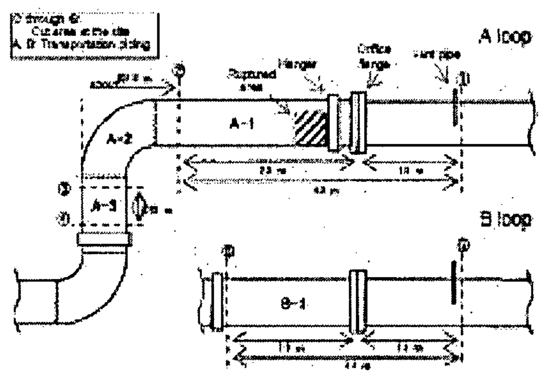
19:00 The fire station confirmed that no victims were found in the turbine building.

Appendix 2

Ruptured condition of secondary piping at Mihama Power Station, Unit 3

1. Summary of investigation





Main data:

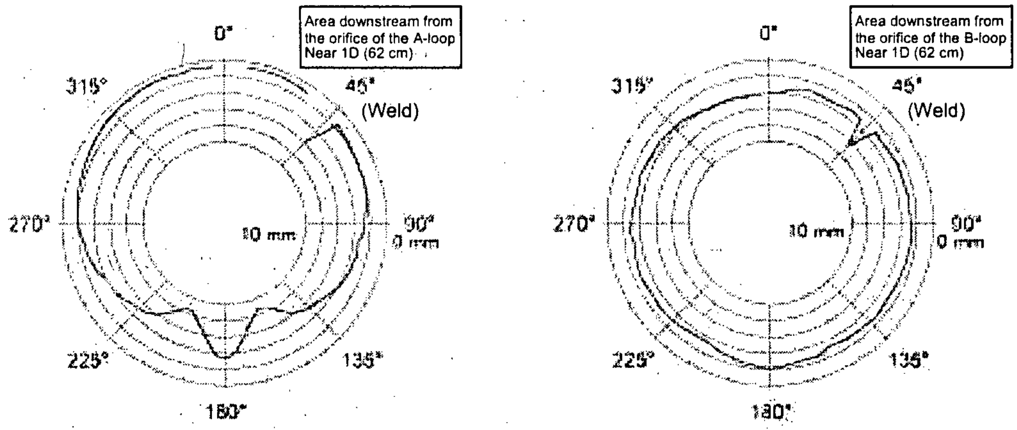
(1) Piping downstream of the orifice; Material: JIS G SB42, Diameter (hereinafter referred to as D): approximately 560 mm, Initial thickness: approximately 10 mm

(2) Flow condition during operation; Flow rate: approximately 1,700 t/h, Pressure in use: approximately 0.93 MPa, Temperature: 142 degrees Celsius, Flow velocity: approximately 2.2 m/sec

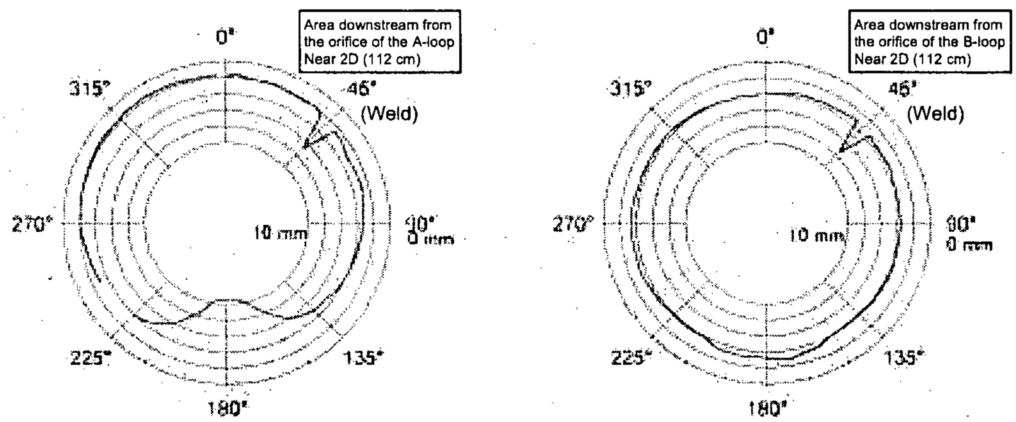
(3) Operation time; approximately 185,700 hours

(4) Water quality; pH: 8.6 to 9.3, Dissolved oxygen concentration: less than 5 ppb

2. Results of pipe wall thickness measurements



Near 1D from the downstream end of the orifice



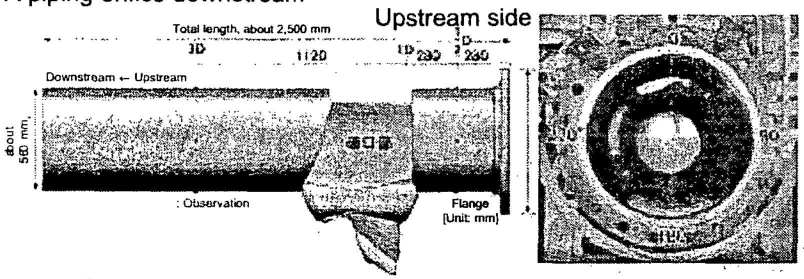
Near 2D from the downstream end of the orifice

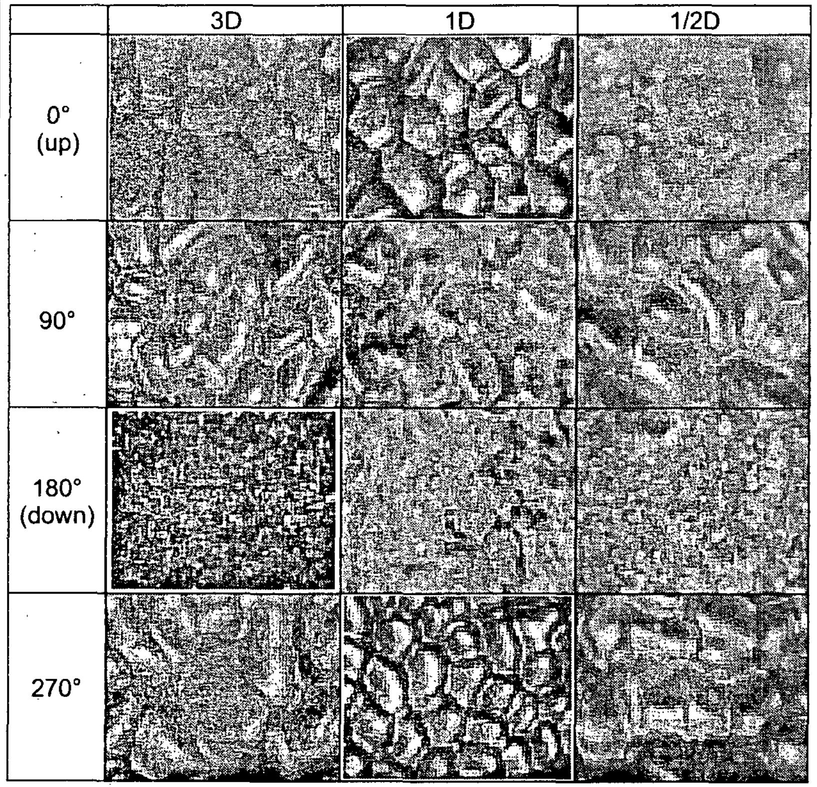
Situation of reduced thickness at the downstream orifice of A-piping

Situation of reduced thickness at the downstream orifice of B-piping

3. Observation results of the inner surfaces of the piping

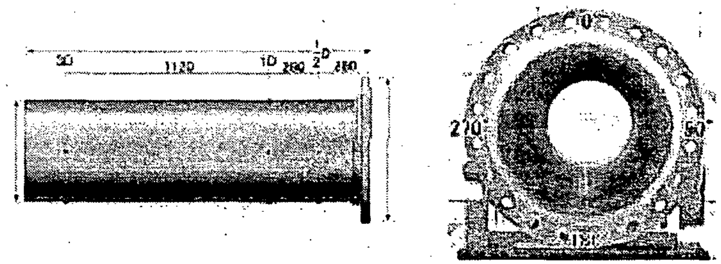
A piping orifice downstream

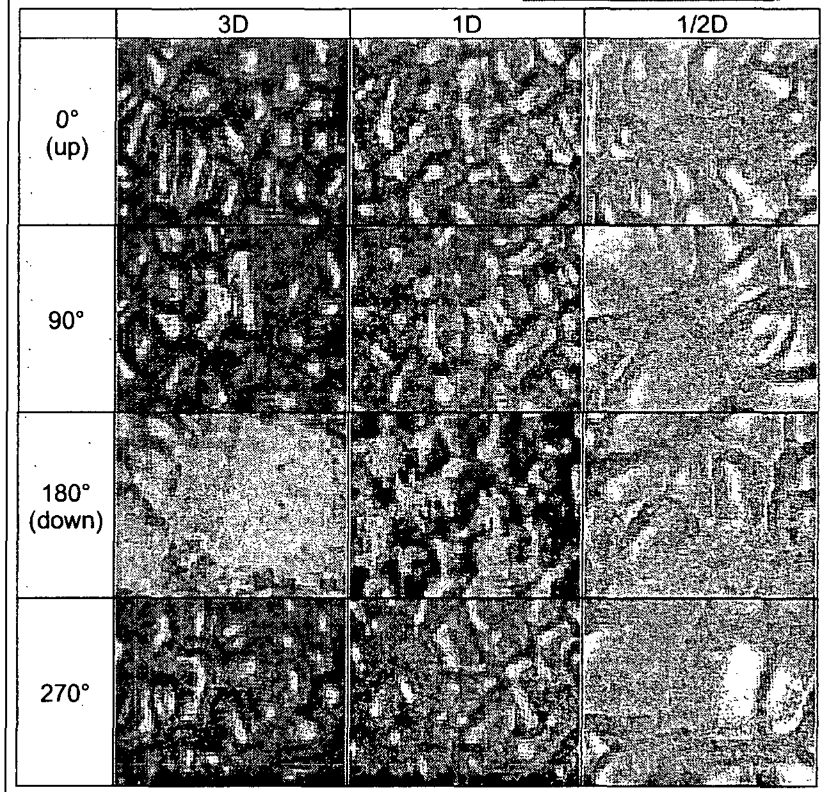




Summary: Fish Scale-like patterns were observed in areas other than at the underside of A piping orifice downstream area (3D and 1/2D at 180 degrees)

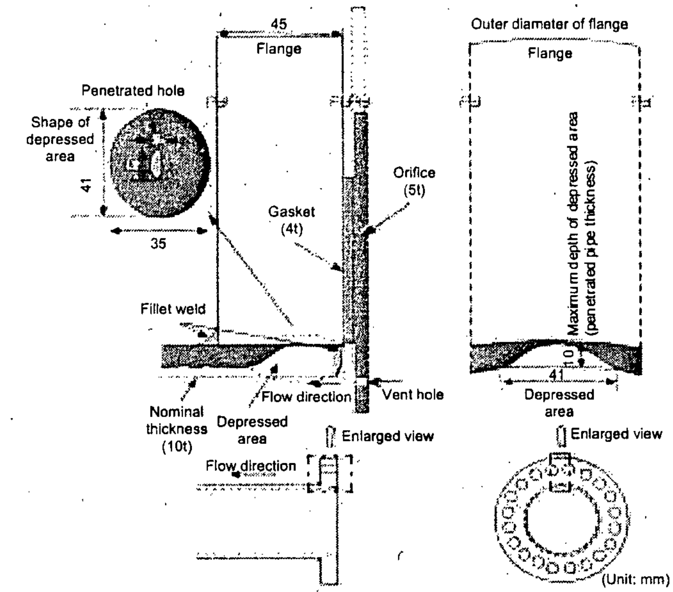
B piping orifice downstream



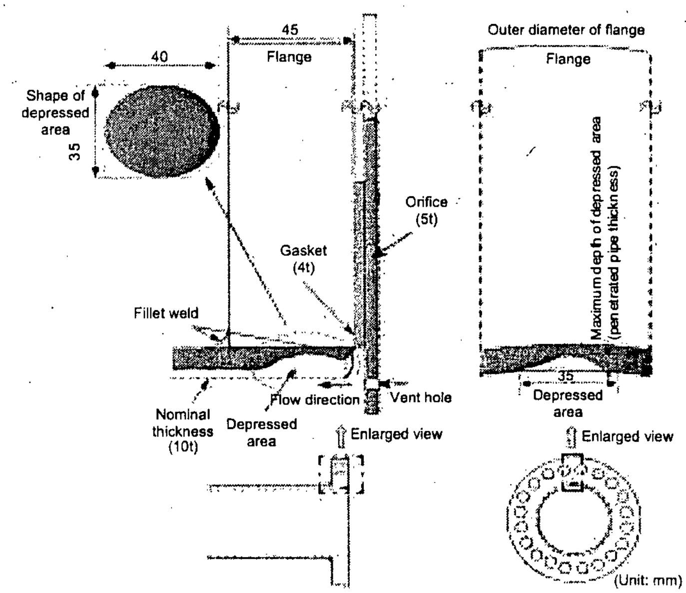


Summary: Fish Scale-like patterns were observed at B piping orifice downstream area

4. Situations at downstream of the vent hole



A piping orifice downstream flange



B piping downstream flange

Sources: Extracted for Section 1, 2, and 3, from Material 7-1-1 (Attachment 1-1) of the 7th accident investigation committee, and for Section 4, from Material 5-1-2 (Attachment 1) of the 5th accident investigation committee (documents submitted from JAERI and JNES)

Appendix 3

Results of metallurgical investigations by JAERI

Summary

By using a scanning electron microscope (SEM), the fracture surface of the ruptured opening was observed with emphasis on the vicinity of the thinnest area. In each SEM photograph, there were dimples (small depressed areas formed on a fracture surface at the time of the occurrence of ductile fracture) on the fracture surface. In addition, in comparison with the hardness in the areas other than the ruptured opening, the hardness in the vicinity of the ruptured opening had a tendency to increase toward the edge of the ruptured opening. Therefore, it is considered that plastic deformation occurred at the time of the occurrence of the fracture. For these reasons, it was proved that the fracture mode was ductile fracture.

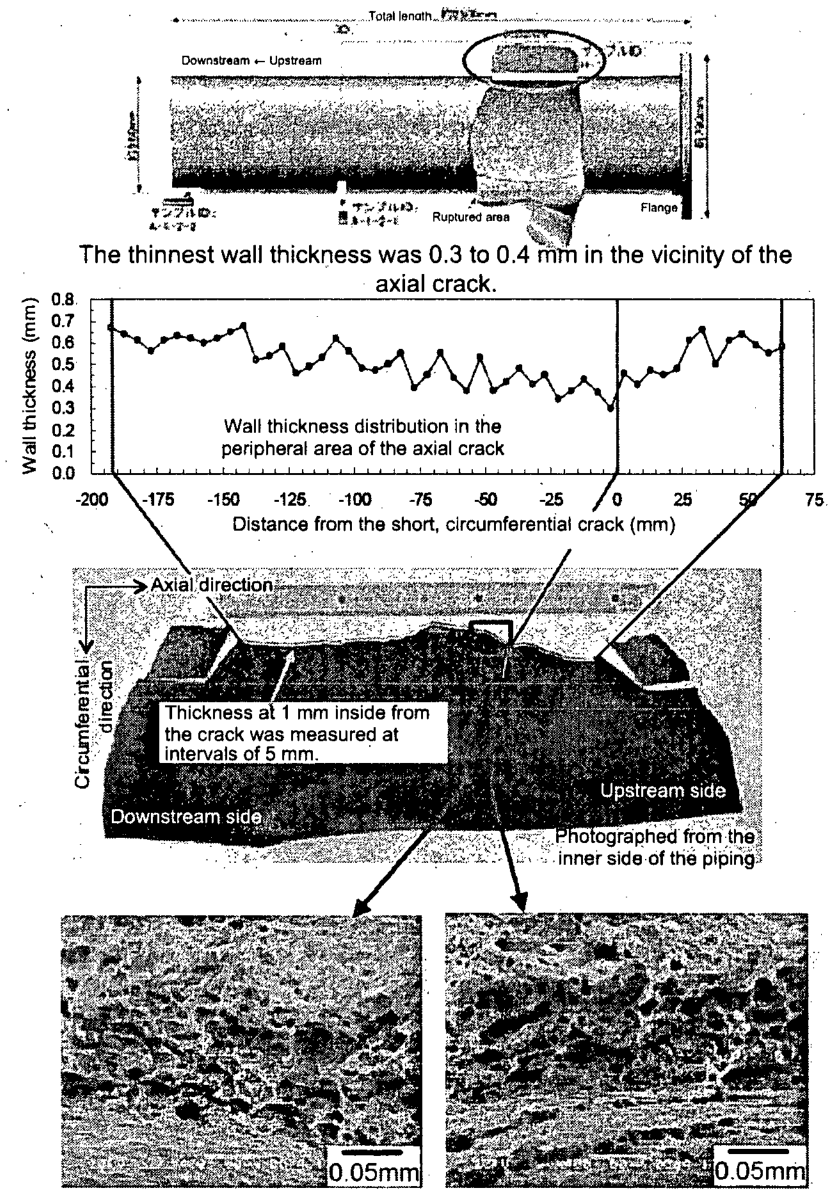


Figure 1 Condition of the fracture surface and wall thickness distribution in the vicinity of the crack at the ruptured opening

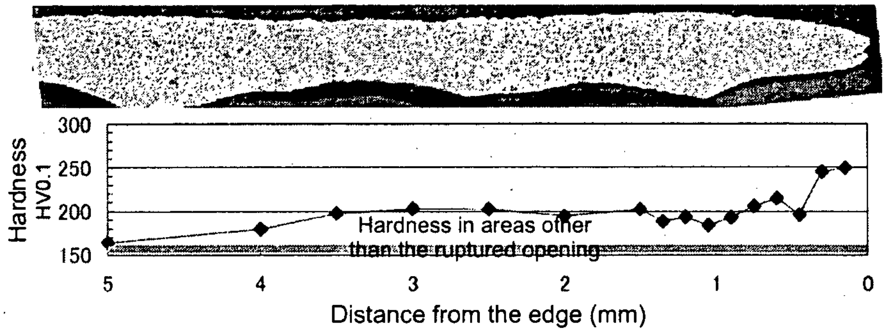


Figure 2 Hardness distribution on a cross-section surface in the vicinity of the ruptured opening

Sources: Extracted from Material 7-1-1 (Attachment 1-1) of the 7th accident investigation committee (documents submitted from JAERI)

Appendix 4

Results of pipe flow analysis by JNES and JAERI

Summary

The straight pipes on both sides of the orifice of the secondary piping were investigated by a 3-dimensional turbulent flow analysis. Then the predicted distribution of the thinning amounts obtained by conversion from the maximum value of near-wall turbulence energy was compared with the measured values of the actual equipment. According to the comparison, an abrupt thinning tendency at the orifice downstream and the position where the thinning amount became maximum (at a distance of approximately 1.2 times the diameter of the pipe downstream from the orifice: approximately 700 mm) was reproduced well by the calculation. Incidentally, the thinning amount predicted by the calculation at downstream area from the maximum thinning position was smaller than the measured value. Therefore, the pipe wall thinning area was underestimated. It is considered that the reason is the effects of other parameters related to thinning phenomena other than near-wall turbulence energy.

In order to analyze the difference of circumferential thinning tendencies between the A and B piping, a 3-dimensional turbulent flow analysis was conducted for the entire piping. In the flow velocity distribution at the orifice inlet, a strong counterclockwise swirling flow as seen from the upstream side was confirmed for the A piping, and a weak clockwise swirling flow as seen from the upstream side was confirmed for the B piping. It is considered that the difference has an effect on the difference of the pipe wall thinning behaviors in the circumferential direction between the A and B piping. These swirling flows occur when a flow into a branch pipe from the header of a main condensate pipe reaches the first elbow. Because the directions of the elbows differ by 180 degrees each other, the direction of a swirling flow in the A piping is opposite to that in the B piping. In addition, because swirling strength depends on the degree of eccentricity of a flow into an elbow, the A piping, whose eccentricity is high, is higher in swirling strength than the B piping, whose eccentricity is low.

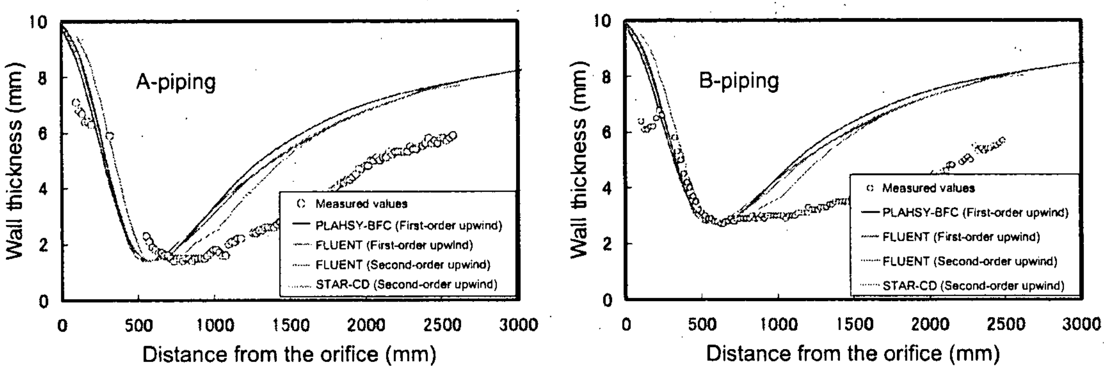


Figure 1 Comparison between the thinning amounts predicted by near-wall turbulence energy and the measured values (at 270 degrees clockwise as seen from the upstream side)

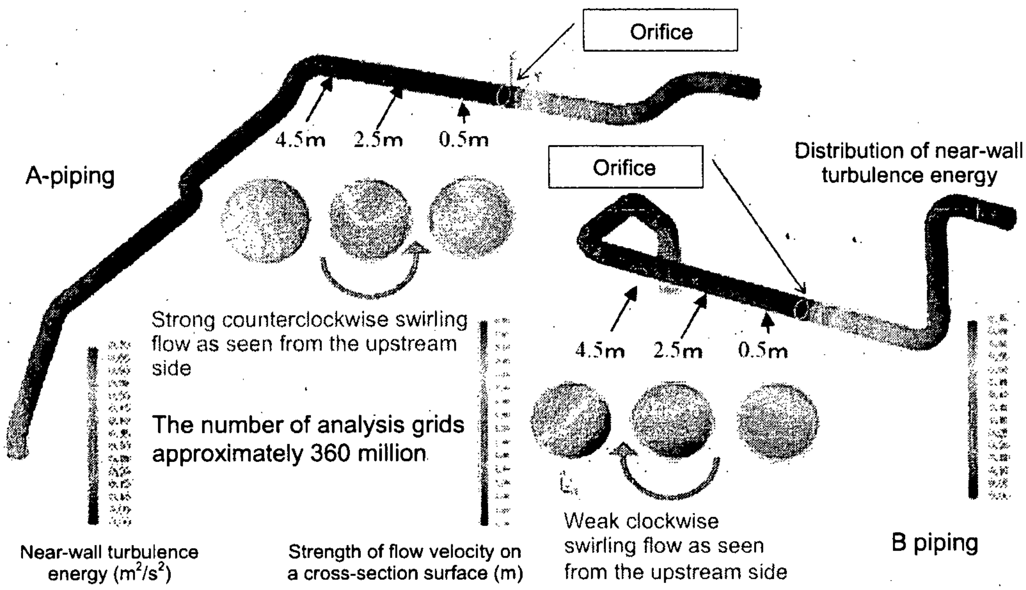


Figure 2 Analysis results based on the simulation of the actual piping

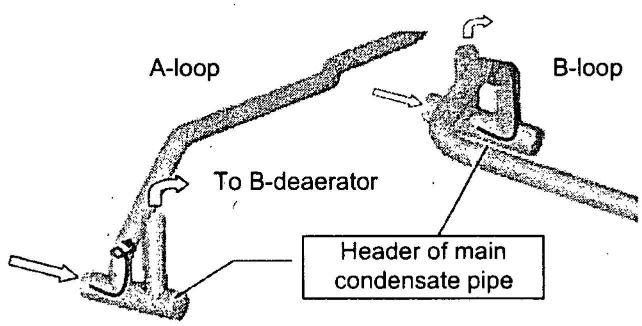


Figure 3 Mechanism of the occurrence of swirling flow in piping

Sources: Extracted from Material 7-1-1 (Attachment 2-1) of the 7th accident investigation committee (documents submitted from JAERI and JNES)

Appendix 5

Results of thinning behaviors analysis by JNES

Summary

Regarding the thinning amounts, by using PASCAL-EC, the thinning amounts of carbon steel tube caused by erosion-corrosion (E/C) in single-phase water flow were calculated on the basis of the prediction formula given by Kastner et al. The figure below shows the analysis results related to the wall thinning behaviors by using the actual water environment and material data. In the figure, the maximum thinning amounts of the A and B loop piping in Mihama Power Station, Unit 3, are also shown. In addition, the maximum thinning amount is calculated on the assumption that the initial wall thickness is 10 mm, and error bars are shown in consideration of 0.7mm tolerance of wall thickness. The measured maximum thinning amounts of A and B-loop piping were somewhat larger in comparison with the analysis results as shown in the figure below. In consideration of existing knowledge regarding the prediction accuracy of thinning amounts, it is concluded that the thinning amount of A-loop piping is within the range of predictable variations.

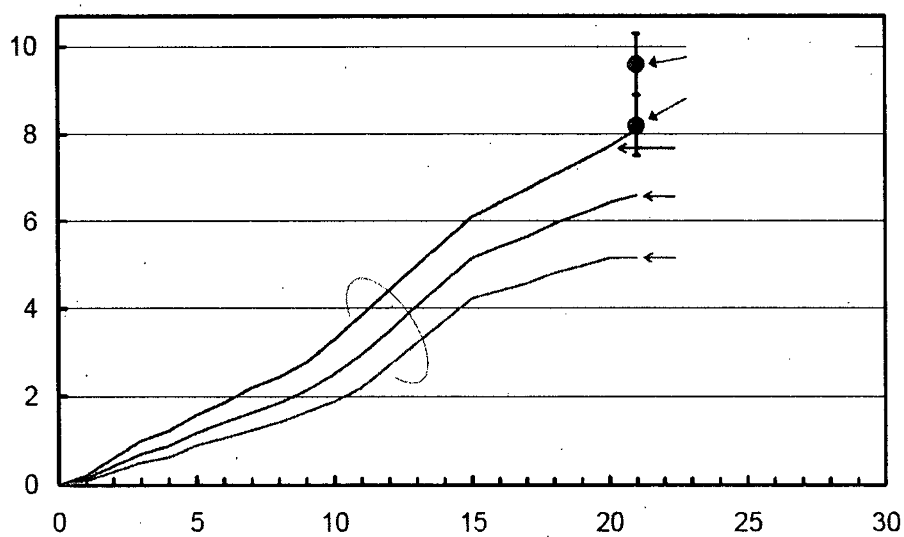


Figure 1 Analysis results of thinning progress based on actual water environment data, etc.
Analysis conditions: Flow velocity = 2.2 m/s,
Water temperature = 146

Appendix 6

Results of pipe rupture structural behavior by JNES

Summary

In order to investigate the fracture mechanism of the pipe ruptured opening, the opening progress is analyzed by using the nonlinear dynamic analysis code AUTODYN-3D. As a result, it is estimated that the crack progressed and became the final form in one hundredth of a second after the occurrence.

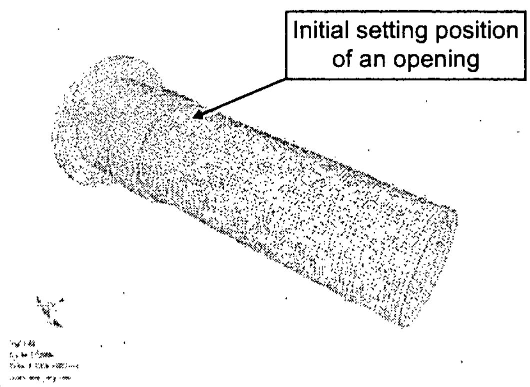


Figure 1 Analytical model of an opening progress

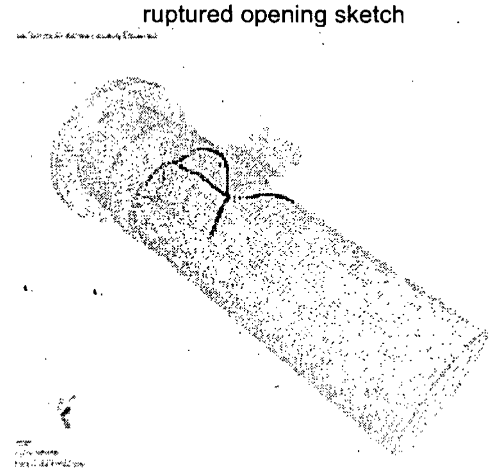


Figure 2 Comparison of the opening conditions (30 ms, oblique perspective)

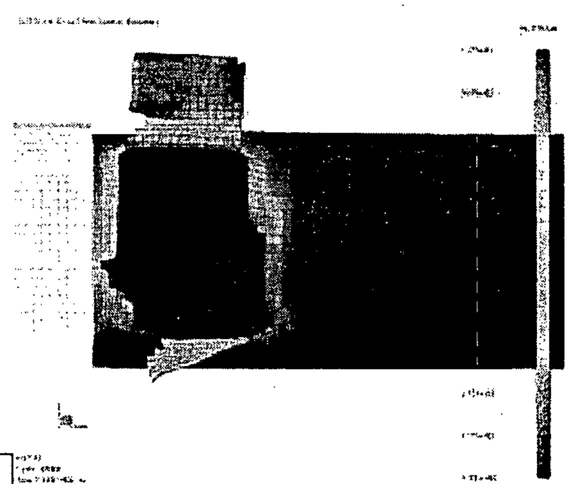


Figure 3 The opening condition and the plastic strain distribution of piping (30 ms)

Sources: Extracted from Material 7-1-1 (Attachment 3-2) of the 7th accident investigation committee (documents submitted from JNES)

Appendix 7

Study of validity of "PWR Management Guidelines"

1. Summary of "PWR Management Guidelines"

(1) Scope

Carbon steel piping of PWR plant secondary side (excluding small diameter piping such as instrument system)

(2) Inspection method

Check by ultrasonic thickness measuring instrument based on JIS Z 2355 "Methods for measurement of thickness by ultrasonic pulse echo technique"

(3) Subject of inspection

Areas where channeling occurs and 2 × D downstream areas (D: piping diameter) among main systems to be inspected shown in Table 1 are specified as main inspection areas (Table 1).

For other areas, 25% of areas where channeling occurs are also specified as subject of inspection for ten years.

* Areas where channeling occurs include downstream area of a control valve, downstream area of a globe check valve, elbow, T pipe, orifice downstream, downstream area of a swing check valve, reducer, and curved piping.

(4) Inspection frequency

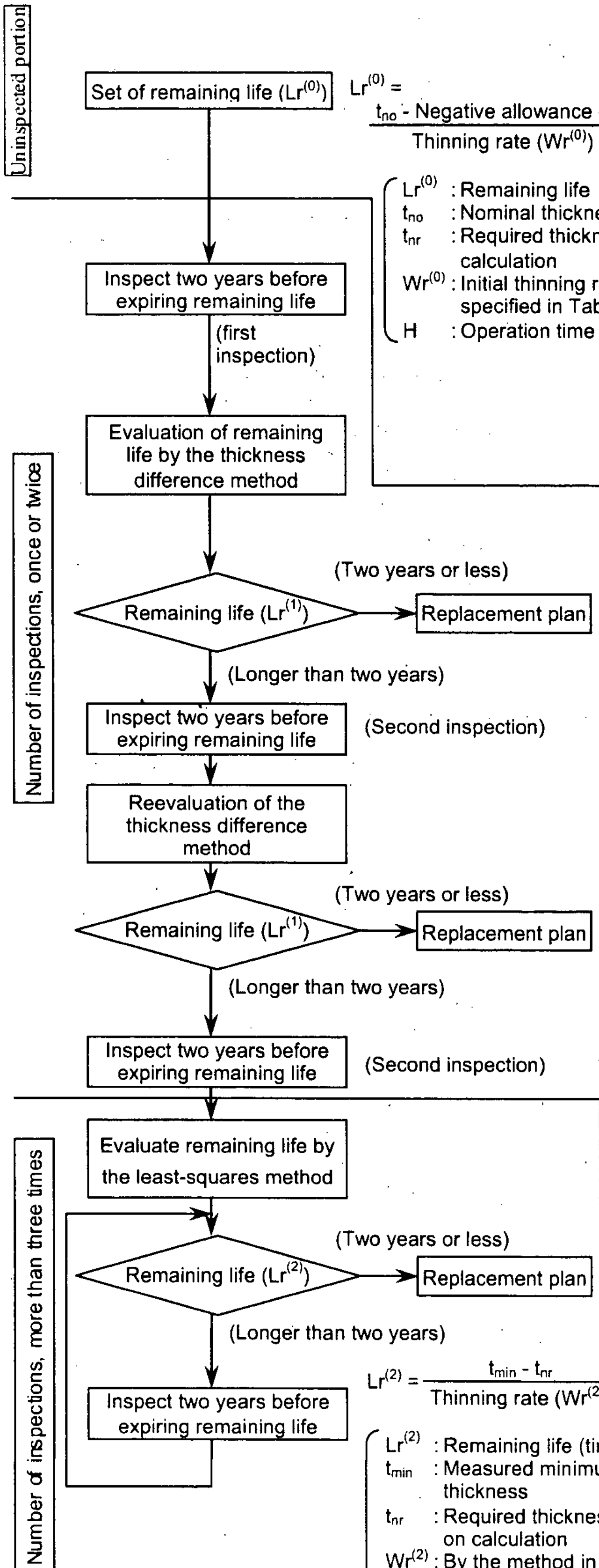
Remaining life to the necessary minimum thickness on calculation should be determined at each location, and the area concerned should be inspected before the remaining life is less than two years. It is also stipulated that the inspection should be repeated using evaluation of inspection results until the remaining life reaches to less than two years (Figure 1).

Table 1 Main systems to be inspected

Classification	Requirements			Typical system name	Remarks
	Wetness fraction	Flow velocity	Temperature		
Two-phase flow	More than 15%	Less than 30 m/sec	150-200°C	No. 6 high pressure heater drain piping, No. 5 high pressure heater drain piping	Apply for all main inspection areas.
			200-250°C	Moisture separator heater drain tank drain piping	
		30-50 m/sec	150-200°C	-	
			200-250°C	-	
		More than 50 m/sec	150-200°C	High pressure exhaust piping drain piping	
			200-250°C	-	
	5-15%	Less than 30 m/sec	150-200°C	-	
			200-250°C	Steam converter heating steam piping	
		30-50 m/sec	150-200°C	No. 5 extract piping, No. 4 extract piping	
			200-250°C	-	
		More than 50 m/sec	150-200°C	No. 5 extract piping, No.4 extract piping	
			200-250°C	No. 6 extract piping, No.5 extract piping	
	Less than 5%	Less than 30 m/sec	150-200°C	Deaerator air vent piping	
			200-250°C	No. 6 high pressure heater air vent piping, No. 5 high pressure heater air vent piping	
			More than 250°C	Moisture separator heater balance piping	
		30-50 m/sec	150-200°C	-	
			200-250°C	-	
			More than 250°C	Moisture separator heater balance piping	
		More than 50 m/sec	150-200°C	-	
			200-250°C	-	
			More than 250°C	-	
Single-phase flow	Water	Less than 3 m/sec	100-150°C	Main condensate piping	
			150-200°C	Feedwater booster pump suction piping, moisture separator drain piping	
		3-6 m/sec	100-150°C	-	
			150-200°C	Main feedwater piping, feedwater booster pump discharge piping	

Single-phase flow (cont.)	Water	More than 6 m/sec	100-150°C	-	
			150-200°C	-	
Two-phase flow	More than 15%	Less than 30 m/sec	100-150°C	No. 4 low pressure heater drain piping	Apply for only down-stream of control valve and globe check valve.
		30-50 m/sec		-	
		More than 50 m/sec		-	
Single-phase flow	Water	Less than 3 m/sec	200-250°C	-	
		3-6 m/sec		Main feedwater piping	
		More than 6 m/sec		-	

-: No piping exists at present plants.



$$Lr^{(0)} = \frac{t_{no} - \text{Negative allowance} - t_{nr}}{\text{Thinning rate } (Wr^{(0)})} - H$$

- $Lr^{(0)}$: Remaining life
- t_{no} : Nominal thickness
- t_{nr} : Required thickness on calculation
- $Wr^{(0)}$: Initial thinning rate specified in Table 1
- H : Operation time

Table-1 $Wr^{(0)}$ value used for $Lr^{(0)}$ set

			Temperature: 100°C or less	100°C - 150°C	150°C - 200°C	200°C - 250°C	250°C or more
Two-phase flow, Wetness fraction, more than 15%	Flow velocity	30 m/s or less		0.30	0.35		
		30 m/s - 50 m/s			1.15		
		50 m/s or more					
Two-phase flow, wetness fraction, 5 to 15%	Flow velocity	30 m/s or less			0.35		
		30 m/s - 50 m/s			1.15		
		50 m/s or more					
Two-phase flow, Wetness fraction less than 5% (possibly involving drain)	Flow velocity	30 m/s or less			0.35		
		30 m/s - 50 m/s			1.15		
		50 m/s or more					
Water single-phase flow	Flow velocity	3 m/s or less		0.45		0.30 (0.30 applied only for downstream of control valve and glove check valve)	
		3 m/s - 6 m/s					
		6 m/s or more					

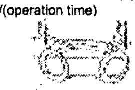
Note) 1. Unit of $WR^{(0)}$: $\times 10^{-4}$ mm/Hr
2. Scope marked with shadow

(1) For downstream of control valve, figures in the table should be multiplied by 5.
(2) For downstream of glove check valve, figures in the table should be multiplied by 2.

$$Lr^{(1)} = \frac{t_{min} - t_{nr}}{\text{Thinning rate } (Wr^{(1)})}$$

- $Lr^{(1)}$: Remaining life (time)
- t_{min} : Measured minimum thickness
- t_{nr} : Required thickness on calculation
- $Wr^{(1)}$: By the method in Table-2

Table-2 $Wr^{(0)}$ value used for $Lr^{(1)}$ set

	Method classification (area concerned)	Calculation of thinning rate
Number of inspections, once or twice	Longitudinal thickness method Thickness immediately after manufacturing is uniform longitudinally (elbow, mother pipe side of T pipe, curved pipe)	$Wr^{(1)}$=(Maximum thickness in pipe axis direction)/(operation time)  Maximum thickness difference = $t_{max} - t_{min}$
	Circumferential thickness method Thickness immediately after manufacturing is uniform circumferentially (reducer, straight pipe*, branch pipe side of T pipe)	$Wr^{(1)}$=(Maximum thickness in pipe axis direction)/(operation time)  Maximum thickness difference = $t_{max} - t_{min}$
	Nominal thickness method (reducer*, straight pipe*)	$Wr^{(1)} = \frac{\text{(Nominal thickness - measured minimum thickness)}}{\text{(operation time)}}$

* For reducer or straight pipe, apply the thinning rate by the thickness difference method or the nominal thickness method, whichever is larger, for evaluation.

$$Lr^{(2)} = \frac{t_{min} - t_{nr}}{\text{Thinning rate } (Wr^{(2)})}$$

- $Lr^{(2)}$: Remaining life (time)
- t_{min} : Measured minimum thickness
- t_{nr} : Required thickness on calculation
- $Wr^{(2)}$: By the method in Table-3

Table-3 $Wr^{(2)}$ value used for $Lr^{(2)}$ set

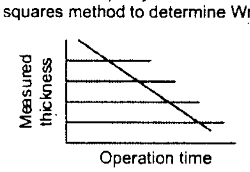
	Method classification (area concerned)	Calculation of thinning rate
Number of inspections, three or more times	Least square method (for all areas)	Obtain the slope by the least-squares method to determine $Wr^{(2)}$ 

Figure 1 Remaining life determination method

2. Piping thinning control method and trend of thinning

(1) Factors of thinning to be controlled

The PWR Management Guidelines used by PWR operators and the management method used by BWR operators are intended to control thinning due to erosion and corrosion. In this case, erosion and corrosion mean the "thinning phenomenon caused by combined actions of mechanical erosion and chemical corrosion," typically showing fish scale-like pattern on the thinned surface.

(2) Evaluation based on data submitted in report collection

We analyzed the thinning trend using the following two materials: (1) Thinning measurement data for individual plants reported from every licensee responding to the report collection for inspection related to piping thinning phenomenon dated August 11, 2004; (2) Thickness measurement data of secondary piping of Mihama Power Station, Unit 3 submitted by KEPCO responding to the report collection on the secondary piping rupture at Mihama Power Station, Unit 3 dated August 18, 2004.

(3) Thinning related to PWR piping

Figure 2 shows the trend of thinning measured by every PWR plant and its resultant actual thinning rate. Comparison between the actual thinning rate and the initially set value of thinning rate specified in the PWR Management Guidelines reveals that the actual thinning rate, except for the main feedwater piping in A-loop, is lower than the initially set value of thinning rate.

Figure 3 shows the trend of thinning measured at Mihama Unit 3, and comparison with the initially set value of thinning rate shown in the PWR Management Guidelines. According to the figure, the actual trend of thinning is lower than the initially set value of thinning rate except small part of data.

Figure 4 shows a comparison of thinning between main inspected systems, all of which are inspected in accordance with the PWR Management Guidelines and other systems inspected on a sampling basis. As a result, the thinning rate of other systems is smaller than that of the main inspected systems as a whole. This suggests that the thinning rate is affected by an environmental difference. Nevertheless some other systems show thinning rates comparable with the main inspected systems.

(4) Estimated thinning rate of ruptured piping of Mihama Unit 3

Estimated thinning rate of ruptured piping of Mihama Unit 3 was calculated based on the remaining life evaluation equation in the PWR Management Guidelines to be 0.47×10^{-4} mm/Hr. This is almost the same as 0.45×10^{-4} mm/Hr, the initially set value of thinning rate in the guidelines.

The remaining life evaluation equation to determine the remaining life for uninspected areas usually uses "nominal thickness - negative allowance" for the original thickness , but for conservative evaluation of thinning rate the negative allowance will not be included in calculation. This is an issue to study in the future.

3. Measuring area and measuring points in main inspection areas

(1) Determination of measuring points

PWR operators determine measuring area and measuring points at every periodic inspection on a contract basis with inspection companies. Concretely, they specify measuring sections depending on the structure at measuring areas and determine eight or four measuring points at a section (hereinafter referred to as "typical measuring points") and apply 3 × D (D: piping diameter) for downstream area of an orifice for measurement. At the typical measuring point, the thickness if less than the threshold thickness for detailed measurement will be measured in detail at a 20 mm pitch around the typical measuring point.

(2) Analysis of measured results

NISA used detailed measurement results of Mihama Unit 3 obtained from KEPCO through the report collection requirement to analyze the relation between the measuring area and measuring points and occurring situation of thinning. Figure 5 shows distribution of measured results. This reveals that measurement by the typical measuring points and resultant detailed measurements are effective to judge the shape and dimensions of the area concerned.

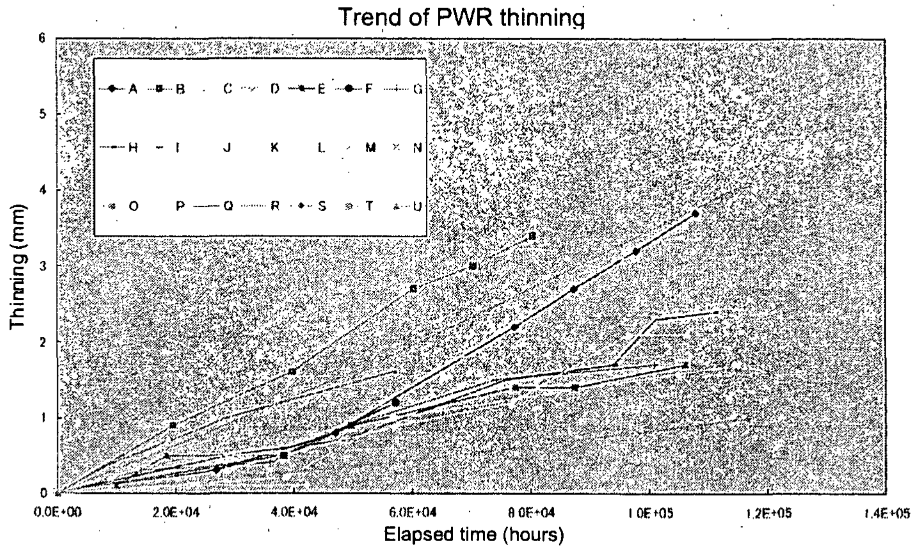
4. Thinning of BWR piping

(1) Applied management method

BWR operators specify their own management methods individually, but the contents have many common descriptions. Comparison with the PWR Management Guidelines shows that the inspection area concerned is wider for BWR than PWR, but the inspection for PWR is more frequently than BWR because of the following reasons. One reason is that PWR has main inspection systems for entire inspection required much more than BWR and the other reason is that BWR has less numbers of inspection areas than PWR because of frequent sampling inspection.

(2) Thinning of BWR piping

Figure 6 shows the trend of thinning measured at BWR plants and its resultant actual thinning rate. Comparison of Figure 2 and 6 reveals that PWR and BWR are different in the trend of thinning and the rate of BWR is lower than that of PWR. This is caused by the difference in water chemistry control between PWR and BWR.



* Elapsed time is the time after an initial inspection.

No.	System name	Inspection area	Material	Temperature (°C)	Flow velocity (m/s)	Wetness Fraction	Thinning rate ($\times 10^{-4}$ mm/Hr)	Guide-line category
A	Main feedwater piping	Straight pipe (Downstream of control valve)	STPT49	228	5.3	Water	0.40	
B	Main condensate piping	Straight pipe (Downstream of orifice)	SB42	145	3.0	Water	0.43	
C	Main condensate piping	Straight pipe (Downstream of orifice)	SB42	147	4.0	Water	0.41	
D	Main feedwater piping	T pipe	STPT49	220	5.4	Water	0.38	Others
E	Condensate piping	T pipe	SB42	118	1.4	Water	0.19	
F	Main feedwater piping	90 degree elbow	SB49	190	5.1	Water	0.42	
G	Condensate system	90 degree elbow	SB42	132	3 or less	Water	0.30	
H	Condensate system	90 degree elbow	STPT38	147	3 or less	Water	0.30	
I	Condensate system	T pipe	SB410	148	3 - 6	Water	0.18	
J	High and low pressure vent drain system	Curved pipe	PG370	187	3 or less	Water	0.26	
K	High and low pressure vent drain system	Reducer	SB42	191	3 or less	Water	0.17	
L	Feedwater system	90 degree elbow	SB42	189	3 - 6	Water	0.24	
M	Feedwater pump minimum flow piping	90 degree elbow	STPT38	182	2.3	Water	0.19	
N	Feedwater pump minimum flow piping	Downstream piping	STPT38	182	2.3	Water	0.32	
O	Main feedwater piping	Straight pipe (Downstream of control valve)	STPT49	221 or less	0.0	Water	0.04	
P	Condensate piping	T pipe (Mother pipe side)	SB42	151	3.7 (Mother pipe side)	Water	0.10	
Q	Condensate piping	T pipe (Branch pipe side)	STPT38	151	3.7 (Mother pipe side)	Water	0.28	
R	Main feedwater booster pump discharge piping	90 degree elbow	SB42	188	5.7	Water	0.35	
S	Main feedwater booster pump discharge piping	Downstream piping	SB42	188	5.7	Water	0.09	
T	Moisture separating heater No. 1, 2 heater air piping	T pipe (Mother pipe side)	STPT38	224	6.1 (Mother pipe side)	5% or less	0.28	
U	Moisture separating heater No. 1, 2 heater air piping	T pipe (Branch pipe side)	STPT38	224	6.1 (Mother pipe side)	5% or less	0.21	

Average thinning rate:
0.26×10^{-4} mm/Hr

(Note) Initially set value of thinning rate in PWR Management Guidelines

<table>
<tr><td colspan="3" rowspan="2"></td><td colspan="5">Temperature</td></tr>
<tr><td>100°C or less</td><td>100°C - 150°C</td><td>150°C - 200°C</td><td>200°C - 250°C</td><td>250°C or more</td></tr>
<tr><td rowspan="3">Two phase flow, Wetness fraction 15% or more</td><td rowspan="3">Flow velocity</td><td>30 m/s or less</td><td></td><td rowspan="3">0.30</td><td colspan="2">0.35</td><td></td></tr>
<tr><td>30 m/s - 50 m/s</td><td></td><td colspan="2" rowspan="2">1.15</td><td></td></tr>
<tr><td>50 m/s or more</td><td></td><td></td></tr>
<tr><td rowspan="3">Two phase flow, Wetness fraction 5 to 15%</td><td rowspan="3">Flow velocity</td><td>30 m/s or less</td><td></td><td></td><td colspan="2">0.35</td><td></td></tr>
<tr><td>30 m/s - 50 m/s</td><td></td><td></td><td colspan="2" rowspan="2">1.15</td><td></td></tr>
<tr><td>50 m/s or more</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Two phase flow, Wetness fraction 5% or less (possibly involving drain)</td><td rowspan="3">Flow velocity</td><td>30 m/s or less</td><td></td><td></td><td colspan="3">0.35</td></tr>
<tr><td>30 m/s - 50 m/s</td><td></td><td></td><td colspan="3" rowspan="2">1.15</td></tr>
<tr><td>50 m/s or more</td><td></td><td></td></tr>
<tr><td rowspan="3">Water single-phase flow</td><td rowspan="3">Flow velocity</td><td>3 m/s or less</td><td></td><td colspan="2" rowspan="3">0.45</td><td rowspan="3">0.30 applied only for downstream of control valve and downstream of globe check valve</td><td></td></tr>
<tr><td>3 m/s - 6 m/s</td><td></td><td></td></tr>
<tr><td>6 m/s or more</td><td></td><td></td></tr>
</table>

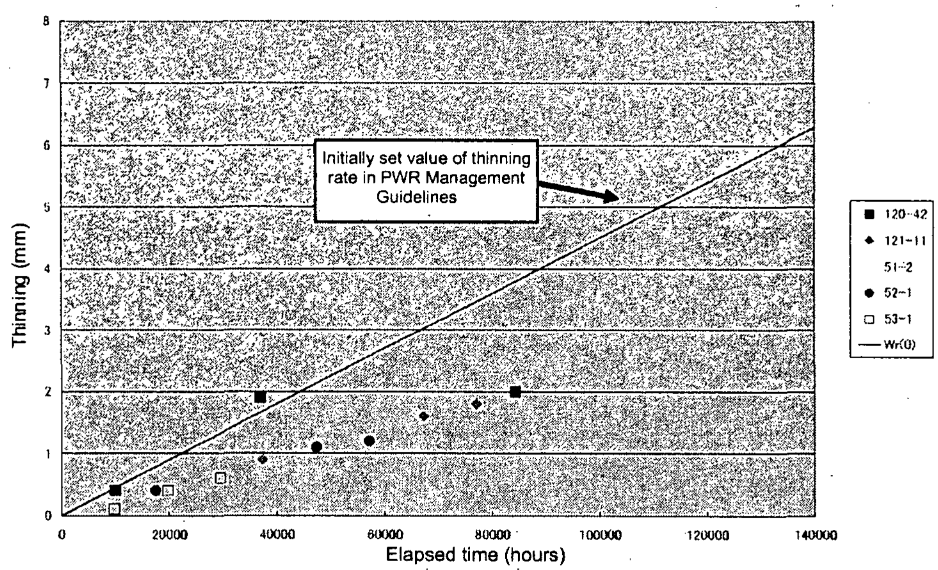
Note) 1. Unit of WR(0): 10^{-4} mm/Hr

2. Scope marked with shadow

(1) For downstream of control valve, figures in the table should be multiplied by 5.

(2) For downstream of globe check valve, figures in the table should be multiplied by 2.

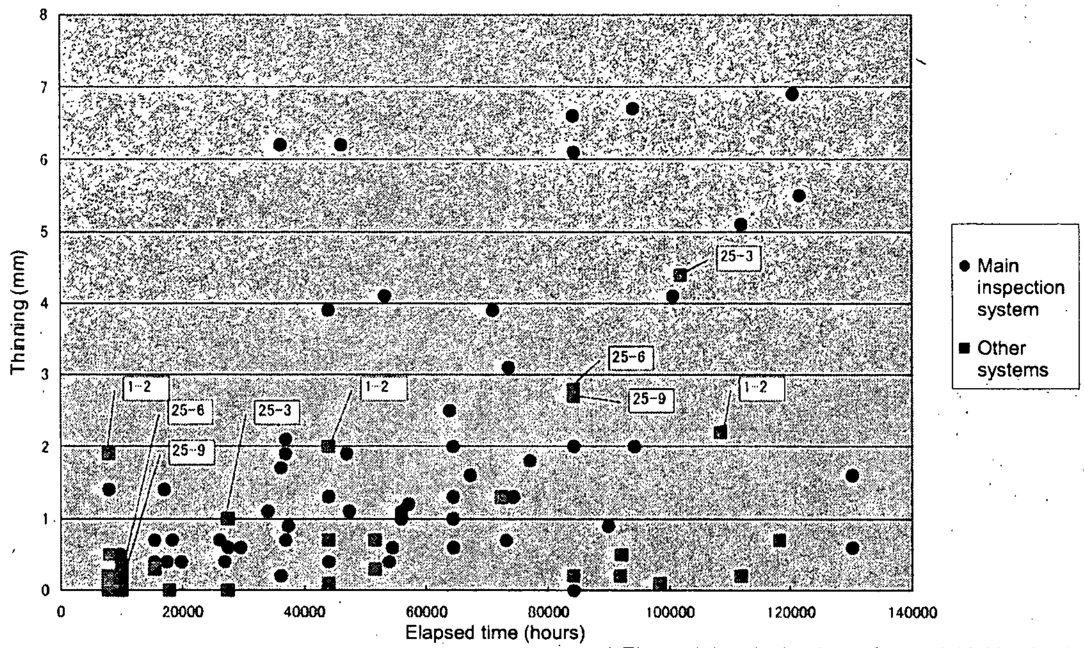
Figure 2 Measurement area and the trend of thinning in PWR piping



* Elapsed time is the time after an initial inspection.

No.	System	Inspection area	Material	Wetness fraction	Flow velocity (m/s)	Temperature (°C)	$Wr^{(0)}$ ($\times10^{-4}$ mm/hr)	Measured thinning rate ($\times10^{-4}$ mm/hr) mm
120-42	Feedwater booster pump suction piping	Elbow	STPT38	Water	3 or less	150 - 200	0.45	0.239
121-11	Feedwater booster pump suction piping	Elbow	SB42	Water	3 or less	150 - 200	0.45	0.242
51-2	Moisture separator drain piping	Elbow	STPT38	Water	3 or less	150 - 200	0.45	0.22
52-1	Moisture separator drain piping	Elbow	STPT38	Water	3 or less	100 - 150	0.45	0.161
53-1	Main feedwater piping	Straight pipe	STPT49	Water	3 - 6	150 - 200	0.45	0.213

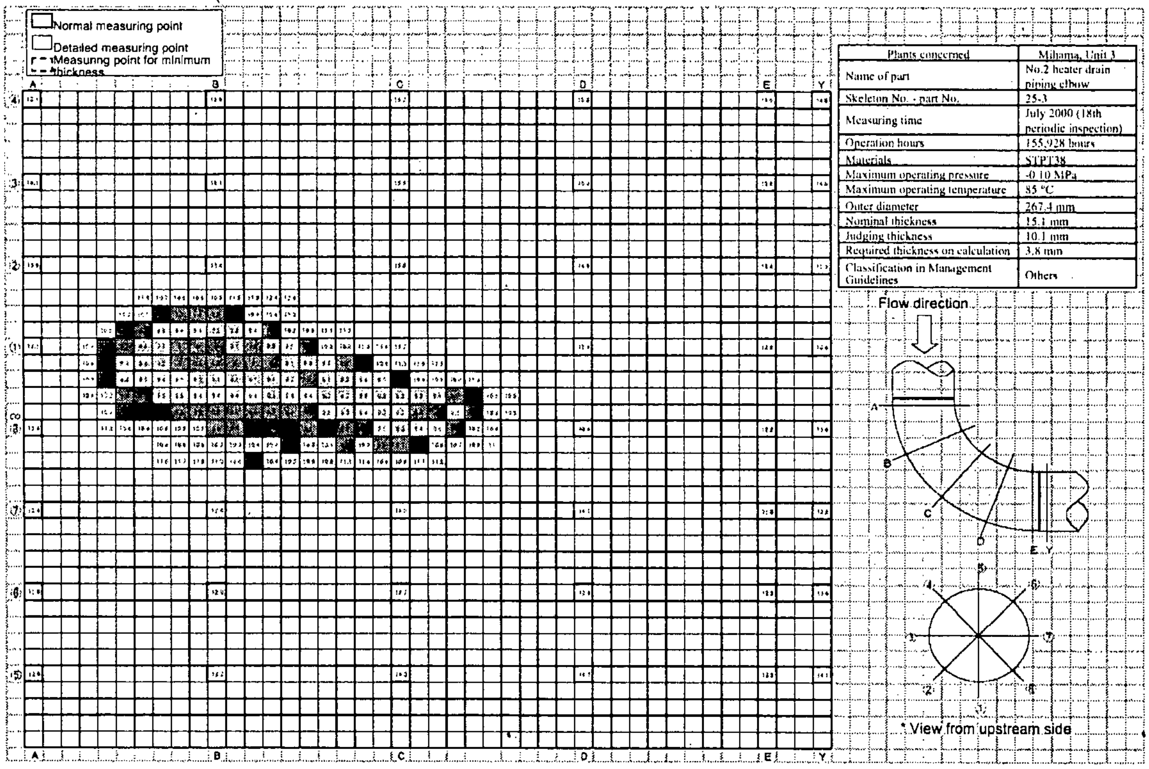
Figure 3 Measurement area and the trend of thinning in Mihama Unit 3 piping



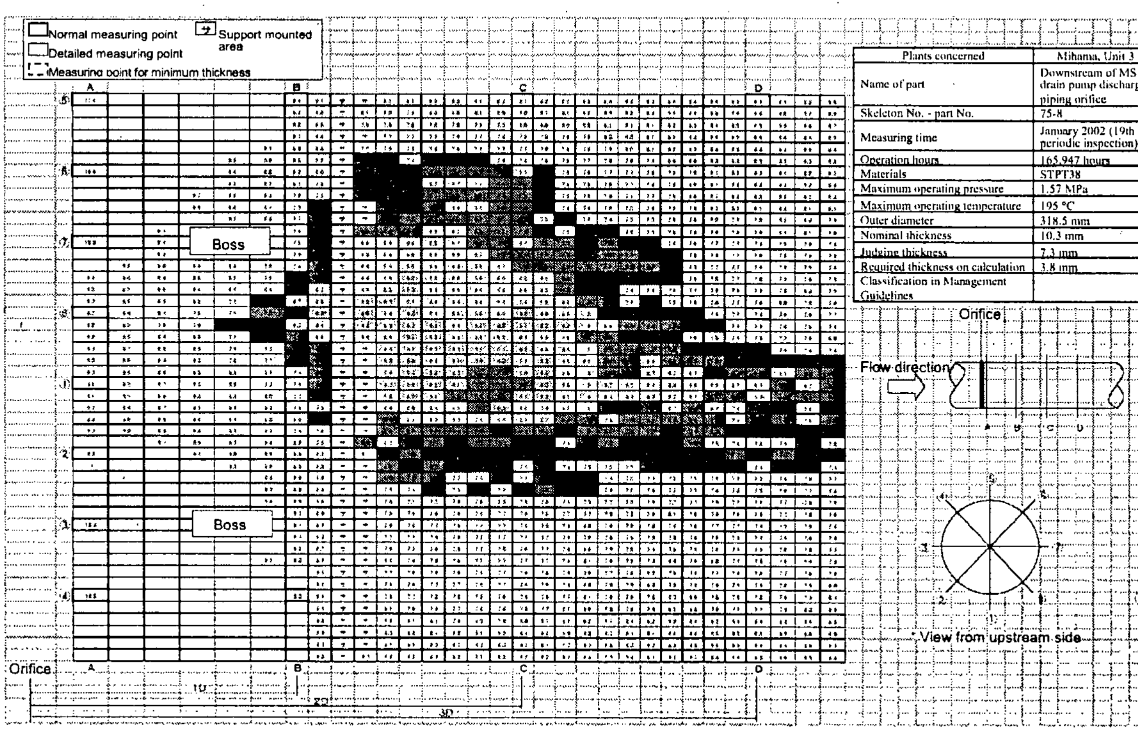
* Elapsed time is the time after an initial inspection.

No.	System	Inspection area	Material	Wetness fraction	Flow velocity (m/s)	Temperature (°C)	Measured thinning rate ($\times 10^{-4}$ mm/hr) mm
1-2	No.3 extracting piping	T pipe	STPT38	5% or less	30 - 50	100 - 150	0.266
15-1	Turbine bypass piping	Reducer	STPT39	5% or less	30 or less	250 or more	0.075
16-5	Turbine bypass piping	Reducer	STPT40	5% or less	30 or less	250 or more	0.024
17-2	Moisture separator heater steam piping	Elbow	STPT41	5% or less	30 - 50	250 or more	0.02
19-1	Moisture separator heater steam piping	Elbow	STPT42	5% or less	30 - 50	250 or more	0.135
20-7	Moisture separator heater steam piping	Reducer	STPT43	5% or less	30 - 50	250 or more	0.032
23-1	Deaerator heater steam piping	Elbow	STPT44	5% or less	30 or less	250 or more	0.203
25-3	No.2 heater drain piping (Downstream of control valve)	Elbow	STPT45	15% or more	30 or less	100 or less	0.438
25-6	No.2 heater drain piping (Downstream of control valve)	Elbow	STPT46	15% or more	30 or less	100 or less	0.334
25-9	No.2 heater drain piping (Downstream of control valve)	Elbow	STPT47	15% or more	30 or less	100 or less	0.327
42-6	Low-pressure drain tank balance piping	Elbow	STPT48	Water	3 or less	100 or less	0.025
65-4	Main steam piping	T pipe	SB42	5% or less	50 or more	250 or more	0.194
66-2	Turbine steam dump piping	T pipe	STPT38	5% or less	30 or less	250 or more	0.101

Figure 4 Comparison of main inspection systems and other systems in Mihama Unit 3

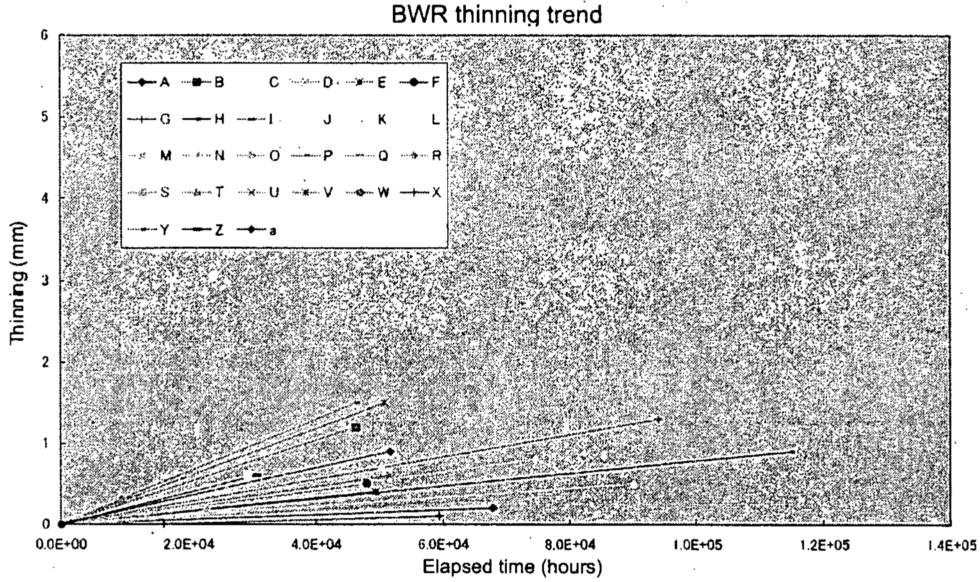


Plants concerned	Mihama, Unit 3
Name of part	No.2 heater drain piping elbow
Skeleton No. - part No.	25-3
Measuring time	July 2000 (18th periodic inspection)
Operation hours	155,928 hours
Materials	STPT38
Maximum operating pressure	-0.10 MPa
Maximum operating temperature	85 °C
Outer diameter	267.4 mm
Nominal thickness	15.1 mm
Judging thickness	10.1 mm
Required thickness on calculation	3.8 mm
Classification in Management Guidelines	Others



Plants concerned	Mihama, Unit 3
Name of part	Downstream of MS drain pump discharge piping orifice
Skeleton No. - part No.	75-8
Measuring time	January 2002 (19th periodic inspection)
Operation hours	165,947 hours
Materials	STPT38
Maximum operating pressure	1.57 MPa
Maximum operating temperature	195 °C
Outer diameter	318.5 mm
Nominal thickness	10.3 mm
Judging thickness	7.3 mm
Required thickness on calculation	3.8 mm
Classification in Management Guidelines	

Figure 5 Measured results of Mihama Unit 3 (example)



* Elapsed time is the time after an initial inspection.

No.	Inspection part	Material	Temperature (°C)	Flow velocity (m/s)	Wetness fraction	Thinning rate (×10⁻⁴ mm/Hr)
A	Reactor feedwater pump inlet elbow	SB49	114	3.1	Water	0.10
B	Moisture separator drain line elbow	STPT42	194	0.4	Water	0.26
C	Downstream of condensate cleanup line orifice	STPT38	34	6	Water	0.16
D	Downstream of M/DRFP outlet line valve	STPT49	196	6.3	Water	0.02
E	Feedwater heater drain line elbow	STPT38	113	5.6	Water	0.08
F	Straight piping at downstream of feedwater recirculation line orifice	SB49	34	4.3	Water	0.10
G	HPCP suction line elbow	SB46	33	2	Water	0.14
H	M/DRFP suction header line T pipe	SB49	190	4	Water	0.08
I	M/DRFP mini-flow valve after valve downstream elbow	STPT49	145	5	Water	0.04
J	No.3 feedwater heater outlet line straight pipe	SB42	144	5	Water	0.01
K	M/DRFP mini-flow piping orifice upstream safe end	A105	190	5.2	Water	0.14
L	M/DRFP mini-flow valve downstream reducer	SF50A	144	5.1	Water	0.08
M	Condensate pump discharge flow rate regulating valve downstream reducer	STPT38	60	1.3	Water	0.04
N	T/DRFP discharge piping elbow	SB49	145	5.4	Water	0.05
O	T/DRFP mini-flow line FCV downstream	STPT49	145	5.1	Water	0.30
P	High pressure drain pump seal water regulating valve downstream elbow	STPT370	43	1.8	Water	0.05
Q	Main steam stop valve outlet straight pipe	STPT42	277	39.3	0.4%	0.05
R	T/DRFP outlet elbow	STPT42	158	4.7	Water	0.05
S	Feedwater pump recirculation line condenser return area straight pipe	STPT49	160	6.6	Water	0.02
T	Condensate pump outlet straight pipe	SM41A	33	1.2	Water	0.10
U	Condensate system orifice downstream straight pipe	STPT38	65		Water	0.11
V	Extracting system reducer	SB46	207		1.5% or more	0.30
W	Feedwater system flow nozzle downstream straight pipe	SB480	231		Water	0.31
X	Downstream of extracting system T pipe	SB42B	193	43	Water	0.05
Y	Feedwater heater inlet elbow	SM50A	98	4.5	Water	0.40
Z	Drain system cap	SM41A	40		1.5% or more	0.20
a	Condensate system elbow	STPT49	70		Water	0.18

Averaged thinning rate: 0.13×10^{-4} mm/Hr

Figure 6 Measured parts of thinning and its trend of BWR piping

Appendix 8

General description of thinning phenomenon of main feed water piping of Ohi Power Station, Unit 1

On July 5, 2004, measurement of thickness of main feedwater piping (carbon steel) connected to the steam generator at KEPCO, Ohi Power Station, Unit 1 (PWR, rated electric output of 1,175,000 kW) under periodic inspection revealed that the thickness of piping elbows at three lines in four lines was partially thinner than the thickness required on calculation (subject of report based on the law.)

Visual inspection of the inside of cut-off piping shows that no abnormality such as cracks or corrosion, etc. occurred, but thickness decreased with fish scale-like patterns characteristic of erosion/corrosion on the entire region. Analysis for flow condition at the elbow and its upstream main feedwater isolation valve (globe valve) reveals that the flow disturbance that occurred inside the piping was further intensified, potentially causing erosion/corrosion.

In 1989 and 1993, the elbow area concerned was inspected in the self-controlled inspection by KEPCO to detect the trend of thinning, but since then the area had not been inspected until the periodic inspection this time.

KEPCO decided to take the following countermeasures considering the above findings.

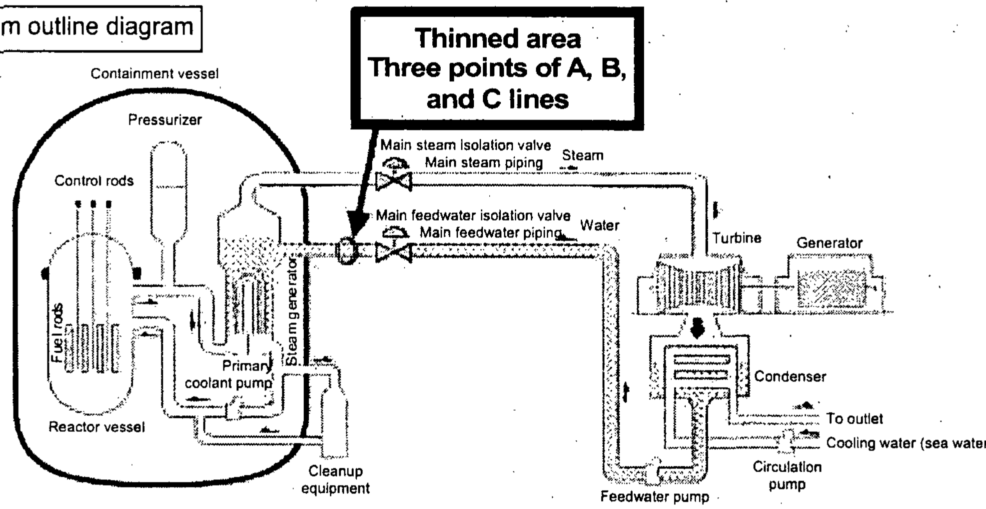
1) To replace the elbow area concerned with piping manufactured at the same dimensions using the same material.

2) To strengthen, in the future, monitoring of thinning trends at the areas concerned including Ohi Power Station, Unit 2 with the same type of main feedwater isolation valve, and to take the same countermeasures for areas with the potential to generate significant thinning at the main feedwater system, including at other plants.

3) To review the total maintenance management system mainly for issues clarified this time regarding the maintenance management and to take measures based on the results.

This thinned area belongs to the water piping operated at 230°C, so it is classified into "other systems" in the PWR Management Guidelines. "Other systems" require inspection on a sampling basis. The thinning phenomenon causes a need to review the PWR Management Guidelines regarding whether the sampling inspection requirement is adequate for "other systems" and how to manage the D system, because no significant thinning was detected in the D system, which has the same structure and environment as the area concerned.

System outline diagram



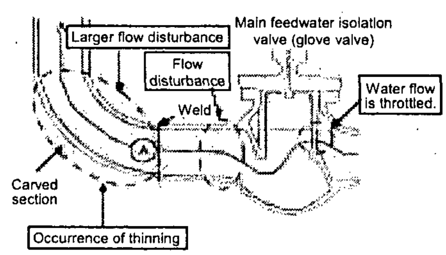
Measurement results

Piping shape	Required thickness on calculation	Measured minimum thickness
A main feedwater piping curved section (45°)	15.7 mm	14.5 mm
B main feedwater piping curved section (90°)		12.1 mm
C main feedwater piping curved section (90°)		13.9 mm
D main feedwater piping curved section (90°)		20.0 mm

Piping specification

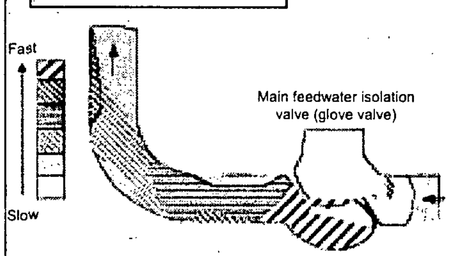
Outer diameter: about 410 mm
Thickness: about 21 mm
Maximum internal pressure: about 8 MPa
Maximum temperature: about 230°C
Material: Carbon steel pipe
Flow rate: about 1,700 t/h, loop

Thinning mechanism



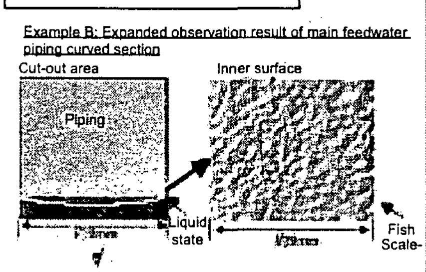
It was confirmed that the flow disturbance that occurred at the inside of the main feedwater isolation valve (globe valve) was further intensified at the piping curved section to potentially cause erosion/corrosion.

Flow pattern analysis



It was confirmed that flow was disturbed downstream of the main feedwater isolation valve to potentially cause erosion/corrosion.

Enlarged view of "A" area



Fish Scale-like pattern typically appearing in erosion/corrosion leading to thinning

Figure Investigation results of thinning at secondary system main feedwater piping elbow area at Ohi Power Station, Unit 1

Results of verification by NISA for the reports of control situation of piping thinning from electric power companies

		Number of inspection areas concerned	Number of areas applying thinning control		Number of areas missing inspections	Remarks
		After confirmation based on instruction (*1)	Inspected (*2)	Already evaluated at typical inspection area, etc. (*3)		
PWR (23 units)	Condensate system	12,027	8,985	3,042	0	Area where accident occurred at Mihama, Unit 3 and the similar area are excluded.
	Feedwater system	7,374	6,761	608	5	Takahama, Unit 3 (5)
	Main steam system	14,376	9,834	4,538	4	Takahama, Unit 3 (2) and Ohi, Unit 3 (2)
	Extracting system	4,357	3,139	1,212	6	Mihama, Unit 3, Takahama, Unit 1, 3, and 4, Ohi, Unit 3 and 4 (1 each)
	Drain system	35,661	28,859	6,802	0	
	Others	7,974	4,356	3,618	0	Steam dump system, SG blow-down, etc. (Some companies counted this system as part of the drain system or main steam system.)
	Subtotal	81,769	61,934	19,820	15(*4)	
BWR (29 units)	Condensate system	34,343	4,815	29,528	0	
	Feedwater system	7,308	2,446	4,862	0	
	Main steam system	7,971	928	7,043	0	
	Extracting system	1,966	326	1,640	0	
	Drain system	14,558	1,213	13,345	0	
	Subtotal	66,146	9,728	56,418	0	
Total		147,915	71,662	76,238	15(*4)	

(*1) "After confirmation based on instruction": Total number of inspection areas after reviewing the inspection area concerned by comparing PWR Management Guidelines.

(*2) "Inspected": Number of areas inspected at reporting time.

(*3) "Already evaluated at typical inspection area, etc.": Number of areas other than typical inspection area and number of areas scheduled in the future among areas adequate for sampling inspection and number of areas using low alloy steel

(*4) "Number of areas missing inspections": Except for the area of Mihama, Unit 3 where the accident occurred, 14 of 15 areas reported to have missed inspections at the time of reporting have now been inspected.

Appendix 10

Pipe wall thickness control at thermal power stations

1. Legal positioning regarding the pipe wall thickness control

Pipe wall thickness measurements at thermal power stations were not subject to the periodic licensee's inspections based on the Electricity Utilities Industry Law. Therefore, until now, some licensees have verified conformance to the technical standards on the pipe wall thickness as part of self-imposed safety preservation.

2. Implementation situation of the pipe wall thickness control by licensees

Regarding thermal power stations, on August 11, 2004, based on Paragraph 3 and 4 of Article 106 of the Electricity Utilities Industry Law, electric licensees, etc., that had thermal power generation facilities (general electric enterprises and joint thermal power structure and captive electric structure establishers, etc.) were requested to make a report on the implementation situation of non-destructive inspections of water and steam pipe wall thickness at the portions where thinning can occur and inspection implementation plans for the portions not subjected to inspections yet.

As a result, by October 19, the inspection implementation plans of pipe wall thickness were submitted by electric licensees, etc. The compiled results are shown in "Table 1. Implementation situation of the inspections for pipe wall thickness at thermal power stations." According to the reports, approximately 487,000 portions among approximately 541,000 portions to be inspected had not been inspected until that time, but all licensees had the plans to conduct inspections and evaluations concerning the pipe wall thickness to verify the safety of piping, and expressed that inspections, etc., would be conducted in sequence.

Table 1. Implementation situation of the inspections for pipe wall thickness at thermal power stations

	Number of the portions to be inspected	Number of the portions that were inspected	Number of the portions that were not inspected
Eleven general electricity licensees	Approximately 166,000 portions	Approximately 14,000 portions	Approximately 152,000 portions
Captive electric structure establishers	Approximately 374,000 portions	Approximately 39,000 portions	Approximately 335,000 portions
Total	Approximately 541,000 portions	Approximately 53,000 portions	Approximately 487,000 portions

3. Responses of NISA

3.1 Addition of the pipe wall thickness control to the periodic licensee's inspections

In consideration of the indications in the interim report, in order to ensure that conformity to the technical standards regarding the pipe thinning phenomena would be continuously verified. NISA decided that the wall thickness inspections on the pipe susceptible to thinning would be added to the objects of the periodic licensee's inspections.

Specifically, in the amendment of the Rules for the Enforcement of the Electricity Utilities Industry Law described in 4.4.1 (1) of this report, the equipment subject to the periodic licensee's inspections was clarified regarding steam turbines, etc., of thermal power generation equipment. In addition, in response to the Rules, the notice that the pipe wall thickness inspections related to thermal power generation equipment would be newly added to the objects of the periodic licensee's inspections will be enforced as of April 1, 2005.

Consequently, in April of 2005 or later, licensees will have to conduct the periodic inspections according to the new notice, and will control the pipe wall thickness based on the plans for pipe wall thickness inspections prepared on their own. Incidentally, the government and registered agencies for the reviews of safety management will verify the implementation system for the periodic licensee's inspections in the safety management reviews.

3.2 Request for establishment of standards to JSME

On a request from NISA, JSME is proceeding with the work of establishing standards (see 4.4.1 (2) in this report) The objects of the work include not only standards for nuclear power plants, but also standards for thermal power plants. In the past, regarding thermal power plants, common technical guidelines for the pipe wall thickness control were not prescribed. Some licensees defined their own self-imposed management policies. However, most licensees inspected only a small portion of the piping based on the past troubles of other power plants.

In addition, many licensees of thermal power plants make implementation plans for inspections by using the PWR Management Guidelines as reference. However, unlike nuclear power plants, thermal power plants have a variety of operating conditions, such as responses to base load and peak load, and suffer different temperature and pressures. Therefore, it is necessary to collect data on measurement results obtained under inspection execution plans of each licensee to a neutral organization, analyze the data, and develop technical guidelines for appropriate pipe wall thickness control at thermal power plants.

JSME established a functional standard concerning the pipe wall thickness control on March 16, 2005, and intends to establish a technical standard as soon as possible in the future.

Appendix 11

Ministry of Economy, Trade and Industry

February 16, 2005, Gen-in No. 1
February 18, 2005

Requirements for pipe wall thickness control at nuclear power stations

Nuclear and Industrial Safety Agency
NISA-163a-05-1

In response to the interim report concerning the "secondary piping rupture accident at Mihama Power Station, Unit 3, of the Kansai Electric Power Co., Inc." that occurred on August 9, 2004, the Nuclear and Industrial Safety Agency (hereinafter called NISA) amended a portion of the Rules for the Enforcement of the Electricity Utilities Industry Law (the ministerial ordinance of Ministry of International Trade and Industry, No. 77, 1995) as of December 28, 2004, as measures for preventing a recurrence of the accident, and clarified the legal positioning of pipe wall thickness measurements at boiling water nuclear power plants and pressurized water nuclear power plants (hereinafter called "BWR plants" and "PWR plants," respectively) as inspections that should be conducted as periodic licensee's inspections based on Article 55 of the Electricity Utilities Industry Law.

In association with the amendment of the Rules for the Enforcement of the Electricity Utilities Industry Law, NISA laid down the items concerning the selection of locations subject to inspections, the selection of measuring points, the determination of the timing for the implementation of inspections, the measures that should be conducted depending on the calculated remaining life, etc., on the occasion of the implementation of the pipe wall thickness control, which was entrusted to licensees in the past, with which each licensee should comply on the occasion of the implementation of the inspections. In addition, NISA decided to request licensees to comply with the items.

Incidentally, this request is positioned as a provisional measure to be applied until the Japan Society of Mechanical Engineers establishes technical standards concerning the pipe wall thickness control of nuclear power generation equipment and then the technical standards is positioned as criteria after NISA technical evaluations.

1. Selection of locations subject to inspections

As for the locations that fall under 1. (1) among the pipes subject to the control of periodic licensee's inspections, conduct inspections properly in accordance with the rules from 2. to 4.

In addition, as for the locations that do not fall under 1.(1), conduct inspections properly in accordance with the rule of 5, which is also applied to the locations that fall under 1. (1).

(1) Locations

As for locations that are affected by channeling flow, including areas downstream from an orifice, areas downstream from a control valve or a flow regulating valve, areas downstream from a globe valve, areas downstream from a globe check valve, areas downstream from a swing check valve, elbows, T-tubes, reducers, and bent pipes, select locations where the significant progress of thinning is forecast to occur due to erosion, corrosion, the interaction between them, etc., as locations subject to inspections, in consideration of existing engineering knowledge concerning the temperature, the flow rate, and the condition (a single-phase flow or a two-phase flow) of the fluid that flows inside a pipe, frequency of use of such locations, the control guidelines that were adopted so far by each licensee, actual thinning experiences included in the past failures and troubles, degradation, failure modes, etc.

If locations subject to inspections were selected by a narrowing down method before this document issuance, verify their adequacy again by using Attachment 1 as reference. There is possibility that the degrees of thinning vary even among the locations where environmental conditions (temperature, wetness fraction, flow velocity, dissolved oxygen concentration, etc.) and structural conditions (inside diameters, wall thicknesses, materials, etc.) and other conditions seem to be similar. Therefore, when locations subject to inspections are selected as representatives (representative locations), verify the adequacy of the selection cautiously by making comprehensive judgments in consideration of the layout of upstream and downstream pipes of a location where channeling flow occurs and other factors.

However, when locations subject to inspections are selected by a narrowing down method and the calculated remaining life of a representative location becomes 5 years or less, select all locations as the objects of inspections without narrowing down.

In addition, as for locations where the significant progress of thinning is forecast to occur on the basis of existing engineering knowledge, including past failures record, actual operating experience of troubles, degradation and failure modes, etc., select all locations as the objects of inspections without narrowing down.

Incidentally, as for the selection of locations subject to inspections from the pipes subject to control, in order to verify the adequacy of such selected locations, inspect locations other than the selected locations subject to inspections as needed.

(2) Materials

Carbon steel, low alloy steel, stainless steel

(3) Reexamination of locations subject to inspections

As a result of inspections, if it is determined that a reexamination is necessary, reexamine locations subject to inspections as soon as possible.

2. Determination of measuring points

When measuring points concerning locations subject to inspections are determined, classify each case into "cases where measurement is conducted to determine whether there is a thinning tendency (normal measurement)" and "cases where measurement is conducted to determine the progress of thinning in case the occurrence of thinning is confirmed by a normal measurement (detailed measurement)," and comply with the following:

(1) Grasping whether there is a thinning tendency (normal measurement)

1) For PWR plants

When measuring points are determined, comply with Attachment 2 "Regarding the determination of measuring points depending on the structure of a location to be measured."

A. Circumferential direction

Determine the number of measuring points depending on the inside diameter of a pipe as follows, and ensure that the measuring points are at nearly equal spacing in a circumferential direction.

Nominal diameter of a pipe	Number of measuring points
5 inches or less	No fewer than 4 points
Over 5 inches	No fewer than 8 points

B. Axial direction

For the areas downstream from an orifice, determine suitable measuring points within the range from the installation location of an orifice to up to 3 times the nominal pipe diameter.

For other locations that are considered to be affected by channeling flow (areas downstream from a control valve or a flow regulating valve, areas downstream from a globe valve, areas downstream from a globe check valve, elbows, T-tubes, areas downstream from a swing check valve, reducers, bent pipes, etc.), determine suitable measuring points within the range from the area where channeling flow occurs to up to twice the nominal pipe diameter.

2) For BWR plants

When measuring points are determined, comply with Attachment 2 "Regarding the determination of measuring points depending on the structure of a location to be measured."

A. Circumferential direction

Determine the number of measuring points depending on the inside diameter of a pipe as follows, and ensure that the measuring points are at nearly equal spacing in a circumferential direction.

Nominal diameter of a pipe	Number of measuring points
5 inches or less	No fewer than 4 points
Over 5 inches	No fewer than 8 points, or a measuring pitch of not more than 100 mm

B. Axial direction

Where the inside diameter of a pipe is 5 inches or less, within the range from the area where channeling flow occurs to up to 300 mm, ensure that the measuring pitch is the shorter of twice the inside diameter of the pipe and 100 mm. Beyond the range, determine suitable measuring points in accordance with Attachment 2.

Where the inside diameter of a pipe is over 5 inches, within the range from the area where channeling flow occurs to up to 500 mm, ensure that the measuring pitch is the shorter of twice the inside diameter of the pipe and 100 mm. Beyond the range, determine suitable measuring points in accordance with Attachment 2.

Incidentally, it is acceptable to measure at narrower pitches than the above.

(2) Determining the progress of thinning (detailed measurement)

When a measuring point, where thickness is less than the following criterion, is found as a result of normal measurement, determine measuring points at narrower pitches (approximately 20 mm as a criterion) in a grid pattern whose center is the measuring point where thickness is less than the criterion, in order to grasp the range where the thickness is less than the criterion.

Criterion of thickness = minimum necessary thickness + (minimum thickness of pipe manufacturing - minimum necessary thickness) × 2/3

When the criterion of thickness is determined, use the "minimum necessary thickness" prescribed in "Technical Standards on Structure, etc., of Nuclear Power Generation Facilities," "Ordinance of Establishing Technical Standards on Thermal Power Generation ," and "Interpretation of Technical Standards on Thermal Power Generation " as a minimum necessary thickness. In addition, for a "minimum thickness of pipe manufacturing," use the value that is obtained by subtracting a tolerance from a nominal thickness.

3. Determination of timing for the implementation of inspections

(1) For PWR plants

For timing for the implementation of inspections, where the remaining life obtained by Attachment 3 "Evaluation method of the remaining life of piping" is 5 years or more, comply with the following.

However, when the calculated remaining life is below 5 years in all the following cases, comply with "4. Measures that should be conducted depending on the calculated remaining life." In addition, for locations where it is necessary to strengthen the monitoring in consideration of existing engineering knowledge, including past inspection results, actual thinning experiences included in the past failures and troubles, degradation and failure modes, etc., increase the frequency of inspections regardless of the following.

1) Timing of the first inspection

For the first inspection, the timing for the implementation of the first inspection shall be set up as prior to the time that the remaining life calculated by using the initial thinning rate of "Guidelines for Secondary Piping Wall Thickness Control at Nuclear Facilities (PWR)" prescribed on the basis of past records, etc., becomes 5 years,

When it is difficult to determine the initial thinning rate based on the past records, etc., the first inspection shall be performed as soon as possible. Then, based on the remaining life obtained by Attachment 3 "Evaluation method of the remaining life of piping," the timing for the implementation of the next inspection shall be set up as prior to the time that the remaining life becomes 5 years.

When the calculated remaining life is supposed to become below 5 years during the next operating cycle, the timing for the implementation of the inspections shall be set up as at the next periodic licensee's inspections.

2) Timing of the second or a later inspection

Regarding the timing of the second inspection, the timing of the next inspection shall be set up as prior to the time that the remaining life, which is calculated by using the first inspection results and the method described in Attachment 3 "Evaluation method of the remaining life of piping," becomes 5 years.

Regarding later inspections, the timing of the (n+1)-th inspection shall be set up in a similar manner as prior to the time that the remaining life, which is calculated using the n-th inspection results, becomes 5 years.

However, when the calculated remaining life is supposed to become below 5 years during the next operating cycle, the timing for the implementation of the inspections shall be set up as at the next periodic licensee's inspections.

(2) For BWR plants

For timing for the implementation of inspections, where the remaining life obtained by Attachment 3 "Evaluation method of the remaining life of piping" is 5 years or more, comply with the following.

However, when the calculated remaining life is below 5 years in all the following cases, comply with "4. Measures that should be conducted depending on the calculated remaining life." In addition, for locations where it is necessary to strengthen the monitoring in consideration of existing engineering knowledge, including past inspection results, actual thinning experiences included in the past failures and troubles, degradation and failure modes, etc., increase the frequency of inspections regardless of the following.

1) Timing of the first inspection

The location subject to inspections (representative locations) (Note 1) shall be inspected within a certain period (approximately 5 years) since the piping was put into service.

(Note 1) Representative locations include the locations that are selected as locations subject to inspections because the significant progress of thinning is forecast to occur, in consideration of existing engineering knowledge, including past inspection results, actual thinning experiences included in the past failures and troubles, degradation and failure modes, etc.

2) Timing of the second or a later inspection

Regarding the timing of the second inspection, where the remaining life calculated with the first inspection results is over 5 years, the timing of the next inspection shall be set up at either of the time that the remaining life calculated by using the method described in Attachment 3 "Evaluation method of the remaining life of piping" becomes 5 years or the time that half of the remaining life passes (Note 2), which is earlier.

Regarding later inspections, the timing of the (n+1)-th inspection shall be set up in a similar manner as prior to the time that the remaining life, which is calculated using the n-th inspection results, becomes 5 years.

However, when the calculated remaining life is supposed to become below 5 years during the next operating cycle, the timing for the implementation of the inspections shall be set up as at the next periodic licensee's inspections.

(Note 2) The reason why the time that half of the remaining life passes is added as the timing for the implementation of inspections is that it is necessary to immediately reexamine the locations subject to inspections on the basis of inspection results because the locations subject to inspections are selected by a narrowing down method at first in BWR plants.

4. Measures that should be conducted according to the calculated remaining life

In order to ensure the integrity of piping, it is necessary to take measures like replacement of pipes deliberately in advance to some extent. Therefore, take measures described in the following table according to the remaining life calculated on the basis of Attachment 3 "Evaluation method of the remaining life of piping."

However, in case of a narrowing method used for selection of locations subject to inspections, after the calculated remaining life of a representative location becomes 5 years or less, take measures described in the following table for all locations subject to inspections and similar locations without narrowing down.

Table: Measures that should be taken according to the calculated remaining life

Calculated remaining life	Measures that should be taken
Not less than 5 years	According to the remaining life, determine the timing for the next inspection.
Less than 5 years, but not less than 2 years	Make the pipes replacement plan, and conduct inspections at each periodic licensee's inspection until the replacement carried out.
Less than 2 years, but not less than 13 months	Replace pipes during the next coming periodic licensee's inspection.
Less than 13 months	Replace pipes during the said periodic licensee's inspection.

5. Preparation of a medium-term plan for inspections

In order to conduct adequately the wall thickness control on pipes subject to the control of periodic licensee's inspections, prepare a medium-term plan (10 years) and conduct inspections.

In particular, also for the locations in PWR plants that are categorized as "others" in "Guidelines for Secondary Piping Wall Thickness Control at Nuclear Facilities (PWR)" and the locations in BWR plants that are not representative locations, prepare a medium-term plan and conduct inspections based on the plan.

6. Starting date to apply this document

Apply the piping wall thickness control based on this document for the first periodic licensee's inspection after this document issuance.

However, "5. A medium-term plan for inspections" shall be prepared within 6 months after this document issuance.

Practical examples of narrowing down locations subject to inspections

(1) Where one line branches into two or more lines with the same configuration in parallel in one system, select one or more lines at random from among those lines. (See Figure 1)

For plural lines in parallel where environmental conditions (temperature, wetness fraction, flow velocity, dissolved oxygen concentration, etc.) and structural conditions (pipe inside diameter, wall thickness, material, etc.) are equal and also the route shape of pipes, configuration, etc., are similar, select one or more lines from among those lines as a line subject to inspections supposing that the turbulent conditions of flows in pipes are considered to be the same.

(2) For multiple locations subject to inspections where environmental conditions and structural conditions are equal, select one or more locations at random from among those locations. (See Figure 2)

For multiple locations subject to inspections where environmental conditions (temperature, wetness fraction, flow velocity, dissolved oxygen concentration, etc.) and structural conditions (pipe inside diameter, wall thickness, material, etc.) can be equated, for example, multiple locations subject to inspections that are placed on the same line, select one or more locations from among those locations as a location subject to inspections supposing that the turbulent conditions of flows in pipes are considered to be the same.

(3) Where it can be judged that the environmental conditions and structural conditions of one location are more severe than those of other locations, select such a location as a location subject to inspections. (See Figure 3)

Where it can be judged that the thinning conditions of one location are more severe than those of other locations among multiple locations subject to inspections on different lines in the same plant in consideration of environmental conditions (temperature, wetness fraction, flow velocity, dissolved oxygen concentration, etc.) and structural conditions (pipe inside diameter, wall thickness, material, etc.), select the said location as a location subject to inspections.

Figure 1 Practical example 1 of narrowing down locations

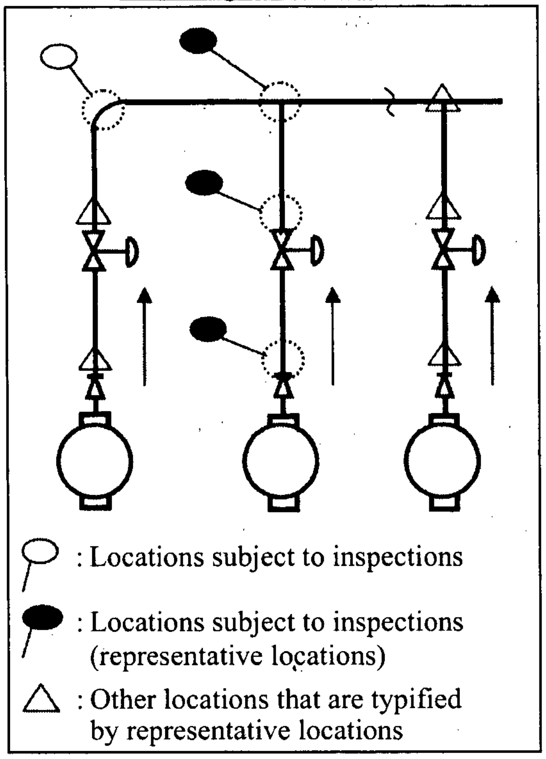


Figure 2 Practical example 2 of narrowing down locations

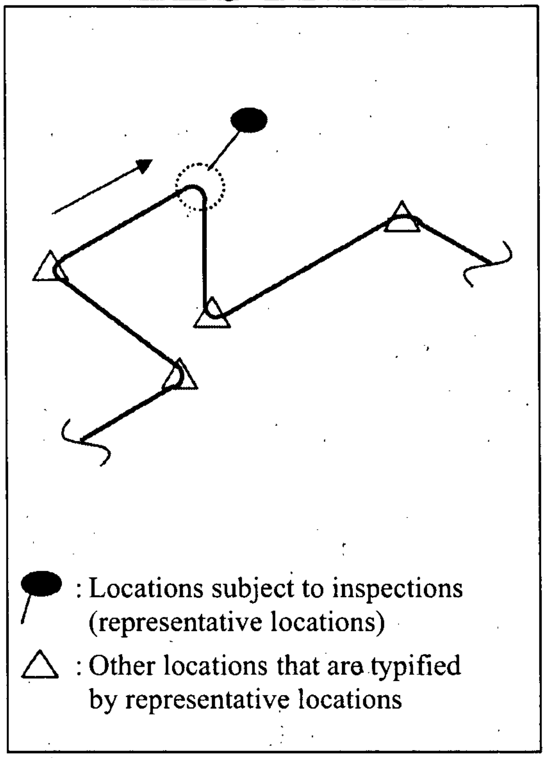
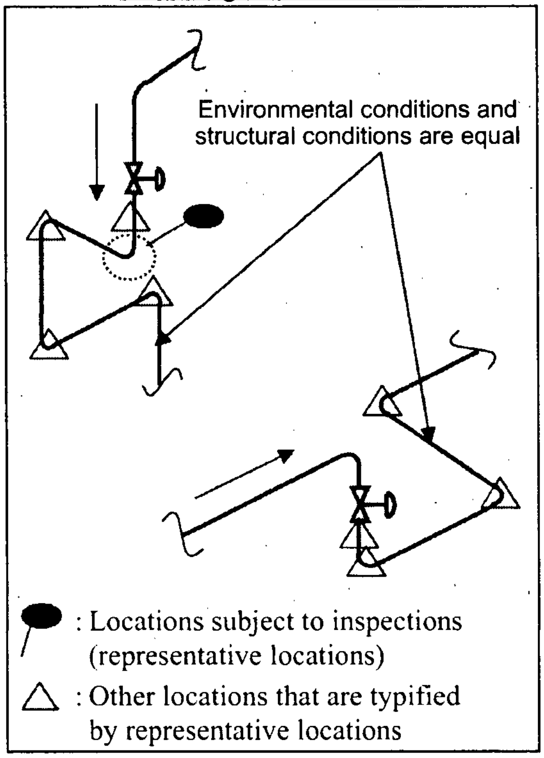
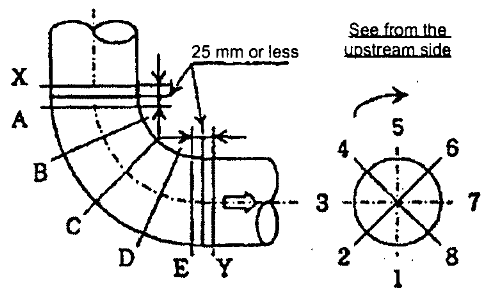


Figure 3 Practical example 3 of narrowing down locations

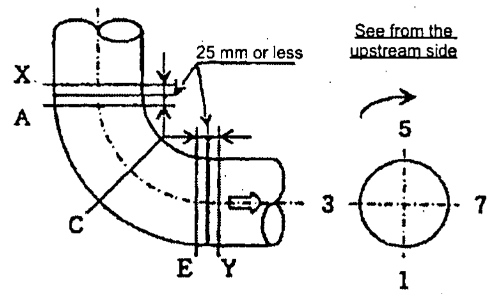


Determination of measuring points according to the structure of the location to be measured

(1) 90-degree elbow <over 5 inches>

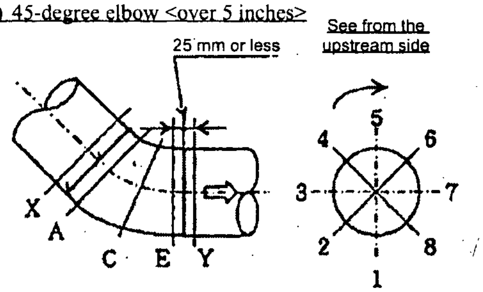


<5 inches or less>

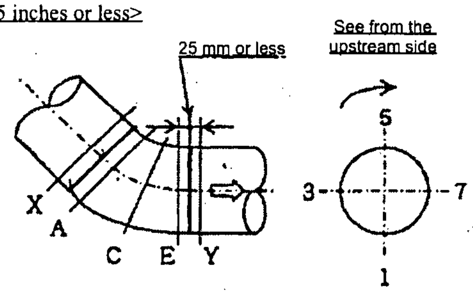


(Note) If an abnormality was found on the A side in the vicinity of a weld line or can be predicted, measure the upstream pipe X.

(2) 45-degree elbow <over 5 inches>

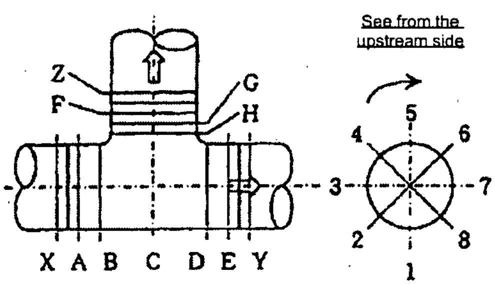


<5 inches or less>

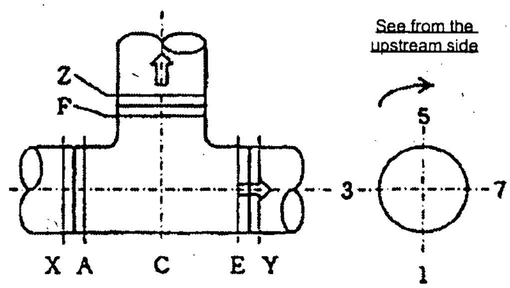


(Note) If an abnormality was found on the A side in the vicinity of a weld line or can be predicted, measure the upstream pipe X.

(3) Tee (T-tube) <over 5 inches>

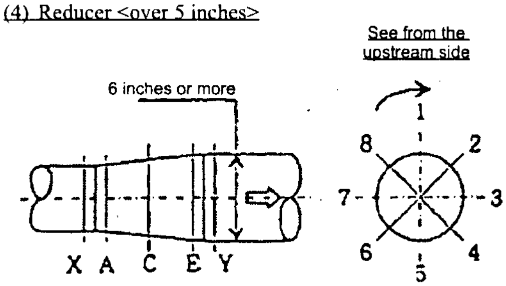


<5 inches or less>

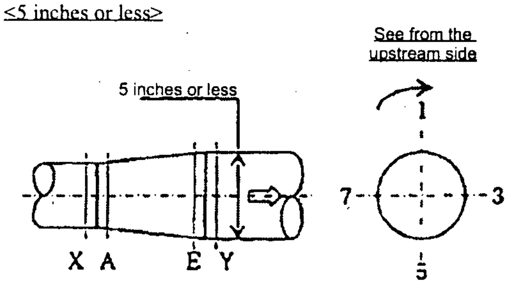


(Note) If an abnormality was found on the A side in the vicinity of a weld line or can be predicted, measure the upstream pipe X.

(4) Reducer <over 5 inches>



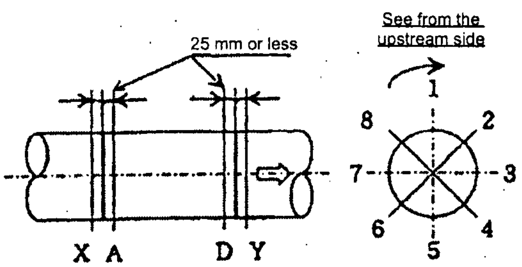
<5 inches or less>



(Note) If there is an elbow or a tee in the vicinity, define its position on the back side as starting point 1. Take the same steps as in section (1) for X.

Determination of measuring points according to the structure of the location to be measured

(5) Straight pipe, short pipe <over 5 inches>



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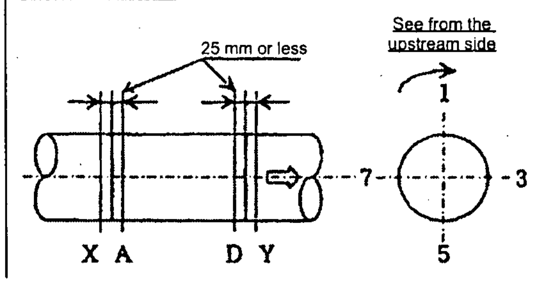
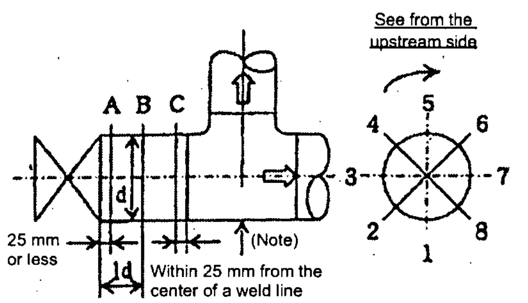
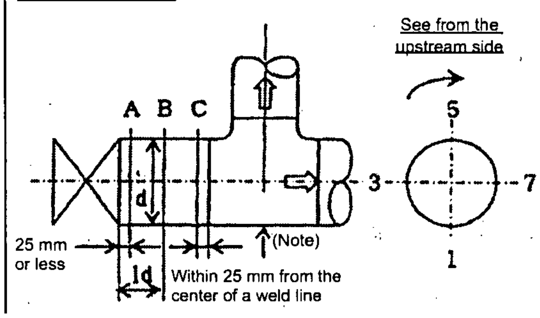


(Note) Take the same steps as in section (4) Reducer. However, if there is no elbow and no tee, define the position described above as starting point 1. Take the same steps as in section (1) for X.

(6) Straight pipe downstream from a valve <over 5 inches>

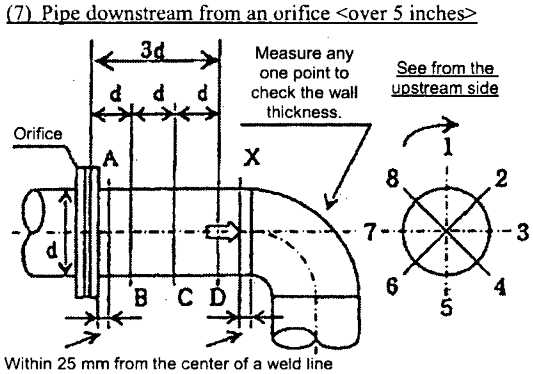


<5 inches or less>

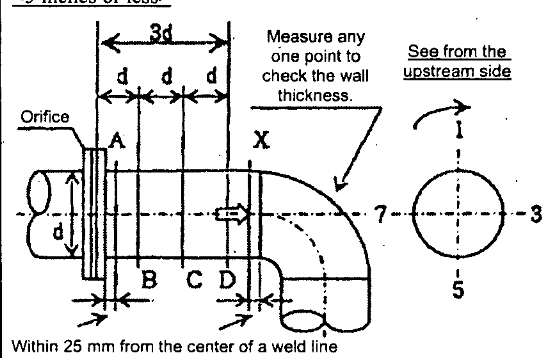


(Note) If there is a tee on the downstream side of a valve, measure any one point to check the wall thickness.

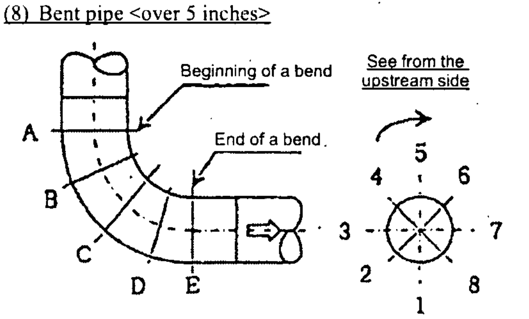
(7) Pipe downstream from an orifice <over 5 inches>



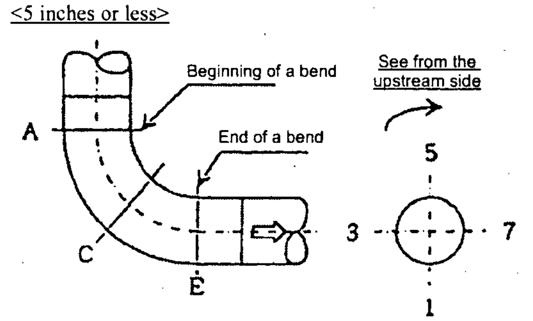
<5 inches or less>



(8) Bent pipe <over 5 inches>



<5 inches or less>



Evaluation method of the remaining life of piping

When the remaining life of a certain measuring location of piping is evaluated, the remaining life calculated from a combination of the maximum value (maximum thinning rate) among thinning rates at all measuring points of the location in question and the minimum value (minimum wall thickness) among wall thicknesses at all measuring points of the location in question is defined as the remaining life of the location in question.

(1) Calculation method of a thinning rate

Depending on the number of measurements from the commencement of service of the pipe in question to the measurement in question, calculate a thinning rate in the following manner:

a. At the time of the first measurement (nominal wall thickness method)

From the difference between the nominal wall thickness and the wall thickness at the first measurement and the operating time, determine a thinning rate [mm/hr] for every measuring point by using the following formula:

Thinning rate [mm/hr]
= (nominal wall thickness - wall thickness at the first measurement) [mm]
/ (operating time from the installation to the first measurement) [hr]

However, if a wall thickness was measured before the commencement of service, substitute the value measured before the commencement of service for the nominal wall thickness and calculate it.

b. At the time of the second measurement

From the difference between the wall thickness at the first measurement and the wall thickness at the second measurement and the operating time, determine a thinning rate [mm/hr] for every measuring point by using the following formula:

Thinning rate [mm/hr]
= (wall thickness at the first measurement
- wall thickness at the second measurement) [mm]
/ (operating time from the first measurement to the second measurement) [hr]

However, if a wall thickness was measured before the commencement of service, use the least squares method described in section c., and calculate it by using measured values, including the value measured before the commencement of service.

c. At the time of the third or a later measurement (least squares method)

Determine a thinning rate [mm/hr] for every measuring point by using the least squares method (primary expression) and the measured wall thicknesses and each operating time from the first measurement to the measurement in question.

However, if a wall thickness was measured before the commencement of service, calculate it by using measured values, including the value measured before the commencement of service.

(2) Calculation method of a remaining life

Calculate a remaining life for every measuring location by using the following formula:

Remaining time [hr]
= (minimum measured wall thickness at the time of the measurement in question
- minimum necessary thickness) [mm] / (maximum thinning rate) [mm/hr]

Remaining life [years] = remaining time [hr] / 8,760 [hr]

However, if the thinning rate obtained in (1) is zero, do not calculate the remaining time. If the remaining time is over one million hours, do not evaluate the remaining life.

(Note 1) As for the remaining life used for the determination of the timing for the implementation of the first inspection in PWR plants, calculate it in the following manner:

Remaining time [hr]
= (minimum thickness of pipe manufacturing
- minimum necessary thickness) [mm] / initial thinning rate [mm/hr]

Remaining life [years] = remaining time [hr] / 8,760 [hr]

For an "initial thinning rate," use the value that was set for each location in consideration of past records, etc.
However, if a wall thickness was measured before the commencement of service, substitute the value measured before the commencement of service for the "minimum thickness of pipe manufacturing," and calculate it.

(Note 2) In case the locations of thin-wall parts arising from a manufacturing process, such as welding grooves, are clear, it is acceptable to use the measured data of appropriate points other than the measuring points in question of the locations in question.

Appendix 12

Ministry of Economy, Trade and Industry

September 22, 2004, Gen No.7
September 27, 2004

The Kansai Electric Power Co., Inc.
Mr. Yousaku Fuji, President

Regarding the occurrence of the accident caused by the dysfunctional quality assurance system, etc., our ministry severely reprimands your company responsible for the assurance of the safety of nuclear power stations.

Since the last year revision of systems, our ministry has demanded thorough development of the quality assurance system from all nuclear licensees. As a result of the periodic safety management review conducted to verify the quality assurance system of your company under the new system, it was judged that "there are minor non-conformances, but the quality assurance system is functioning" for Mihama Power Station, Unit 1, Takahama Power Station, Unit 3, and Ohi Power Station, Unit 2, of your company. However, in consideration of the recently-found problems, our ministry annulled the judgment, and newly judged that "there are major non-conformances, and the quality assurance system is not functioning." Our ministry strongly demands that your company should review your company's quality assurance system and should resolve the above problems related to systems in order to prevent such accidents.

In addition, our ministry takes the long-term nonobservance of technical standards for secondary piping in Mihama Power Station, Unit 3, seriously and issues a technical standard conformance order to your company. Therefore, our ministry orders the suspension of the use of electric facilities until our ministry confirms conformance to the standards.

Our ministry demands that your company should feel deeply responsible for the accident and should develop effective recurrence prevention measures in consideration of the above indications and actions, and then should report the measures to our ministry by the end of this fiscal year.
In addition, in order to verify the efforts of your company to improve the quality assurance system, etc., our ministry will temporarily adopt administrative measures (see Attachment), which are the implementation of a special safety inspection and the strict implementation of a periodic safety management review.

Incidentally, our ministry is continuing to investigate the accident. Therefore, if new facts are found, our ministry will again adopt the necessary measures as a matter of course.

(Attachment)

1. Implementation of a special safety inspection

All nuclear power plants of your company will be subject to the priority inspections of safety inspections by the government based on Paragraph 5 of Article 37 of the Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors. Specifically, a special safety inspection will be conducted with particular emphasis on the maintenance management, including the thinning control of secondary piping, which your company conducted as a self-imposed inspection in the past, and the actual conditions of subcontract management (procurement control) for affiliated companies on the occasion of the said maintenance management.

In addition, various measures clarified in the recurrence prevention measures to be submitted by your company will be verified in a special safety inspection.

2. Strict implementation of a periodic safety management review

For electric facilities in each nuclear power station of your company, on the occasion of the implementation of a periodic safety management review to be conducted by Japan Nuclear Energy Safety Organization (hereinafter called JNES) based on Paragraph 4 of Article 55 of the Electricity Utilities Industry Law, our ministry will order JNES to conduct the review temporarily with emphasis on the inspection items that were positioned as a self-imposed inspection in the past. On that occasion, our ministry will demand that JNES should increase the number of items subject to sampling in comparison with normal reviews and should strictly conduct a periodic safety management review regarding the implementation system of periodic inspections by your company.

In addition, regarding recurrence prevention measures to be submitted by your company, the state of the implementation of relevant items will be verified properly.

Appendix 13

Requirements necessary for establishment of concrete recurrence prevention measures

March 14, 2005
Nuclear and Industry Safety Agency

The Kansai Electric Power Co., Inc., submitted a report regarding recurrence prevention to NISA on March 1, 2005. NISA presented the interim evaluation result of the report at the accident investigation committee on March 3. In the evaluation result, NISA indicated that an action program that fully took feasibility into account should be presented because a concrete process toward the realization of the recurrence prevention measures presented by the Kansai Electric Power Co., Inc., was not presented.

Because recurrence prevention measures must be able to be implemented adequately and certainly as a company-wide activity, many detailed implementation plans presented by the Kansai Electric Power Co., Inc., are insufficient. In other words, the framework of an action program must be based on the commitment of the top management, and each action must be implemented adequately under the commitment.

For this reason, NISA presented the requirements necessary for establishment of the concrete recurrence prevention measures as follows to the Kansai Electric Power Co., Inc., on March 10. In evaluating the recurrence prevention measures submitted by the Kansai Electric Power Co., Inc., NISA will take the requirements into consideration.

1. Commitment regarding safety

(1) Change the management policy or "assurance of safety takes top priority" into a policy that is feasible depending on the actual conditions of the organization and is easily understandable and clear for each employee when making judgments for executing daily work.

(2) Each item of recurrence prevention measures described in the report may give the impression that it seems to be a please-everyone policy. Therefore, make the commitment of the top management as several types of basic action policies (master plans) in consideration of lessons learned at the accident, regardless of superficial events.

(3) Ensure that basic action policies include the preparation of maintenance plans, items related to safety in an actual process, items related to safety in procurement work and procurement control, items related to accountability concerning nuclear safety inside and outside of the company and outside evaluation, etc. Clarify that each item of recurrence

prevention measures will be adequately implemented in accordance with the above basic action policies.

2. Reallocation of resources to make nuclear workplaces free of pressure

(1) Necessary reallocation of major management resources, including "personnel, things, funds, information, and time," must be continually conducted depending on actual conditions.

(2) On the occasion of an organizational reform, clarify its significance, and set up an adequate organization.

(3) On the occasion of the implementation of periodic inspections, sweep out the work climate where workers on site may have a false impression that processes are placed at the highest priority, for example, 40-day periodic inspections. Ensure the implementation of periodic inspections that "place safety at the highest priority" in order to ensure safety by inspections.

(4) In order to ensure the safety of aging power stations, establish a mechanism that allocates the management resources necessary for power plants fairly and certainly.

3. Actions and declaration of safety standards by each person

(1) Without excessively depending on the self-imposed activities of each worker, establish a mechanism that enables systematic implementation.

(2) Because one-way information provision, including campaigns, posters, and lecture meetings is considered to be a supplementary measure, do not depend on it excessively.

4. Collaboration with plant makers and affiliated companies, and coexistence with local societies

(1) Cooperate with plant makers and other PWR licensees and establish a mechanism that utilizes the technical capabilities and information resources possessed by each company.

(2) As a procurer of maintenance activities, establish a mechanism for creating a high sense of ethics and the improvement of the technical capabilities of affiliated companies, including subcontractors.

(3) Strengthen the disclosure of information to the surrounding areas of power stations.

5. Mechanism for ensuring the implementation of action plans

(1) In order to ensure a steady implementation of basic action policies, set the timing for the implementation adequately, depending on the urgency and importance, and on the capability of the current organization. At the end of the 2005 fiscal year, evaluate the state of the implementation of the plans prepared on this occasion, and improve problems. In addition, repeat this process also in the next fiscal year and later fiscal years, and continuously improve the problems.

(2) Establish a mechanism that enables periodic evaluations with transparency. For example, it is advised that the state of the implementation of the action plans be evaluated by a working committee that consists of external knowledgeable persons for each power plant. In addition, report the results of the above evaluations to citizens and societies.