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Interim Summary on Secondary Piping Rupture Accident at Mihama Power Station, Unit 3 of the Kansai Electric Power Co., Inc.

September 27, 2004
The Nuclear and Industrial Safety Agency

(Translated by JNES)

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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. 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 and established an on-site countermeasure headquarters to take measures after the accident.

On the following day, the 10th, Minister Nakagawa of the Ministry of Economy, Trade and Industry visited the site. At the same time, NISA held a meeting of the Nuclear Reactor Safety Subcommittee of the Nuclear Power Safety and Security Committee under the Advisory Committee for Natural Resources and Energy and established an Investigation Committee on the Secondary Piping Rupture Accident at Mihama Power Station, Unit 3 (abbreviated to the Investigation Committee hereinafter) to investigate and discuss the secondary piping rupture accident that occurred at Mihama Power Station, Unit 3 of KEPCO. The Investigation Committee immediately dispatched two committee members and held the first Investigation Committee meeting on August 11.

After that, on August 11, NISA instructed the licensees of existing nuclear power plants or thermal power plants above a certain scale to report the state of implementation of pipe wall thickness control and on August 13, NISA conducted an on-the-spot inspection at the Mihama Power Station to investigate the ruptured portion and interviewed persons concerned of the power station. Additionally, on August 30, NISA collected reports from the business operators who did maintenance and inspection of the ruptured portion in question.

NISA has made efforts to fulfill its accountability for this accident by directly explaining the progress status of the investigation and discussion to local governments like Mihama-cho, Fukui Prefecture, etc.

The Investigation Committee has held six Investigation Committee meetings (4th meeting held in Fukui Prefecture) so far to identify the causes of the accident and discuss the measures to take for the problems identified so far. On the other hand, the investigation to find the causes of the pipe rupture is ongoing and, moreover, it was decided to conduct detailed analysis and assessment to elucidate the phenomenon. Therefore, it seems that an additional investigation period will be needed before the final result is obtained. Thus, NISA arranged the investigation results so far as an interim summary based on the discussion at the Investigation Committee.

2. Accident situations

While Mihama Power Station, Unit 3 was in operation at the rated thermal output, a "Fire Alarm Operation" alarm was generated at 15:22 on August 9 in the central control room. 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 leaking from the secondary piping. The operator started emergency load reduction at 15:26. While operations for that 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.

The operator made an inspection in the turbine building and confirmed a rupture opening in a A-loop condensate pipe at 17:30, 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 security inspector also confirmed the same situation.

For the unit in question, the 21st periodical inspection was planned from August 14, 2004. In the turbine building, a total of 105 workers of KEPCO and maintenance contractor employees were proceeding with preparation for the periodical inspection at the occurrence of the accident. Of them, the workers working near the ruptured A-loop condensate pipe fell victim to steam and hot water flown out of the rupture opening, and 5 were killed and 6 were injured.

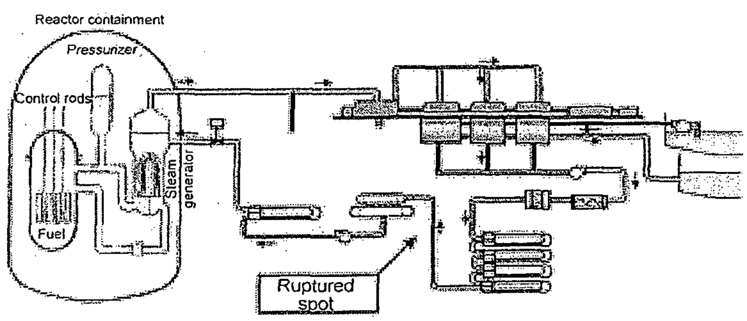

Figure 1 Major systems of PWR and the ruptured spot

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.

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 induce the accident of this time.

3. Influences of the accident

3.1. Influences on the reactor

The type of Mihama Power Station, Unit 3 is a pressurized water reactor (PWR) in which the heat of the reactor is exchanged at the steam generator and the exchanged heat is conducted to the turbine. The system before the heat exchange is called the primary system and the system after the heat exchange is the secondary system, and they are isolated from each other.

Therefore, basically, no radioactive material is contained in the cooling water and in one view the secondary system of a PWR is equivalent to a thermal power plant. However, the secondary system of a PWR has the role of cooling the reactor (relieving the heat generated in the reactor). Therefore, from the viewpoint of securing the safety of the reactor facility, it is necessary to consider it as a whole system including not only the primary system but also the secondary system.

In this concept, the influence of secondary system damage on the reactor must be assessed. For this purpose, safety assessment analysis is performed in the safety review of a reactor facility, assuming a "main feed water pipe rupture accident[4]," "main steam pipe rupture accident[5]" and the like according to the "Regulatory Guide for Reviewing Safety Assessment of Light Water Nuclear Power Reactor Facilities (August 1990)" stipulated by the Nuclear Safety Commission.

The accident this time was a rupture of a condensate system pipe that caused cooling water in the secondary system to flow out of the system. As the influence on the reactor, part of the feed water to the steam reactor will be shut off and the heat removal capacity for the reactor will be reduced. Therefore, this accident can be said to be equivalent to a "main feed water rupture accident."

In the accident this time, the systems related to reactor safety operated normally and reactor pressure, primary coolant temperature and other major parameters did not indicate more severe influence than the result assumed in the safety assessment analysis performed at the safety review.

The time series of and about this accident is given in Appendix 1 and the process of actions taken by the nuclear security inspector is given in Appendix 2.

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4 Main feed water pipe rupture accident: The phenomenon in which a rupture occurs in a feed water pipe during power operation of the reactor and the coolant in the secondary piping is lost, resulting in a reduction in reactor cooling capacity.

5 Main steam pipe rupture accident: The phenomenon in which the primary coolant temperature drops at a hot shutdown of the reactor due to a rupture or the like of the secondary cooling system, resulting in an addition of reactivity.

NISA performed a provisional assessment of this accident based on the International Nuclear Event Scale (INES) and the result was 0+. The assessment result is low in spite of the death and injury of as many as 11 persons. This is because this scale is intended to indicate the severity of a nuclear accident and therefore consists of the severity of radiation effects on humans and the safety impact on reactor facilities.

3.2. Influences on neighboring environment

The record of outdoor monitors and ventilation duct monitors was examined and the result was that no significant change was recognized between before and after the accident and no influence of radiation on the neighboring environment due to the leaked secondary cooling water was observed.

3.3. Evaluation of leaked amount

According to a report from KEPCO, the amount of secondary cooling water that flowed out of the ruptured pipe was calculated based on the amount of make-up water from the secondary makeup water tank, the drop of water level in the deaerator and the amount of water contained in the piping (from the 4th low-pressure feed water heater to the deaerator) and it was evaluated to be about 885 tons. The amount of water contained in the secondary system in operation is about 1,100 tons.

Table 1 Leaked amount from various parts

(Unit: ton)

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

(Reference information) Outline of the 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
6. Commissioning: December 1, 1976
7. Operating time: 185,700 hours

4. Investigation on pipe rupture mechanism

4.1. 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[6] for measuring the condensate flow of the A-loop.

NISA conducted an on-the-spot inspection and as a result confirmed a fracture opening in the ruptured portion, which extended a maximum of 515 mm in the axial direction and 930 mm in the circumferential direction of the pipe. KEPCO measured the pipe in the presence of the police, and the result was 0.4 mm at the thinnest portion of the pipe. As shown in Appendix 3, thinning was striking in the upper part of the pipe.

The A-loop pipe was cut out including the ruptured portion in question and examined at the Japan Atomic Energy Research Institute (abbreviated to JAERI hereinafter). As a result, a portion was found out downstream of the vent hole of the orifice[7] where pipe wall thinning reached to the flange for the orifice support.

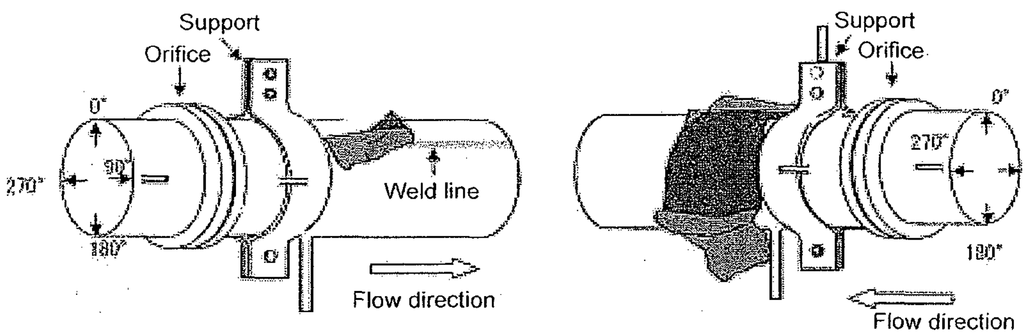

Figure 2 Ruptured condition of pipe

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[8], downstream of the orifice and over the entire surface except at the bottom (180°) of the pipe. At the bottom (180°) of the pipe, a portion of almost nominal wall thickness existed where a thick surface

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6 Orifice: A throttling mechanism to narrow down the cross section of a pipeline through which fluid is flowing. It is installed to measure the flow rate of the fluid flowing in the pipe.

7 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).

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

film (0.4 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.

4.2. 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). The B-loop piping was cut out including the similar portion and pipe wall thickness measurement and internal surface observation were performed at JAERI.

As a result, a thinning tendency was observed almost over the entire surface downstream of the orifice as shown in Appendix 3. 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.

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

4.3. Major specifications of piping

Major specifications of the piping in question are as follows:

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 (kg/cm^2G)	13

(Source: Application Document for Approval of Construction Plan, Mihama Power Station, Unit 3)

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 specifications of this piping were decided considering the service environment. The mill sheet[9] was examined concerning the tensile strength, material ingredients, etc. However, no problem was identified by NISA.

4.4. Investigation of installed condition of piping and the like

The roundness deviation of the A-loop pipe in question and B-loop pipe at the similar potion was examined. The results were that the tolerance of 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.

The installed condition of the orifice and the like 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.

4.5. Quality control of secondary system cooling water

According to KEPCO, 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. 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[10] 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 and as a result it says that both the feed and condensate water quality data have been maintained within the water quality control values. At Mihama Power Station, Unit 3, condenser tube leaks occurred twice in the past and seawater flowed into the secondary system cooling water. However, KEPCO says that there was no variation in pH, dissolved oxygen, etc. in either case.

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

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9 Mill sheet: In case of receiving an order of steel with specified standard, 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.

10 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 600-alloy tube.

Table 3 Secondary system water quality control values for Mihama Power Station, 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
Ethanol amine (at injection of ETA in feed water)		≤ 3 ppm
Hydrazine (Feed water)	1	Dissolved oxygen in condensate + 5 ppb
	2 - 7	≥ 2 ppb
	8 - 15	≥ 5 ppb
	16 - 18	≥ 200 ppb
	19 - 21	≥ 100 ppb + (dissolved oxygen in condensate) × 40
Dissolved oxygen (in feed water)		≤ 5 ppb
Dissolved oxygen (in condensate)	1 - 15	≤ 50 ppb
	16 - 21	≤ 10 ppb
Total iron (in feed water)	1 - 15	≤ 20 ppb
	16 - 18	≤ 10 ppb
	19 - 21	≤ 20 ppb

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

4.6. Estimation of rupture mechanism

From the investigations performed so far, the following has been revealed.

- The ruptured pipe is of carbon steel and the ruptured portion was downstream of the orifice where channeling is apt to occur.
- The pH, dissolved oxygen and other water quality data of the feed water and condensate systems have been maintained within the control values.
- 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.
- The inner surface of the pipe suffered substantial thinning and exhibited a fish scale-like pattern almost over the entire surface, which is characteristic of so-called erosion/corrosion.
- 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.

From these, the cause for the pipe rupture in question 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.

4.7. Investigation of the ruptured portion

Concerning the case in question, NISA is performing metallurgical and analytical investigations, including the following, of the ruptured portion by commissioning them to JAERI and an incorporated administrative agency, the Japan Nuclear Energy Safety Organization (abbreviated to JNES hereinafter). The investigation plans for the future and the analysis results about the rupture mechanism obtained so far are as follows:

1) Pipe flow analysis in neighborhood of the orifice (JNES, JAERI)

   Since flow analysis is apt to exhibit the feature of the method employed to make the model and the code used for the analysis, a flow confirmation analysis will be performed using multiple codes to evaluate the erosion tendency due to turbulence. The investigation will proceed also on the thinning of the vent hole.

   According to a one-dimensional two-phase flow analysis using the design values (at JNES), the result obtained is that the possibility of flash boiling (cavitation) is low downstream of the orifice.

   JNES and JAERI did an analysis to predict the thinning tendency due to turbulence and obtained the result that the largest thinning will occur downstream of the orifice (at a distance of about 1.2 times the pipe diameter).

2) Thinning behavior analysis of the ruptured portion (JAERI)

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

   So far, thinning and rupture analyses have been performed using PASCAL-EC and the following results have been obtained.

   - The thinning analysis results almost coincided with the maximum amount of thinning actually measured on the A- and B-loop pipes. From the sensitivity analysis of thinning rate, the result that pH and dissolved oxygen have large influences was obtained.

- In the case where an A-loop pipe is loaded with the operating pressure and design bending moment, the wall thickness at rupture is 0.6-0.7 mm. Bending moment does not have a large influence on the wall thickness at rupture.

3) Pipe rupture structural behavior analysis (JNES)

This analysis has the purpose of understanding the behavior outline of the rupture phenomenon, and dynamic analysis will be performed on the behavior of a two-phase flow and structural behavior after the pipe rupture to understand the spouting behavior of the two-phase flow.

JNES did an analysis using a two-dimensional model and obtained the result that steam would spout upward at high speed (100 m/s or more) from an enlarged opening of several millimeters at the top portion of the pipe.

4) Metallurgical ingredient analysis of the ruptured portion (JAERI, JNES)

An appearance inspection, wall thickness measurement, fracture surface observation, hardness test, pipe material ingredient analysis, etc. will be performed to identify the causes of the rupture.

5. Pipe wall thinning management

The actual condition, tasks and future actions to take for pipe wall thinning management practiced at nuclear power plants will be described separately for PWR and BWR and the implemented condition and future actions of wall thickness inspection related to pipe thinning at thermal power plants will be given.

5.1. Pipe wall thinning of PWR

(1) Control techniques

For PWR, thinning due to erosion/corrosion occurred in some plants in the latter half of the 1970s and investigations were carried out on pipe thinning. 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, the licensees, who had then conducted an investigation of the thinning condition of secondary system piping at various PWR plants, statistically evaluated the data obtained from the investigation results and examined the control method for such thinning.

As a result, the "Guidelines for Secondary Piping Wall Thickness Control at Nuclear Facilities (PWR)" (abbreviated to the PWR Management Guidelines hereinafter) were laid down in May 1990 and these guidelines have been used as a common control technique for secondary piping wall thickness. In the process of establishing the guidelines, opinions were heard from the Nuclear Power Generation Technical Advisors established in the then Ministry of International Trade and Industry.

The PWR operators reported to the then Public Utilities Department of the Agency for Natural Resources and Energy in July 1990 to the effect that they had established the PWR Management Guidelines and appended a note to the effect that they would conduct voluntary inspections after that according to the Guidelines.

(2) Validity of PWR Management Guidelines

The PWR Management Guidelines were laid down in 1990. Now, more than 10 years have passed since then and a lot of data has been obtained. However, no review has been done based on the latest data. Therefore, the validity of the PWR Management Guidelines was examined this time based on the thinning data[11)] measured at various PWR plants (Appendix 4).

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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 electric utilities.

1) Measured points and thinning tendency of major pipings

The PWR Management Guidelines prescribe the initial thinning rate by flow velocity and temperature, differently for two-phase and single-phase water flow, for the systems to be inspected. This time, actual values of 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.

2) 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.

3) 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 bore 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 and if the wall thickness at a measuring point falls short of a certain criterion of wall thickness, 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.

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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 Utility Law.

(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 a 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 4 and the case of Ohi Power Station, Unit 1 shown in Appendix 5, 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 reflected in the Guidelines by adding this detailed measuring technique to the Guidelines or otherwise.

5.2. Pipe wall thinning of BWR

(1) Control techniques in use

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 data at various plants and each public utility has set down a control technique on its own right based on such measurements.

(2) Analysis of in-house control guidelines of BWR operators

Each BWR operator has set down control guidelines on its own right and in content there is much common matter. Compared to the PWR Management Guidelines, the BWR guidelines are wider as to the scope of entities to be inspected. As to 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), the PWR Guidelines are higher (Appendix 6).

The change of the amount of thinning measured at various BWR plants and the actual values of 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.

For the BWR as well, efforts should be made to utilize the thinning data at the utilities after this and make common control guidelines in the possible portions.

5.3. Pipe wall thinning of thermal power plants

On August 11, NISA requested a report from the electric utilities having thermal power generation facilities based on Paragraphs 3 and 4, Article 106 of the Electric Utilities Industry Law. The content was the state of execution of nondestructive inspection of water and steam pipe wall thickness at the portions where thinning can occur and an inspection execution plan for the portions not subjected to inspection yet.

According to the state of execution of wall thickness inspection reported to August 20, 1,467 units at 802 power plants are subject to reporting and, of these, nondestructive wall thickness inspection is carried out at 704 units and is not carried out at 763 units.

Table 4 State of execution of nondestructive wall thickness inspection at thermal power generation facilities

Number of power plants subject to reporting	Number of units subject to reporting	Nondestructive inspection	
		Units inspected	Units not inspected
802	1,467	704	763

By September 21, wall thickness inspection plans were reported from electric utilities, etc. (general electric enterprises and joint thermal power structure and captive electric structure establishers, etc.) for their thermal power plants aged over 20 years after commissioning. According to the reports, there are about 249,000 facilities to be inspected and, of these, inspection has not been performed at about 213,000 facilities yet. For these facilities, the operators claim that they will carry out the inspections, etc. one by one.

For the thermal power plants aged less than 20 years after commissioning, inspection execution plans will be reported in October.

NISA requires operators to surely perform safety assurance measures to prevent damage to the workers by a pipe rupture, etc. during operation of the facility in question until safety can be confirmed by conducting a pipe wall thickness inspection or otherwise.

5.4. Actions in the future

Thus far, a large amount of data on secondary piping thinning has been accumulated at each PWR plant by the inspections according to the PWR Management Guidelines. From the result of assessment using part of such data, the Guidelines are thought appropriate as a control technique in principle. To make assurance doubly sure on the control of pipe wall thinning, however, the persons concerned including the PWR operators should formulate new private guidelines to be discussed through a transparent process and disclosed by a neutral organization, referring to the actual measured values and overseas findings. At that occasion, it is thought necessary to consider the following matters.

1) Thinning rate based on actual measurements

2) Measuring area based on actual measurements

3) Division between portions subjected to 100% inspection and portions subjected to sampling inspection and the appropriate sampling number

4) Inspection frequency according to the remaining life evaluation result

5) Necessary minimum wall thickness and integrity assessment method based on the local thinning phenomenon and other new findings (minimum wall thickness value, maximum thinning rate, change rate of thinning rate, and the like)

6) Examination of measuring techniques (addition of the detailed measurement method to the guidelines, etc.)

For BWR as well, it is desirable that the licensees conduct the inspections using a unified control technique. Therefore, the persons concerned including the BWR operators should act and examine in harmony with the efforts made in PWR.

For thermal power plants, there are no common technical guidelines for pipe wall thickness at present. It is desirable to accumulate actual data of pipe thinning measured by the licensees after this and lay down appropriate technical guidelines for pipe wall thickness control.

In the control technique given in "5.1 Pipe wall thinning of PWR" and "5.2 Pipe wall thinning of BWR", measurement is done at 8 or 4 measuring points per cross section and, if a measured value falls short of a certain criterion of wall thickness, a detailed measurement is done. Judgment is made by comparing the measured minimum wall thickness with the necessary wall thickness calculated from technical standards. In this control technique, judgment is done assuming that the entire circumference of the pipe has thinned to the measured minimum wall thickness.

This control technique for pipe thinning is sufficiently conservative as long as the measurement detects the region of minimum wall thickness. In the actual pipe thinning phenomenon, however, such local thinning that the progress of thinning is locally different is seen in many cases.

Therefore, in discussing new private guidelines at a neutral organization as described above, it is desirable to extract the regions where such local thinning is liable to occur and additionally discuss a measuring method for that and an integrity assessment method, etc. in the case where this condition is confirmed in the detailed measurement.

6. Managerial processes of the ruptured portion

Thus far, NISA has conducted a survey on the contract relations among the 3 parties of KEPCO, Mitsubishi Heavy Industries (abbreviated to MHI hereinafter) and Nihon Arm Co., Ltd. (abbreviated to Nihon Arm hereinafter) and the thinning control system at them. The facts revealed are as follows.

6.1. Details of registration omission for the ruptured portion

(1) Before preparation of the PWR Management Guidelines (to 1990)

KEPCO has conducted thinning investigation by sampling of the secondary piping since the latter half of the 1970s. In February 1983, a steam leakage trouble occurred due to thinning of the balance pipe's branch pipe of the moisture separator drain tank at Takahama Power Station, Unit 2. To prevent this from recurring, KEPCO carried out, by commissioning to MHI, a systematic thinning examination and evaluation of the data obtained from this examination from 1985 to 1989.

In 1984, KEPCO laid down the "Procedure of Secondary Piping Aging Deterioration Survey Work and Countermeasures (July 1984)" and formulated the inspection details as an in-house standard according to the importance of the regions concerned.

After that, a feed water pump inlet pipe rupture accident occurred at the Surry Nuclear Power Station in the US in December 1986. This accident triggered KEPCO to commission the preparation of secondary piping inspection guidelines based on the data obtained by the thinning examination described above to MHI and to lay down the "PWR Management Guidelines" based on the results of that commissioning in May 1990.

(2) Preparation of the initial inspection list by MHI (1990)

In 1990, MHI prepared an inspection list and the like for Mihama Power Station, Unit 3 based on the PWR Management Guidelines. At that time, the registration of the ruptured portion in question had already been missing.

Of the total of 39 portions downstream of the orifices of Mihama Power Plant, Unit 3, the registration of 3 portions were missing, i.e., two portions downstream of the condensate flow meter and one portion downstream of the steam converter heating steam flow meter (the two portions downstream of the condensate flow meter are the ruptured portion in question (A-loop) and the portion downstream of the condensate flow meter of the B-loop. For the one portion downstream of the steam converter heating steam flow meter, KEPCO made an announcement on August 18 to the effect that the registration had already been missing). MHI explains that the process of the registration of the ruptured portion in question becoming overlooked is unknown.

The preparation of the inspection list and the like specifying the ruptured portion in question was performed by the "Secondary Piping Aging Deterioration Survey Work" commissioned by KEPCO to MHI. However, the commission furnisher, KEPCO, did not check the inspection list in question as a final outcome of the work from the standpoint of looking for registration omission.

(3) Registration of the overlooked portion of Tomari Power Station, Unit 1 of Hokkaido Electric Power Company corresponding to the ruptured portion in question in the checklist (1995)

MHI did maintenance and inspection of Tomari Power Station, Unit 1 of Hokkaido Power Electric Company and found the registration omission for the portion corresponding to the ruptured portion in question of Mihama Power Station, Unit 3. MHI itself registered this portion in the checklist in 1995 and this fact was disclosed after the accident when Hokkaido Electric Power Company made a general checkup according to the instruction of NISA.

MHI explains that the process of registration of this portion becoming overlooked is unknown and it had not been recognized until Hokkaido Power Electric Company made the announcement.

(4) Transfer of inspection service from MHI to Nihon Arm (1996)

KEPCO changed the contractor of inspection service from MHI to Nihon Arm in 1996. At that occasion, according to a commission from KEPCO, MHI marshaled the latest inspection drawings and actual data obtained from the past maintenance and inspections of the nuclear power plants of KEPCO, then owned in-house, and submitted them to KEPCO. The marshaled actual data was handed over to Nihon Arm. At this point in time, however, the registration omission of the ruptured portion in question of Mihama Power Station, Unit 3 was not corrected.

The marshalling of actual data and the like was carried out according to the "Survey on Nuclear Power Secondary Piping Thinning Evaluation" commissioned by KEPCO to MHI. The commission issuer, or KEPCO, did not make a check as to whether the actual data submitted from MHI conformed to the PWR Management Guidelines.

In January 1997, Nihon Arm made a commission contract for "Instrumentation Guidance Work for Secondary Piping Aging Deterioration Survey Work" with MHI. According to the contract, MHI made preparation for an inspection plan and undertook the task of teaching of instrumentation work at 4 plants (Ohi Power Station, Unit 1, Mihama Power Station, Unit 3, Takahama Power Station, Unit 4, and Ohi Power Station, Unit 4). In 1996, these were done by Nihon Arm.

(5) Commissioning of preparation of inspection drawings, etc. from KEPCO to Nihon Arm (1997)

KEPCO commissioned the amendment of inspection drawings based on an on-site survey and CAD formatting of inspection drawings (inspection drawings made in an electronic format) to Nihon Arm in 1997. At this point in time, the registration omission of the ruptured portion in question of Mihama Power Station, Unit 3 was not corrected yet.

The CAD formatting work described above was performed according to the "Preparation of Secondary Piping Inspection Data and Drawings" commissioned by KEPCO to Nihon Arm. However, the commission issuer, or KEPCO, did not make a check as to whether or not the data was prepared according to the PWR Management Guidelines when the work of CAD formatting, etc. was carried out.

(6) Registration of the overlooked portion in Tsuruga Power Station, Unit 2 of Japan Atomic Power Company corresponding to the ruptured portion in question in the checklist (2000)

After the accident, a general inspection was conducted according to instructions of NISA. As a result, Japan Atomic Power Company made an announcement to the effect that there was also registration omission for the portion in Tsuruga Power Station, Unit 2 corresponding to the ruptured portion in Mihama Power Station, Unit 3, but this portion was in fact registered as an inspection portion in 2000. Regarding this, MHI explains that, for Tsuruga Power Station, Unit 2 of Japan Atomic Power Company, the information on the condensate piping's thinning downstream of its orifice in Tomari Power Station, Unit 1 of Hokkaido Electric Power Company (in 1998) was spread horizontally and as a result the registration omission of the corresponding portion was discovered in 2000, so they made an additional registration of the portion in question as an inspection portion.

The registration omission in question seems to have existed since 1990 when application of the PWR Management Guidelines began. However, MHI explains that the process of registration of this portion becoming overlooked is unknown. MHI spread the information on thinning horizontally, but did not provide the information on the registration omission of the portion in question.

(7) Holding of regular liaison meetings of Nihon Arm and Nuclear Power Service Engineering Company (since 1998)

Nihon Arm and Nuclear Power Service Engineering Company (NUSEC hereafter), a subsidiary of MHI, have regularly held liaison (working) meetings as part of the contract between them since the commission recipient of inspection service was changed from MHI to Nihon Arm. In these meetings, NUSEC provided information to Nihon Arm about the progress of pipe wall thinning downstream of the orifice at other plants.

MHI explains that there was an agreement to the effect that horizontal spread of the pipe wall thinning information to the plants of KEPCO was a duty of Nihon Arm, who did maintenance and inspection of those plants. On the other hand, Nihon Arm explains that this thinning information is general technical information and the registration omission of the portion in question of Mihama Power Station, Unit 3 had not been pointed out.

(8) Discovery of registration omission of inspection portions by Nihon Arm (April 2003)

Nihon Arm did maintenance of inspection portion data from the year 2001 to 2002. In April 2003, a worker at work on this maintenance discovered the registration omission of the ruptured portion in question of Mihama Power Station, Unit 3 and registered it in the control system of that company. The ruptured portion in question registered in the control system was entered in the 20th periodic inspection work report (July 2003) and was proposed as an inspection portion for the 21st periodic inspection work plan by Nihon Arm to KEPCO (November 2003).

KEPCO did not make a check for the newly added portion in question when the periodic inspection work report was submitted or when the periodic inspection work plan was submitted. KEPCO and Nihon Arm made a service contract for inspection (Secondary Piping Aging Deterioration Survey Work) at each periodic inspection. In this contract, duty to report or otherwise was not stipulated in case of discovery of registration omission of an inspection portion.

KEPCO explains that they became aware of the registration of the portion in question for the first time after the occurrence of this accident.

6.2. Contractual relationship

From the viewpoint of quality assurance, it is important how the procurement requirements for quality assurance are positioned in the contractual relationship among the parties concerned.

The details of the contractual relationship regarding maintenance and inspection between KEPCO and MHI or Nihon Arm are as follows.

Considering the fact that the PWR Management Guidelines were laid down in 1990 through discussions between MHI and KEPCO and the fact that a copy of the PWR Management Guidelines was attached to the work reports submitted by MHI or Nihon Arm to KEPCO, it is estimated that the maintenance and inspection service proceeded on the premise of existence of the PWR Management Guidelines. However, it is not described explicitly in any contract that the inspection portions should be reviewed according to the PWR Management Guidelines.

- According to the contractual relationship concerning maintenance and inspection between KEPCO and MHI or Nihon Arm, the contractor proposes a survey work plan, etc. to KEPCO for each periodic inspection and a final draft is attained through discussions on the details. For each periodic inspection, a service contract is made for such a final draft as "Secondary Piping Aging Deterioration Survey Work."

- Checklists, etc. were prepared in 1990 based on the PWR Management Guidelines. At that occasion as well, the contractual relationship between KEPCO and MHI was only for "Secondary Piping Aging Deterioration Survey Work."

- When KEPCO changed the contractor of maintenance and inspection service from MHI to Nihon Arm in 1996, the following contracts were entered into among these companies:

  a) "Survey for Evaluation of Nuclear Secondary Piping Thinning" (September 1996)
  Commissioned by KEPCO to MHI. This stipulates preparing inspection drawings, marshaling actual data about maintenance and inspection in the past and submitting them to KEPCO.

  b) "Instrumentation Guidance Work for Secondary Piping Aging Deterioration Survey Work" (January 1997)
  Commissioned by Nihon Arm to MHI. This stipulates that MHI should give Nihon Arm guidance on preparation of an inspection plan and instrumentation work for doing the piping aging deterioration survey work, which Nihon Arm did in 1996 at the 4 plants (Ohi Power Station, Unit 1, Mihama Power Station, Unit 3, Takahama Power Station, Unit 4, and Ohi Power Station, Unit 4).

  c) "Secondary Piping Aging Deterioration Survey Assistance Work" (contracted for each periodic inspection every year)
  Commissioned by Nihon Arm to NUSEC. This stipulates that NUSEC should do,

for Nihon Arm, collecting of information on piping-related troubles, reporting them and reflecting them in the survey plan and making proposals, etc.

6.3. Investigations in the future

The investigation so far has revealed that the direct cause for this accident consists in "the portion to be controlled was missing from the initial control list and this could not be corrected until the accident" due to "a mistake in thinning control of the secondary piping involving the 3 parties of KEPCO, MHI and Nihon Arm." That is, quality assurance and maintenance management were not functioning well at KEPCO. Because of this, 1) the portion in question was missing from the portions to be inspected, 2) this has been left untouched for a long time without being corrected, and 3) when the missing inspection was discovered the communication to the parties concerned was insufficient and that was not appropriately reflected in the subsequent inspection plans; these can be cited as the causes.

It is important to cope with these problems immediately. On the other hand, it is also important to take an uninterrupted approach to investigate how these mistakes occurred in quality assurance and maintenance management, not only from the technical aspect but also from the managerial aspect. In concrete terms, it is suspected as the background of this accident that the organizational structure was not prepared or not functioning to reduce or overcome human or managerial mistakes and therefore the fundamentals of work management were made light of. It is necessary to investigate from this viewpoint why such a serious situation occurred.

It is necessary to admit that mistakes or so-called human errors inevitably occur in human actions. For example, a mistake in selecting potions to be inspected may cause an accident. How could such an accident be predicted and what was the recognition of the severity of the accident? Was there not a naive attitude in the persons in charge? It is required to investigate the actual condition based on objective facts about these. Deliberation about these will make an effective mechanism to prevent problems from occurring due to human errors. It is necessary to assess and examine anew how quality assurance was functioning at the licensee and maintenance contractors.

Thus, quality assurance was introduced in the safety regulations last year by the amendment of the inspection system for nuclear facilities. Investigation and discussion should proceed from the viewpoint of such quality assurance and mistake prevention measures should be considered in the managerial aspect. In concrete terms, it is required to proceed with the examination concerning the following matters after this.

1) Maintenance management, procurement management and other related processes at KEPCO (existence or absence of in-house procedures and standards, check whether or not these documents were used at the period relevant to 6.1)

2) In-house work processes at MHI and Nihon Arm (existence or absence of in-house procedures and standards, check whether or not these documents were used at the period relevant to 6.1)

3) Actual conditions of information communication in case of transfer of pipe inspection service from MHI to Nihon Arm and after that

7. General investigation on maintenance management for pipe wall thinning

7.1. Confirmation of maintenance management based on inspection management guidelines at KEPCO

(1) Process

For the accident this time, NISA instructed KEPCO on August 11 based on Paragraph 1, Article 106 of the Electric Utilities Industry Law to the effect that they should confirm whether there are potions where pipe wall thickness control has not been applied, and received reports on the confirmation result on August 18. NISA made report collection for additional confirmation of wall thickness measurement and received a report on August 23.

Besides the report collection stated above, NISA is doing sampling confirmation of inspection records by on-the-spot nuclear security inspectors. In parallel, it is proceeding with an examination about the adequacy of maintenance management for pipe thinning by KEPCO. As of now, the assessment by NISA is as follows.

(2) Outline of maintenance management for pipe thinning

In the latter half of the 1970's and the first half of the 1980's, KEPCO did wall thickness measurement for the thinning phenomenon of steam pipes and feed water pipes around the turbine. In February of 1983, a steam leakage trouble occurred due to thinning of the moisture separator drain tank balance pipe's branch pipe of Takahama Power Station, Unit 2. This accident triggered KEPCO to conduct a systematic thinning investigation from 1985 to 1987 for recurrence prevention by commissioning this to MHI.

From 1989 to September 2003, the maintenance management activities at KEPCO have been operated based on an in-house standard, "Guidelines for Repair Service Procedures." In response to the amendment of the inspection system at nuclear facilities in October 2003, KEPCO prepared and is using in-house Maintenance Guidelines at each power station.

(3) Assessment of uninspected portions, etc.

KEPCO reported in the report of August 18 that it had not been doing thinning control at 4 portions of a total of 4 steam converter pipelines, including the one of Mihama Power Station, Unit 3. At 3 units including Takahama Power Station, Unit 3, a total of 11 portions were missing from the objects of inspection. However, KEPCO reported that the integrity of these portions could be confirmed from the measured results at plants of the same specifications.

Thus, NISA inspected the validity of this report and checked the past records, separately from the sample measurement carried out by KEPCO itself to confirm the integrity.

1) Confirmation of the number of uninspected (uncontrolled) portions

NISA understood by checking of the records by the on-site Nuclear Security Inspector that two portions related to the portion where the accident occurred at Mihama Power Station, Unit 3 had been missing from the checklist since the beginning of application of the PWR Management Guidelines laid down in 1990, until recently. It also confirmed that thinning control had not been exercised until now at 4 portions of a total of 4 steam converter heating steam pipelines including that of this unit.

KEPCO claims that the 11 portions are controlled by estimation from the measured results at plants of the same specifications. However, the Agency confirmed that these portions had not been included in the objects of inspection and in fact had not been inspected before the instruction of report collection. In addition, thinning control using such an estimation technique is not provided for in the PWR Management Guidelines and is not made as a rule in the in-house standards, so its rationality cannot be admitted. Therefore, NISA judged that appropriate control had not been exercised on these 11 portions.

NISA did a sampling confirmation of skeletal drawings and the like mainly of major systems, sampled from the past inspection records obtained by report collection from KEPCO, and confirmed that there was no uninspected portion within this scope.

2) Confirmation of integrity of the portions at which thinning control had not been exercised

KEPCO says that they will shut down the plants now in operation as well from August 13, 2004 in a planned way and will confirm the integrity of pipings at all the plants. In concrete terms, they say that they will inspect a total of 293 portions, including the portions at which thinning control had not been exercised, as follows:

- Portions at which thinning control had not been exercised until now:
15 portions (Note 1)

- Portions downstream of the orifice of feed water and condensate systems: 144 portions (Note 2)

Portions in which the thinning phenomenon of the main feed water piping of Ohi Power Station, Unit 1 (Note 3) is reflected: 134 portions

Note 1: Excludes the ruptured portion of Mihama Power Station, Unit 3 and a similar portion.
Note 2: Includes the 17 portions that is overlapping of the portions at which thinning control had not been exercised with the portions in which the thinning phenomenon of the main feed water piping of Ohi Power Station, Unit 1 is reflected.
Note 3: For the thinning phenomenon of Ohi Power Station, Unit 1, refer to Appendix 5.

NISA confirmed, in the presence of the on-site nuclear security inspectors, that there was no problem at any of the 238 portions inspected by September 16.

3) Confirmation of the integrity of the portions at which NISA instructed inspections

NISA additionally instructed inspections at 21 portions (one portion of Mihama Power Station, Unit 1, 6 portions of Mihama Power Station, Unit 2, 2 portions of Takahama Power Station, Unit 2, 2 portions of Ohi Power Station, Unit 1, 6 portions of Ohi Power Station, Unit 2, one portion of Ohi Power Station, Unit 3, and 3 portions of Ohi Power Station, Unit 4) to examine the past inspection records other than Mihama Power Station, Unit 3. Of these, wall thickness measurement was done at 19 portions excluding Ohi Power Station, Unit 1. As a result, it was confirmed that there was no problem at any of the 16 portions except for the following 3 portions. The problems confirmed were that one portion was discovered in Mihama Power Station, Unit 2 where the remaining life was less than one year and one portion was discovered in each of Mihama Power Station, Units 1 and 2 where the wall thickness fell short of the necessary minimum thickness given in the ministerial ordinance stipulating technical standards for thermal power generation equipment.

The reason why such cases were found is because KEPCO uniquely interpreted the proviso in the "On the Interpretation of Technical Standards for Thermal Power Generation Equipment" and applied it to the pipes with short remaining life (evaluated remaining life less than one year). Such operation cannot be said to be appropriate. Thus, KEPCO says that they will replace pipes at the 3 portions in question.

For Ohi Power Station, Unit 1 as well, KEPCO plans to shut down the plant after this and continue to conduct the remaining inspection work. NISA will monitor the inspections carried out by KEPCO as well as confirm the integrity.

The past inspection records were examined also for Mihama Power Station, Unit 3 and three portions were discovered where the remaining life was less than one year and one portion was discovered where the wall thickness fell short of the necessary minimum thickness laid down in the technical standard. Thus, NISA instructed KEPCO to make additional inspections at the portions in question.

Table 5 State of implementation and results of thinning inspection of secondary piping (as of September 16, 2004)

Plant name		Operation status	State of inspection by KEPCO					State of inspection according to the instruction from NISA			
			Upper figures: Actual results Lower figures: Number of inspection objects			Number of portions requiring actions	Current state	Upper figures: Actual results Lower figures: Number of inspection objects	Number of portions requiring actions	Current state	Reason for the instruction
			A	B	C						
Mihama Power Station	Unit 1	In shutdown		8 8		0	Completed	1 1	1 (Replacement)	Completed	For confirming the remaining life: 1 (replacement)
	Unit 2	In shutdown		8 8	2 2	0	Completed	6 6	2 (Replacement)	Completed	For confirming the remaining life: 4 (replacement: 2 of them) For confirming the appropriateness of the measuring point: 2
	Unit 3	In shutdown	0 1	0 13	0 12			0 4			For confirming the remaining life: 4
Takahama Power Station	Unit 1	In shutdown	1 1	21 21	1 1	0	Completed	0 0	0	Completed	
	Unit 2	In operation		21 21	3 3	0	Completed	2 2	0	Completed	For confirming the remaining life: 2
	Unit 3	In operation	(8) (8)	14⑦ 14⑦	15 15	0	Completed	0 0	0	Completed	
	Unit 4	Under periodic inspection	(1) (1)	14 14	11 11	0	Completed	0 0	0	Completed	
Ohi Power Station	Unit 1	Under periodic inspection (in adjusting operation)		0 10④	0 6	0		0 2			For confirming the remaining life: 1 For confirming the state of control: 1
	Unit 2	In shutdown		9 9④	24 24	0	Completed	6 6		Completed	For confirming the remaining life: 1 For confirming the state of control: 5
	Unit 3	Under periodic inspection	1 (2) 1 (2)	13② 13②	30 30	0	Completed	1 1	0	Completed	For confirming the state of control: 1
	Unit 4	In operation	1 1	13 13	30 30	0	Completed	3 3	0	Completed	For confirming the state of control: 3
Total			3 (11) 4 (11)	121⑬ 144⑰	116 134	0		19 25	3		

Remarks A: Portions at which thinning control has not been exercised so far. Figures in parentheses are the numbers of portions whose integrity has been confirmed by estimation from the measured results at plants of the same specifications, so they are extra numbers.

B: Portions downstream of the orifice of feed water and condensate systems. Encircled figures are the numbers of portions overlapping A or C, so they are included numbers.

C: Portions in which the thinning phenomenon of the main feed water piping of Ohi Power Station, Unit 1 is reflected.

7.2. Confirmation of maintenance management at plants (nuclear power stations) other than KEPCO

For the accident this time, NISA issued an instruction on August 11 according to Paragraph 1, Article 106 of the Electric Utilities Industry Law to the licensees installing nuclear power plants to the effect that they should confirm the presence or absence of portions on which pipe wall thickness control is not exercised and on August 18 received a report of confirmation results from all the licensees.

On receiving the report, NISA made a documentary survey on the state of inspection in pipe wall thickness control at licensees other than KEPCO, that is, assessed the appropriateness of inspection implementation such as survey method, implementing structure, wall thickness control policy and inspection plan. For that purpose, the on-site nuclear security inspector made documentary checks by sampling, on-the-spot visits and the like from August 19 to 25.

Assessment results of the state of inspection at the licensees are as follows:

(1) General assessment

Mistakes were found in accumulated numbers and they are presumably ascribable to a large amount of documentary checking in a limited period. Although control is exercised now, some objects of inspection were recognized to have been missing in the past. Inconsistency was found in the scope of objects of inspection. For other matters, however, there is no fact found in the scope of this survey that will cause problems. Thus, NISA assesses that the inspections by the licensees were implemented appropriately (for the examination results, refer to Appendix 6).

(2) Individual assessment

1) Survey method

In deciding the scope of inspection, each licensee confirmed and marshaled the portions of occurrence of channeling using piping system diagrams (isometric or skeletal drawings) and collated them against the inspection drawings, piping system diagrams, etc. Thus, it was confirmed that appropriate control was exercised.

The number of objects to be surveyed is numerous for the licensees. At implementing the survey, therefore, they established a survey structure with manufacturers added appropriately to conduct the survey work. It was confirmed that a quality assurance section or other third-party section was in charge of checking to confirm the appropriateness of the survey.

2) Control policy

For PWR plants, it was confirmed that control was exercised according to the PWR Management Guidelines. For BWR plants, it was confirmed that they were exercising thinning control according to the rank determined by the fluid environment and material of the piping. For the control policy and the like in question, it was confirmed that appropriate operations were performed by the maintenance officers and other persons concerned of the power plant.

3) Inspection plan

It was confirmed at each of the plant that an appropriate inspection plan was laid out, an organizational structure was established to carry out the inspection work and subcontract management was exercised appropriately, according to their control policy, etc.

8. Immediate measures

NISA will promote detailed investigations of the rupture mechanism and establishment of new Management Guidelines as specified in "4.7 Investigation of the ruptured portion," "5.4 Actions in the future" and "6.3 Investigations in the future" as well as make an investigation focusing on the quality management systems at KEPCO and its maintenance contractors in order to determine the root cause of this accident.

By summarizing the facts that have been revealed so far, some measures readily applicable to operations of nuclear power plants to prevent recurrence of the accident can be clarified as described below. It is important to put these measures into practice as quickly as possible.

8.1. Measures in terms of quality assurance and maintenance management

The background factor behind the occurrence of the "mistake in thinning control for the secondary piping involving KEPCO, MHI and Nihon Arm " which is considered as the direct cause of this accident, may be that the quality assurance and maintenance management systems had not worked properly at KEPCO.

With the revision of the inspection system in October 2003, the specific requirements for quality assurance and maintenance management were enshrined into law and the periodic licensees' inspection was newly introduced. According to this new inspection system, licensees are obliged to establish quality assurance and maintenance management systems. NISA has the mechanism of conducting fitness-for-safety inspections and periodic safety management review to check the state of achievement of quality assurance and maintenance management at licensees. In these situations, it is necessary to take the following measures from the viewpoint of quality assurance and maintenance management regarding thinning control.

(1) Preparation of checklist and unified management

The periodic licensees' inspections to be carried out by licensees are confirmed by the regulatory agency as the periodic safety management review. For this purpose, JNES evaluates the implementation system of periodic licensees' inspections to be carried out by licensees based on the Electric Utilities Industry Law, Article 55. In concrete terms, JNES evaluates [1] the organization for implementation, [2] inspection methods, [3] process control, [4] management of maintenance contractors, [5] management of inspection records and [6] education and training.

Specific judgment criteria used in the reviw are mainly JEAC 4111-2003 "Regulations on quality assurance for safety at nuclear power plants" established by the Atomic Power

Standards Commission, Japan Electric Association, and JEAC 4209-2003 "Regulations on maintenance management at nuclear power plants" established by the Atomic Power Standards Commission, Japan Electric Association.

The fitness-for-safety program of Mihama Power Station specify detailed requirements for implementation of periodic licensees' inspections based on MR-7000 in JEAC 4209. The rules also require preparation of maintenance plans in MR-4000 and inspection plans in MR-4300, so-called "checklists" for implementation of maintenance management.

On the other hand, KEPCO has not established the basic system to prepare systematic "checklists" and to manage in a unified manner for inspection frequencies, timing, methods and other details for the equipment subject to periodic licensees' inspections.

To correct these situations and prevent recurrence of an "omission from checklist" in the future, it is essential for licensees to prepare systematic and unified "checklists" and to ensure maintenance management of the lists. In other words, licensees are required to manage the inspection frequencies, timing, methods, maintenance results and other details for the equipment subject to periodic licensees' inspections under proper outsourcing management, assign checklist managers and establish data management rules among licensees and maintenance contractors. It is necessary to establish as quickly as possible a systematic checklist management system to achieve effective maintenance management by taking these measures.

These measures are vital prerequisites for prevention of occurrence of problems due to human error and proper implementation of periodic licensees' inspections. The licensees should take these actions steadily and strictly. When doing so, they have to be certain to achieve the verification of the current inspection points and the verification of influences of additional or changed inspection points on the entire system, for example, by changing the current method, in which some people extract the points to be managed from piping system diagrams and manage these points, with an improved method, in which administration tables link with the computerized piping system.

(2) Implementation of accurate outsourcing management (management of procurement of maintenance contractors)

Nuclear power plants require services rendered by maintenance contractors to carry out maintenance management activities including periodic licensees' inspections. Reflecting this fact, outsourcing management is a very important task to ensure proper implementation of maintenance management activities. The fitness-for-safety program at Mihama Power Station, for which KEPCO applied for an approval of change in

December 2003 and obtained the approval in May 2004, specify the requirements for procurement management to be carried out as a licensee in outsourcing security activities according to Section 7.4 of JEAC 4111.

By examining the way the pipe ruptured point in this accident was managed, loose outsourcing management (management of maintenance contractors) in preparation of "checklists" can be considered as one of the contributing factors that caused the accident. In other words, KEPCO entrusted MHI with the inspection task for wall thickness control, but KEPCO as the outsourcer failed to thoroughly confirm the adequacy of extracting the points to be managed according to the "PWR Management Guidelines."

After transfer of the inspection task for wall thickness control from MHI to Nihon Arm and when Nihon Arm found omissions of inspection, there was no appropriate communication with KEPCO.

At present, KEPCO has already introduced procurement management rules based on JEAC 4111 as described above. In the future, individual licensees, including KEPCO, must clarify their outsourcing management methods, division of responsibilities and other details in subordinate regulations of the security regulations specified at each power plant according to the requirements of JEAC 4111, conduct a drastic review to make sure the regulations function effectively, and follow them up as the countermeasures against these problems. In addition to the management and inspection tasks for the secondary piping that led to this accident, licensees outsource waste treatment, radiation measurement and management and other various kinds of maintenance management tasks to external companies or agencies. However, rights and obligations in outsourcing these tasks are not always clarified sufficiently. To improve these situations, it is necessary for licensees to organize what is to be specified in contract documents, purchase orders and other documents for outsourcing of important tasks in the implementation of security activities. It is also necessary to actively address education and training to improve the competence of employees in outsourcing management according to the requirements for human resources specified in JEAC 4111, Section 6.2.

NISA will request licensees to strongly recognize outsourcing management as an important responsibility of licensees that conduct periodic licensees' inspections. The Agency will also collect information from maintenance contractors regarding the states of implementation of maintenance inspections at power plants, attitudes of licensees and others in the context of the actual situation, and instruct and supervise the licensees and the maintenance contractors adequately.

(3) Standardization of pipe wall thickness control

It was revealed that KEPCO applies standards not specified in the "PWR Management Guidelines" to the wall thickness control of the secondary piping when the remaining life of the piping becomes shorter than 2 years. Consequently, the pipes had not been replaced properly and there were pipes with wall thicknesses below the minimum necessary wall thickness specified in the technical standards.

In the present system, the in-house regulations on the wall thickness control of the secondary piping hold a subordinate position to the "fitness-for-safety programm" of licensees. Therefore, NISA will carefully check the conditions of licensees' compliance with their in-house regulations in fitness-for-safety inspections to be conducted on the licensees continuously.

In the periodic safety management review, it is necessary to effectively check how the parties concerned, including maintenance contractors, carry out the wall thickness control of the secondary piping.

(4) Sound implementation of sharing information among licensees to prevent problems from occurring

It is very important to promote so-called "horizontal spread," which means making use of knowledge about problems and their solutions obtained by security activities to prevent problems from occurring.

Horizontal spread has been considered a voluntary activity of licensees. With the revision of the inspection system for nuclear facilities in October 2003, licensees were obliged to adequately reflect not only knowledge obtained by implementation of their own security activities but also knowledge obtained from other licensees to promote horizontal spread.

For that purpose, not only KEPCO but also every other licensee must reflect knowledge obtained by this accident on its own security activities as well as establish a system to promote horizontal spread systematically and carry it out steadily. NISA will continuously check whether each licensee is promoting horizontal spread accurately and take measures to prevent problems effectively in fitness-for-safety inspections and on other occasions.

8.2. Clarification of technical guidelines

As specified in "5. Pipe wall thinning management", each PWR plant controls thinning in the secondary piping based on the in-house standards established according to the "PWR Management Guidelines." Each BWR plant uses its own uniquely specified in-house standards, referring to the "PWR Management Guidelines."

More than ten years have passed since the "PWR Management Guidelines" were established in 1990. Data on thinning control in real plant facilities have already been accumulated in Japan. In the United States, ASME Code Case N597-1 and the guidelines of the Electric Power Research Institute (EPRI)(NSAC/L202-R2) were established as the standards for pipe wall thickness control in the period of 1998 through 1999. The Nuclear Regulatory Commission (NRC) approved these standards and revised IP (inspection program) 49001 to check if licensees are implementing the pipe thinning control properly based on the above-mentioned regulations. (Refer to Appendix 7.)

In Japan, the Japan Society of Mechanical Engineers (JSME) is developing a standard regarding pipe wall thickness control techniques for electric power facilities. In developing a standard, it is important to make efforts to improve the accuracy of the standard, for example, by adding data on actual measurement results by each licensee and reflecting the results of investigation of the cause of this accident. NISA will conduct a technological assessment immediately and position it as the judgment criterion in the Administrative Procedures Act in order to utilize the nongovernmental standards developed by JSME for safety control.

In consideration of this case, NISA will conduct activities to ensure that licensees recognize the importance of their well-planned implementation of pipe thinning control based on the above-mentioned standards as well as check whether licensees are conducting the inspections accurately in security inspections and on other occasions, as in the United States.

As a tentative measure to be taken until JSME establishes the standard, NISA will clarify the requirements for safety control in administrative documents by reviewing and verifying the contents of the "PWR Management Guidelines" and in-house standards of each BWR plant.

8.3. Verification of pipe wall thickness control in periodic licensees' inspections

The secondary piping including the ruptured portion in the accident was left to voluntary inspections by licensees in the past. Since October 2003, licensees have been obliged to conduct periodic licensees' inspections on the secondary piping based on the Electric Utilities Industry Law. In other words, the importance of inspections by licensees is clarified in the law. On November 14, 2003, NISA issued written instructions entitled "Interpretation of periodic licensees' inspections at nuclear power plants" and others to each nuclear undertaker, which specify concrete details of periodic licensees' inspections.

The Rules for the Enforcement of the Electricity Utilities Industry Law specify that the ruptured portion in this accident is placed as "main piping" of "pipes and other parts associated with the steam turbine" in the "steam turbine" of the facilities of pressurized-water reactor power plants. The regulations specify that the ruptured portion in this accident is placed as "main piping" of "reactor coolant circulation equipment" in the "reactor cooling system equipment" of the facilities of boiling-water reactor power plants. The regulations also specify that periodic licensees' inspections shall be conducted on the "reactor cooling system equipment" and "steam turbine."

In addition, the regulations specify that periodic licensees' inspections shall be conducted using appropriate methods for confirmation of "situations of occurrence of damage, distortion and abnormality in each part" and "functional and operation conditions."

In consideration of this case, NISA will clarify the aforesaid regulations and take actions to familiarize the regulations to the licensees, and then confirm the "policies and situations of implementation of pipe wall thickness control" during fitness-for-safety inspections by nuclear security inspectors conducted continuously at nuclear power plants. JNES should confirm the system of periodic licensees' inspections conducted by licensees regarding the matters necessary to ensure safety, including piping management, during periodic safety management reviews.

There is an opinion that these pipes should be subject to periodic inspections. However, periodic licensees' inspections are important inspections required by the law to be carried out by licensees and the secondary piping inspections are already positioned in the inspections. For these reasons, it is necessary to discuss carefully whether to impose periodic inspections by the regulatory agency.

8.4. Measures concerning thermal power plants

(1) Positioning of pipe wall thickness measurements at thermal power plants

For thermal power plants, pipe wall thickness measurements were not subject to periodic licensees' inspections based on the Electric Utilities Industry Law. Some plants have confirmed the conformity to technical standards regarding pipe wall thickness as a part of voluntary security activities. However, over half of the power plants have not carried out wall thickness measurements and a majority of points to be investigated have remained unexamined. Licensees are required to confirm the soundness of piping by conducting wall thickness and other inspections one by one on the points that have remained unexamined. To ensure that the conformity to technical standards regarding pipe thinning phenomena are continuously checked in the future, it will be discussed whether to include wall thickness inspections on pipes with possible thinning in periodic licensees' inspections.

(2) Examination of technical guidelines

For thermal power plants, no common technical guidelines have been available regarding pipe wall thickness management. Some licensees defined their own voluntary management policies. However, most licensees did no more than inspect only a part of the piping based on cases of troubles that occurred at other power plants.

Many licensees are making inspection execution plans, for example, referring to the "PWR Management Guidelines." 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 temperatures and pressures. Therefore, it is desirable 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 management at thermal power plants.

9. Ensuring of workers' safety

When the accident occurred, 105 employees of KEPCO and maintenance contractors were working in the turbine building for Mihama Power Station, Unit 3 for preparation of a periodic inspection. Eleven workers working near the ruptured A-system condensate pipe fell victim to the accident.

In nuclear power plants, it is routine for workers to enter turbine buildings even during plant operation for daily walk-around checks by operators and for other purposes. The fact that the workers are working inside the turbine building for preparation of the periodic inspection during plant operation does not directly become a problem. However, the fact that the first fatal accident arising from nuclear power generation occurred as a labor accident must be recognized seriously.

It is important for licensees to clearly position not only prevention of radiation hazards but also prevention of labor accidents at nuclear power plants in their management systems and carry out proper management and administration to respond to every situation.

In nuclear power plant facilities, workers involved in maintenance and inspection tasks for equipment belong to a wide variety of positions. There are probably many cases where workers do not have adequate knowledge of potential risks in the places and environments in which they are working. In terms of radiation control at nuclear power plants, licensees are obliged to provide personnel engaged in radiation work with education and training at nuclear power plants according to the Industrial Safety and Health Law, the Nuclear Reactor Regulation Law and other regulations. However, there is a possibility that potential risks inherent in working environments in terms of general labor accidents have not always been disseminated sufficiently.

NISA will demand that licensees take measures, such as providing preliminary training to workers involved in maintenance and inspection tasks inside facilities of nuclear power plants and putting notices of risk information at dangerous points in order to familiarize those workers with potential risks in their working environments depending on the plant operating conditions.

We should not consider this accident as a mere accident but make use of various lessons learned from this accident to further enhance disaster-prevention measures including improvement and expansion of initial measures and strengthen partnership among pertinent organizations if any trouble or accident occurs at nuclear power plants in the future.

10. Conclusion

Nearly two months have passed since the secondary piping rupture accident occurred at Mihama Power Station, Unit 3. This accident caused eleven causalities and is under the police investigation. The final conclusions will not be obtained for quite a while. Meanwhile, other nuclear power plants continue operation. It is important to put measures into practice as soon as possible for the problems that were revealed by this accident and which have to be reflected on the currently operating plants, rather than waiting to take measures until the final conclusions are obtained. With such a perspective, we have put together the immediate measures in this document. It goes without saying that recurrence prevention measures will be added depending on the progress of the investigations in the future.

In addition, the problem of aging of nuclear power plants is pointed out after this accident. The primary cause of this accident is that necessary pipe thinning management was not carried out properly. At nuclear power plants that have operated over many years, so-called aging nuclear power plants, it is likely that aged deterioration events will increasingly come up to the surface. Needless to say, more careful inspection management will be required in the future.

At present, as a part of periodic safety reviews, the nuclear power plants that have operated over 30 years are required to make a comprehensive evaluation of aging. This accident indicates that this activity will be more important in the future. It is important to make an appropriate evaluation of changes caused by aging for the nuclear power plants that have operated for less than 30 years. It is also necessary to reaffirm the role of the periodic safety reviews that NISA requests to perform each decade.

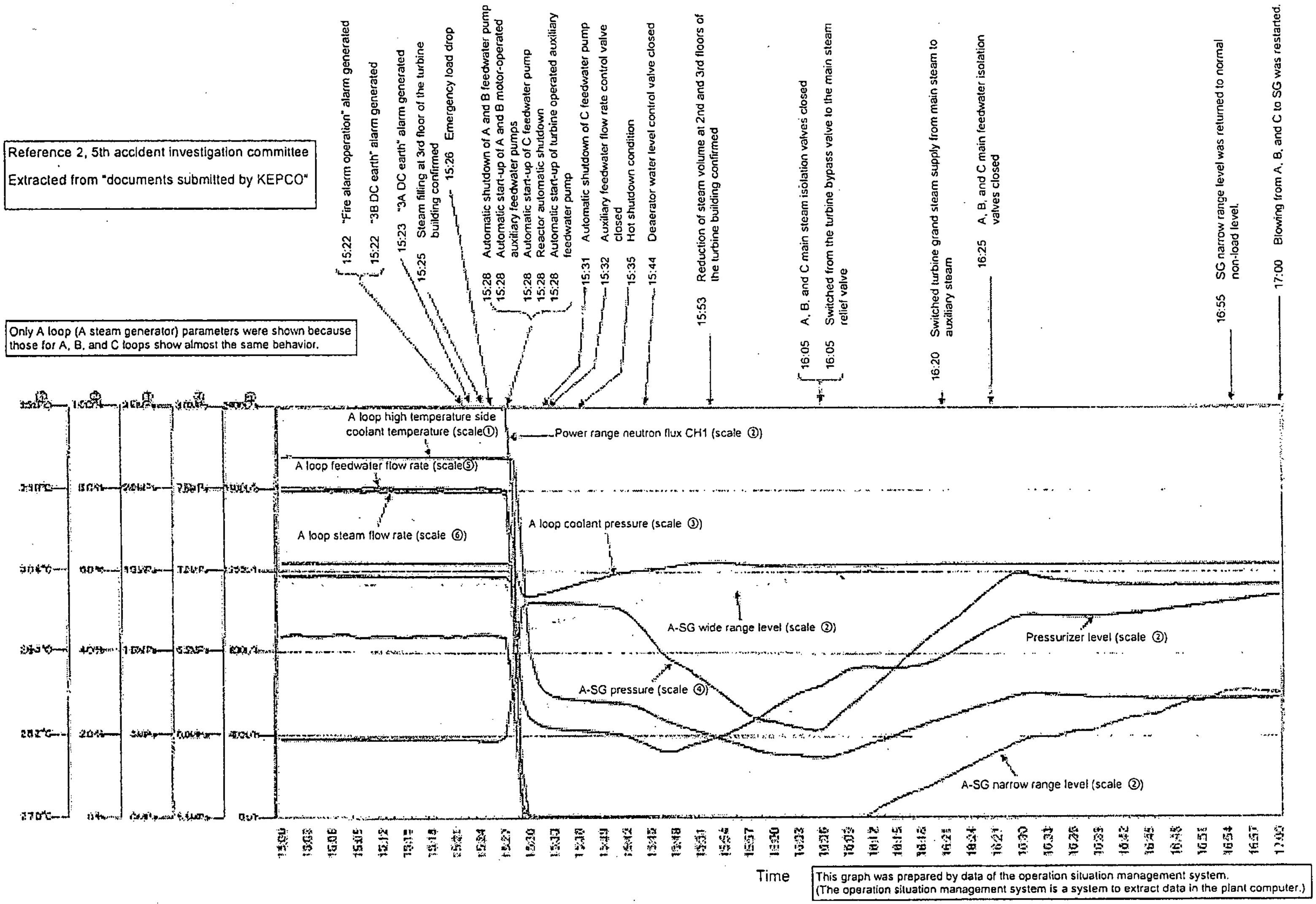
11. List of members of the Accident Investigation Committee for the Secondary Piping Rupture at Mihama Power Station, Unit 3

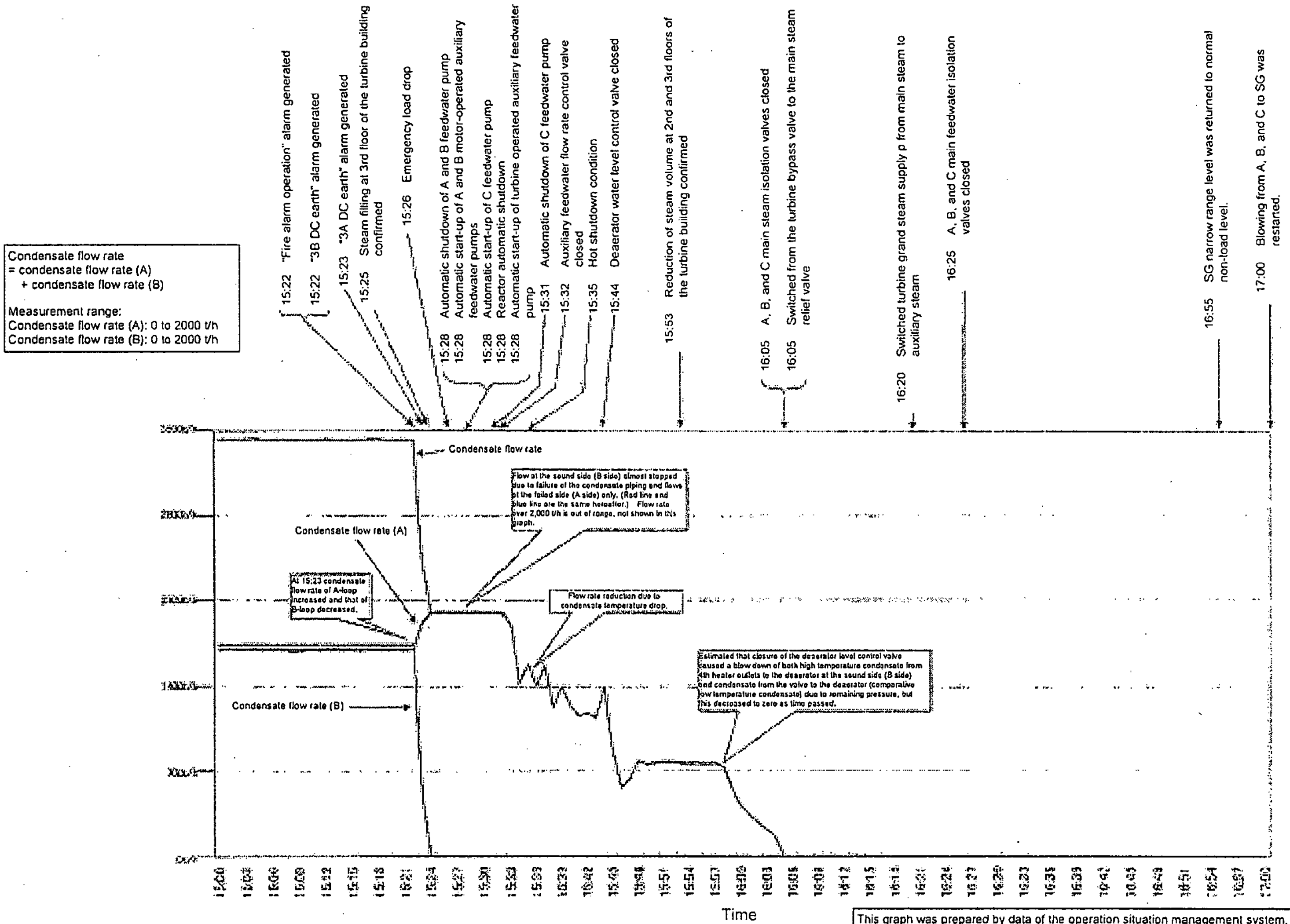
Chairman	Yasuhide Asada,	Technical advisor of the Thermal and Nuclear Power Engineering Society
	Yoshinori Iizuka,	Professor of Graduate School of Engineering, the University of Tokyo (from the fourth meeting)
	Hideo Kobayashi,	Professor of Graduate School of Science and Engineering, the Tokyo Institute 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

<Appendices>

(Appendix 1)	History of major plant parameters at the secondary piping rupture accident
(Appendix 2)	Response of nuclear safety inspectors after accident occurrence
(Appendix 3)	Results of investigation for the secondary piping rupture accident in Mihama Power Station, Unit 3
(Appendix 4)	Study of validity of "PWR Management Guidelines"
(Appendix 5)	General description of thinning phenomenon of main feed water piping of Ohi Power Station, Unit 1
(Appendix 6)	Results of verification by NISA for the reports of control situation of piping thinning electric power companies
(Appendix 7)	Regulation of thinning control in the United States

History of major plant parameters at the secondary piping rupture accident





This graph was prepared by data of the operation situation management system.
(The operation situation management system is a system to extract data in the plant computer.)

<Response of nuclear safety inspectors after accident occurrence>

Action at Mihama Power Station	On-site Response of NISA
August 9 (Monday)	August 9 (Monday)
15:22 "fire alarm operation" alarm generated	
15:25 Operators confirmed that deaerator side on the 3rd floor of the turbine building was filled with steam.	
15:26 Operators judged that steam or high temperature water potentially leaked from the secondary piping and started emergency load drop.	
15:27 Operators found a fallen victim at the front of elevator of the 2nd floor of the turbine building.	
15:28 "3A SG Feed Water < Steam Flow Inconsistency Trip" alarm generated, triggering automatic shutdown of the reactor and turbine.	
15:32 KEPCO delivered the first report to the Safety Agency (the head office and the on-site nuclear safety inspectors).	15:32 The on-site nuclear safety inspectors first received a verbal report at the site inspector's room and instructed the licensee to check for any problem with reactor safety and radiation leakage. Two on-site inspectors started situation investigation.
15:35 Operators confirmed that automatic shutdown situation was normal and the reactor was stable at hot shutdown condition.	15:34 The on-site nuclear safety inspectors telephoned to report to the disaster prevention section in the head office of NISA and the Mihama inspector's office sequentially and started to collect information from people concerned and instructed operators to confirm the situation regarding victims.
15:53 Operators confirmed that steam flow at 2nd and 3rd turbine floors was decreased.	
16:00 The first ambulance left (with one victim).	16:01 The on-site nuclear safety inspectors at the site inspector's room instructed the licensee to report at any time on existence of abnormality for reactor shutdown condition and also confirmed a written report that no radiation leakage had occurred and reported the information and the number of victims to the head office of NISA.

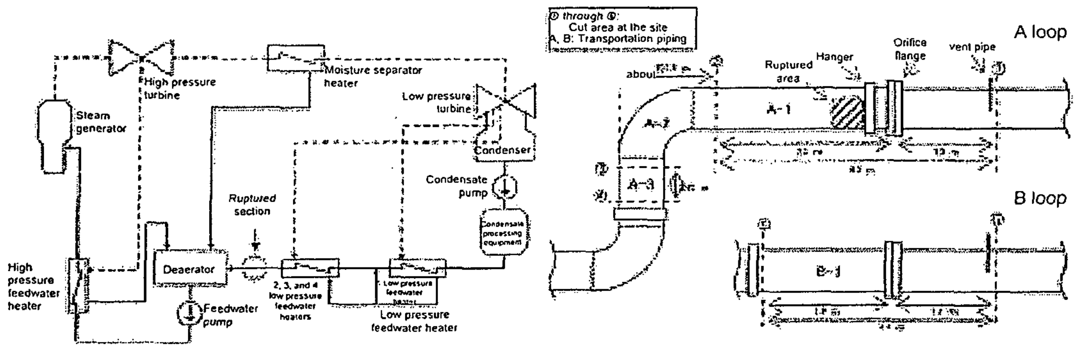
Action at Mihama Power Station	On-site Response of NISA
16:13 The second ambulance left (with three victims). 16:20 The third ambulance left (with two victims).	16:15 The on-site nuclear safety inspector at the site inspector's room continued to instruct the licensee to confirm the situation and reviewed the written report from the operator and reported it to the head office of NISA. Thereafter, the on-site nuclear safety inspectors instructed the operator to report the reactor situation and victims' conditions as needed and reported the information on plant conditions and victims' conditions to the head office of NISA as needed.
16:38 The fourth ambulance left (with two victims). 16:46 The fifth ambulance left (with two victims). Fire station's car left (with one victim).	
17:30 Operators inspected inside of the turbine building to confirm that A loop condensate piping, which connects from the fourth low pressure feedwater heater to the deaerator, was broken around the ceiling on the deaerator side at the 2nd floor of the turbine building .	18:45 After a safety statement by the fire station, the on-site nuclear safety inspectors entered the turbine building to check the situation.
19:00 Fire station confirmed that no victims were found in the turbine building.	19:05 The on-site nuclear safety inspectors confirmed the broken condensate piping and took pictures. 20:50 At the same time as the arrival of a councilor of NISA to Mihama office, an on-the-spot accident countermeasures headquarters of the Ministry of Economy, Trade and Industry was established. 21:00 Establishment of the on-the-spot accident countermeasures headquarters was announced to the local government and towns. Around 21:20 The on-site nuclear safety inspectors checked the situations of the main control room and plant conditions and reported them to NISA. 21:30 A three-way videoconference was held. (Fukui Prefecture, on-the-spot accident countermeasures headquarters, and NISA head office) 22:10 A two-way videoconference was held. (Fukui Prefecture and on-the-spot accident countermeasures headquarters)
23:30 Operators started the low temperature shutdown procedure.	

(Actions at Mihama Power Station were summarized based on the report from KEPCO)

Appendix 3

<Results of investigation for the secondary piping rupture accident at Mihama Power Station, Unit 3>

1. Summary of investigation



Main data:

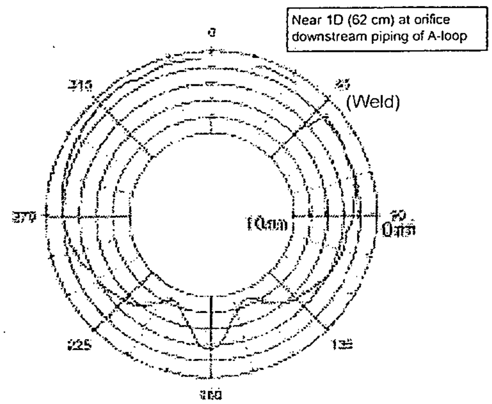
(1) Orifice downstream piping, Material: JIS G3103 SB42 Diameter (hereinafter referred to as D): about 560 mm, Thickness: about 10 mm

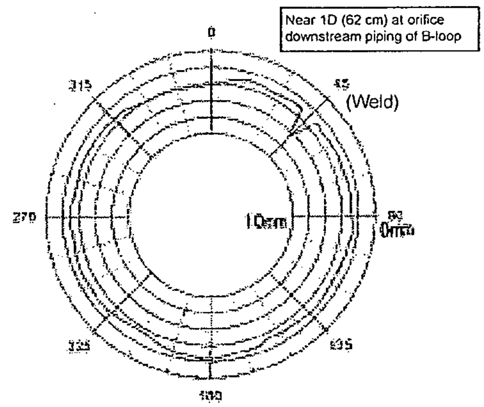
(2) Flow condition during operation, Flow rate: about 1,700 t/h, Pressure: about 0.93 MPa (10 kgf/cm^2), Temperature: 142°C, Flow velocity: about 2.2 m/sec

(3) Operation time, about 185,700 hours

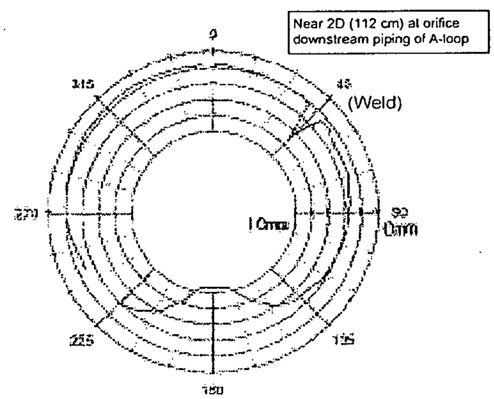
(4) Water chemistry: pH: 8.6 to 9.3, dissolved oxygen concentration: less than 5 ppb.

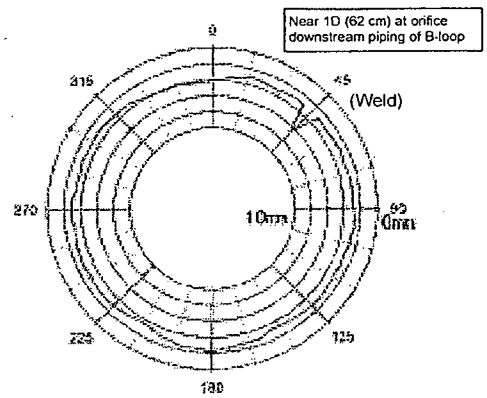
2. Results of piping thickness measurement





Near 1D from orifice downstream end





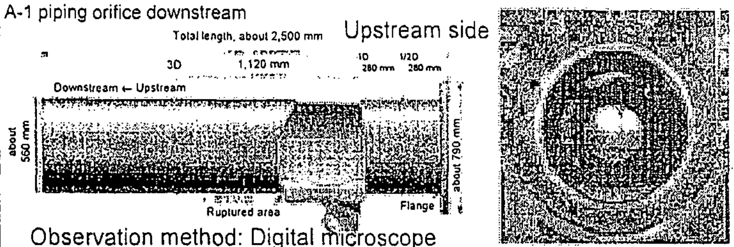
Near 2D from orifice downstream end

A-1 Situation of reduced thickness at orifice downstream piping

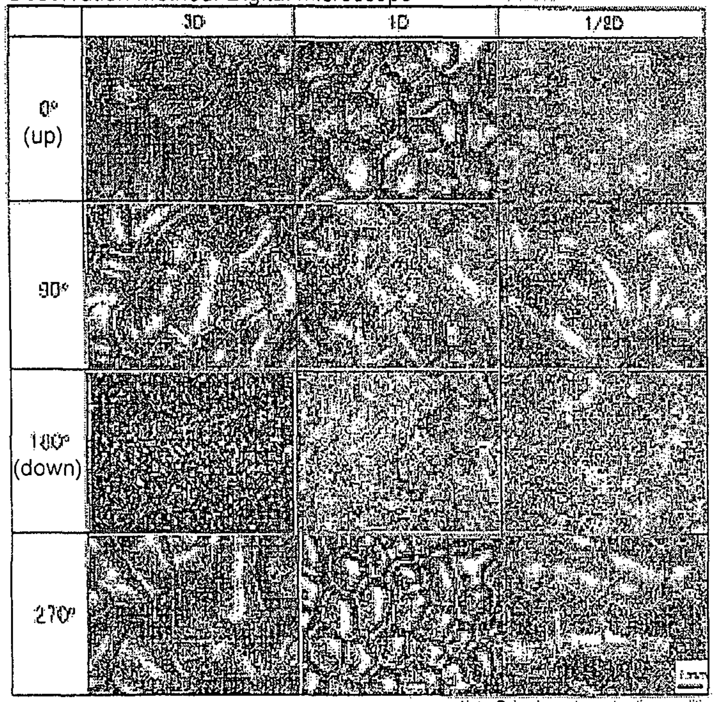
B-1 Situation of reduced thickness at orifice downstream piping

3. Observation results of the inside of the piping

A-1 piping orifice downstream



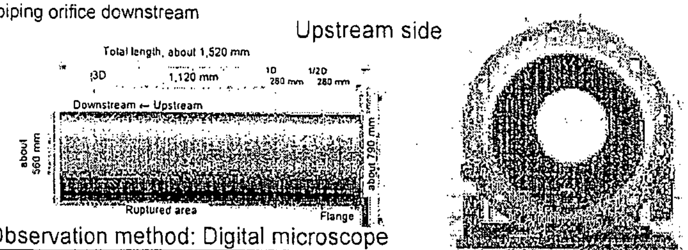
Observation method: Digital microscope



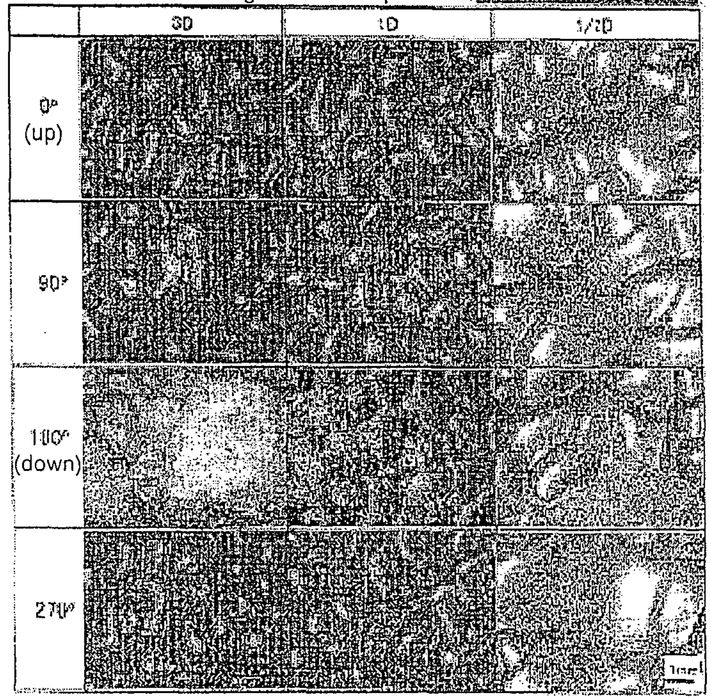
Note: Color depends on shooting conditions.

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

B-1 piping orifice downstream

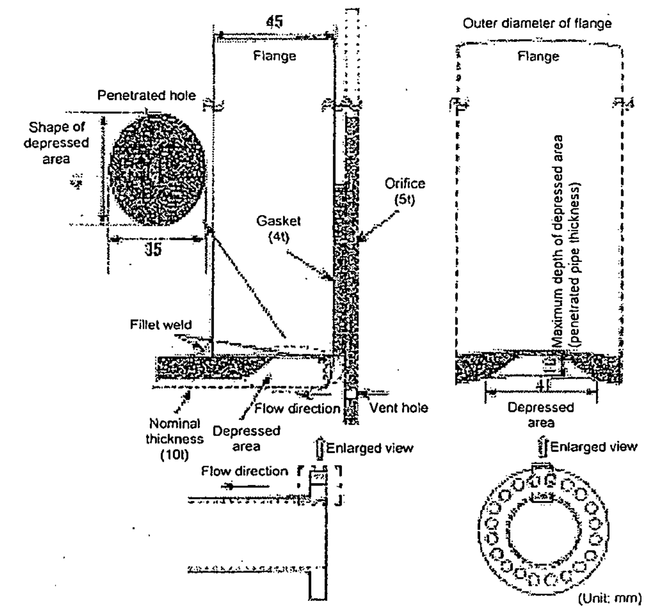


Observation method: Digital microscope

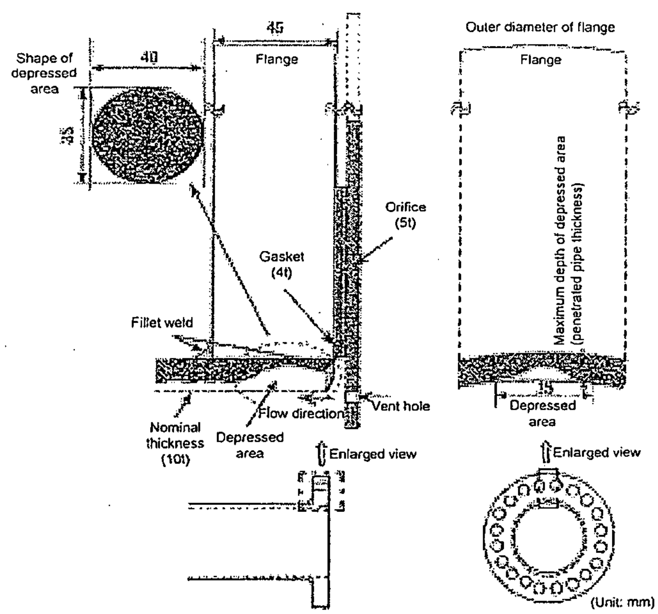


Conclusion: Fish Scale-like pattern was observed at B-1 piping orifice downstream area.

4. Situations at downstream of the vent hole



A loop orifice downstream flange



B loop orifice downstream flange

Source: Extracted from 5th accident investigation committee, reference 5-1-2 (Attachment 1) (documents submitted from JAERI and JNES)

Appendix 4

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

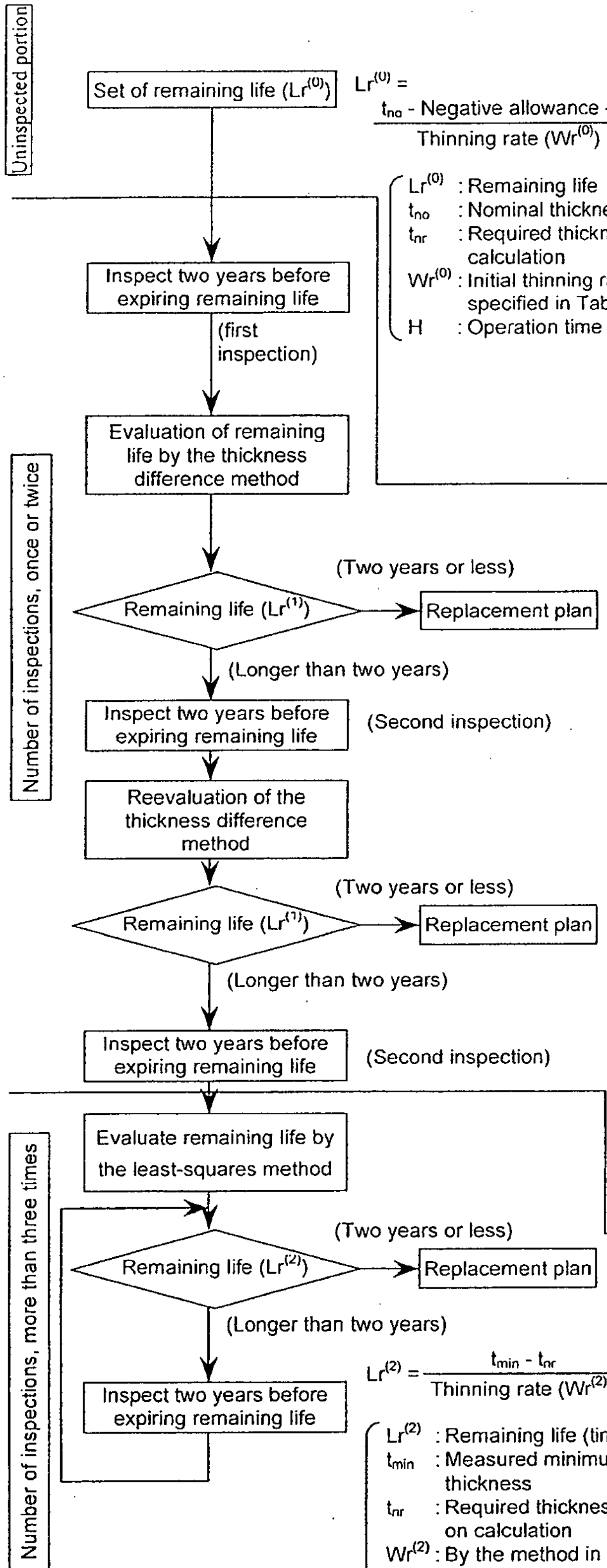
Remaining life to the necessary minimum thickness on calculation should be determined at each location, and the area concerned should be inspected before the remaining life is less than two years. It is also stipulated that the inspection should be repeated using evaluation of inspection results until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

Table 1 Main systems to be inspected

Classification	Requirements: Wetness fraction	Requirements: Flow velocity	Requirements: Temperature	Typical system name	Remarks
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		① 0.30	① 0.35		
		30 m/s - 50 m/s			① 1.15		
		50 m/s or more					
Two-phase flow, wetness fraction, 5 to 15%	Flow velocity	30 m/s or less			① 0.35		
		30 m/s - 50 m/s			① 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			① 0.35		
		30 m/s - 50 m/s			① 1.15		
		50 m/s or more					
Water single-phase flow	Flow velocity	3 m/s or less		① 0.45		① 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 $Wr^{(2)}$ Measured thickness / Operation time

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 $3 \times D$ (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

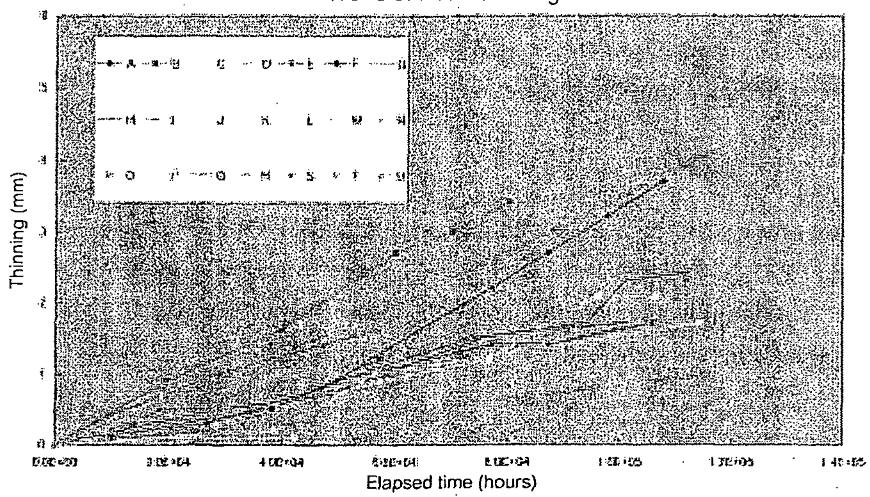
(1) Applied management method

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.

Trend of PWR thinning



* Elapsed time is the time after an initial inspection.

No.	System name	Inspection area	Material	Tempera-ture (°C)	Flow velocity (m/s)	Wetness Fraction	Thinning rate (×10^{-4} mm/Hr)	Guide-line category
A	Main feedwater piping	Straight pipe (Downstream of control valve)	STPT49	228	5.3	Water	0.40	⑨
B	Main condensate piping	Straight pipe (Downstream of orifice)	SB42	145	3.0	Water	0.43	⑧
C	Main condensate piping	Straight pipe (Downstream of orifice)	SB42	147	4.0	Water	0.41	⑧
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	⑧
F	Main feedwater piping	90 degree elbow	SB49	190	5.1	Water	0.42	⑧
G	Condensate system	90 degree elbow	SB42	132	3 or less	Water	0.30	⑧
H	Condensate system	90 degree elbow	STPT38	147	3 or less	Water	0.30	⑧
I	Condensate system	T pipe	SB410	148	3 - 6	Water	0.18	⑧
J	High and low pressure vent drain system	Curved pipe	PG370	187	3 or less	Water	0.26	⑧
K	High and low pressure vent drain system	Reducer	SB42	191	3 or less	Water	0.17	⑧
L	Feedwater system	90 degree elbow	SB42	189	3 - 6	Water	0.24	⑧
M	Feedwater pump minimum flow piping	90 degree elbow	STPT38	182	2.3	Water	0.19	⑧
N	Feedwater pump minimum flow piping	Downstream piping	STPT38	182	2.3	Water	0.32	⑧
O	Main feedwater piping	Straight pipe (Downstream of control valve)	STPT49	221 or less	0.0	Water	0.04	⑧
P	Condensate piping	T pipe (Mother pipe side)	SB42	151	3.7 (Mother pipe side)	Water	0.10	⑧
Q	Condensate piping	T pipe (Branch pipe side)	STPT38	151	3.7 (Mother pipe side)	Water	0.28	⑧
R	Main feedwater booster pump discharge piping	90 degree elbow	SB42	188	5.7	Water	0.35	⑧
S	Main feedwater booster pump discharge piping	Downstream piping	SB42	188	5.7	Water	0.09	⑧
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	⑦
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	⑦

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

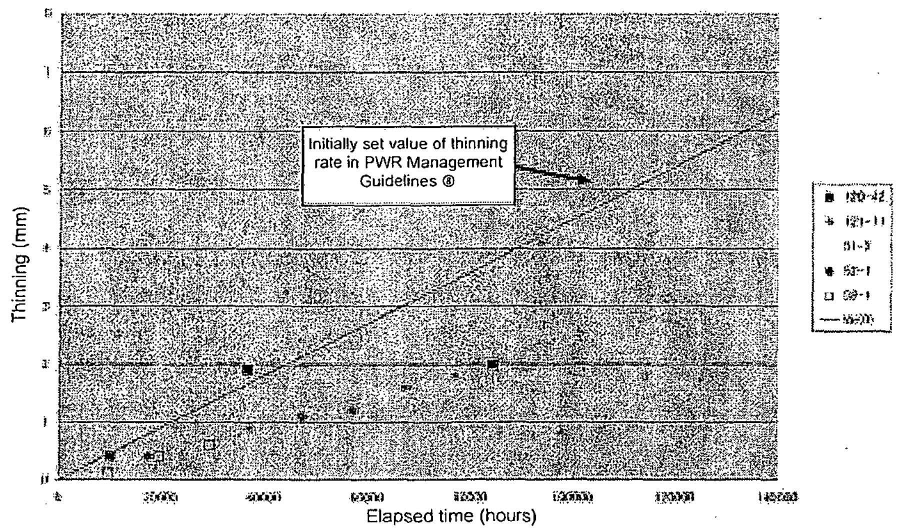
(Note) Initially set value of thinning rate in PWR Management Guidelines

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="5">Temperature</th></tr>
<tr><th>100°C or less</th><th>100°C - 150°C</th><th>150°C - 200°C</th><th>200°C - 250°C</th><th>250°C or more</th></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">① 0.30</td><td colspan="2">② 0.35</td><td></td></tr>
<tr><td>30 m/s - 50 m/s</td><td></td><td colspan="2" rowspan="2">③ 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">④ 0.35</td><td></td></tr>
<tr><td>30 m/s - 50 m/s</td><td></td><td></td><td colspan="2" rowspan="2">⑤ 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">⑥ 0.35</td></tr>
<tr><td>30 m/s - 50 m/s</td><td></td><td></td><td colspan="3" rowspan="2">⑦ 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">⑧ 0.45</td><td rowspan="3">⑨ 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.

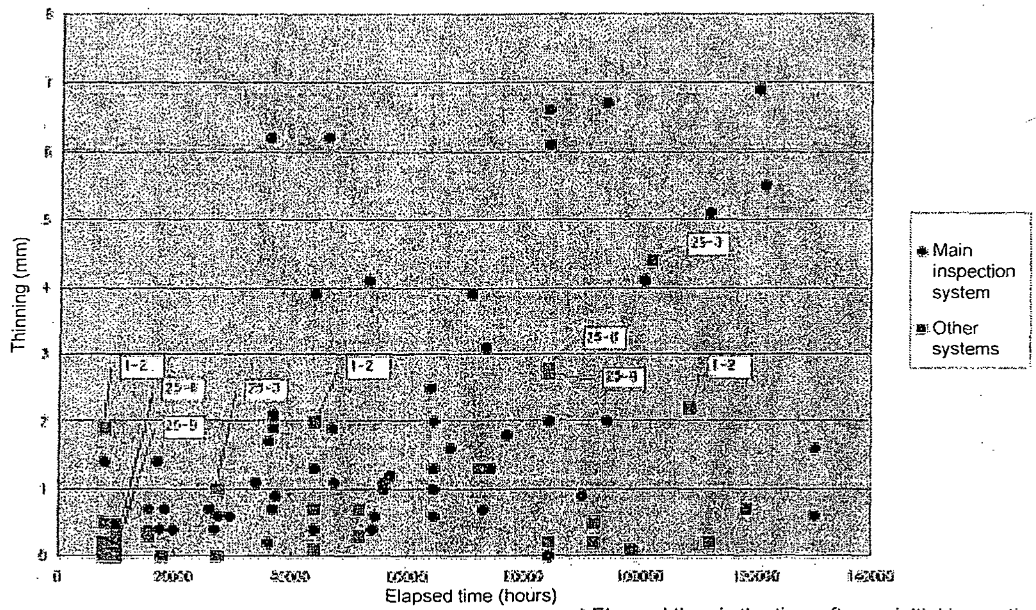
Figure 2 Measurement area and the trend of thinning in PWR piping



* Elapsed time is the time after an initial inspection.

No.	System	Inspection area	Material	Wetness fraction	Flow velocity (m/s)	Temperature (°C)	Wr[(i)] ($\times 10^{-4}$ mm/hr)	Measured thinning rate ($\times 10^{-4}$ 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

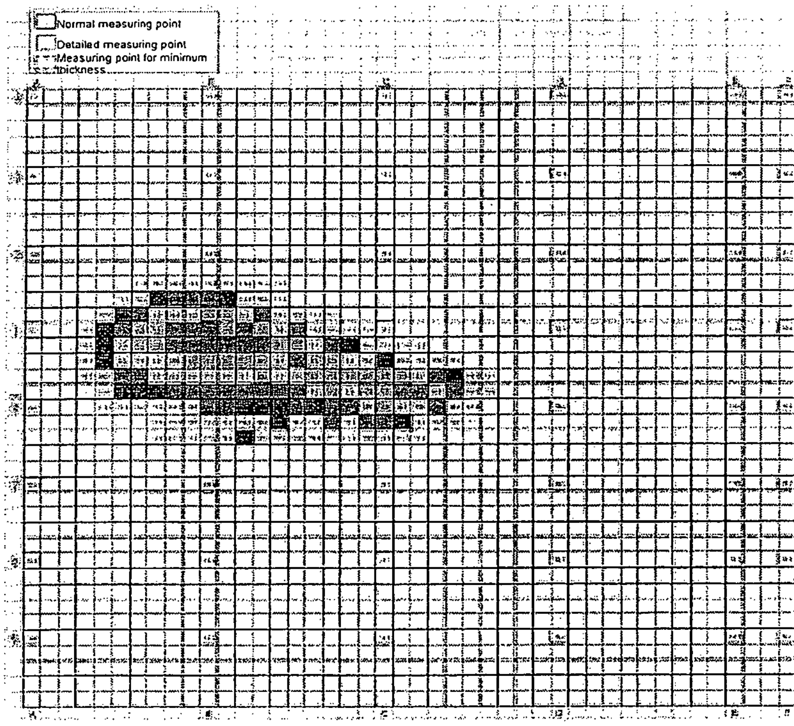
Figure 3 Measurement area and the trend of thinning in Mihama Unit 3 piping



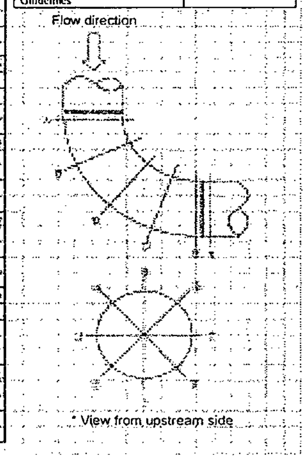
* Elapsed time is the time after an initial inspection.

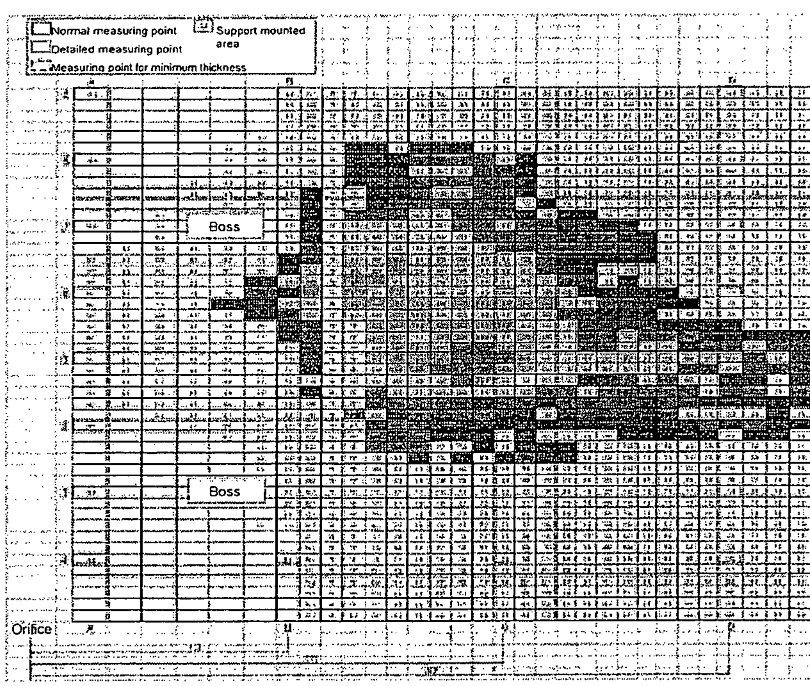
No.	System	Inspection area	Material	Wetness fraction	Flow velocity (m/s)	Temperature (°C)	Measured thinning rate ($\times 10^{-3}$ mm/hr) mm
1-2	No.3 extracting piping	T pipe	STPT38	5% or less	30 - 50	100 - 150	0.266
15-1	Turbine bypass piping	Reducer	STPT39	5% or less	30 or less	250 or more	0.075
16-5	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	ⓓ

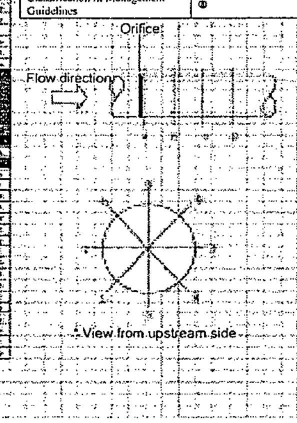
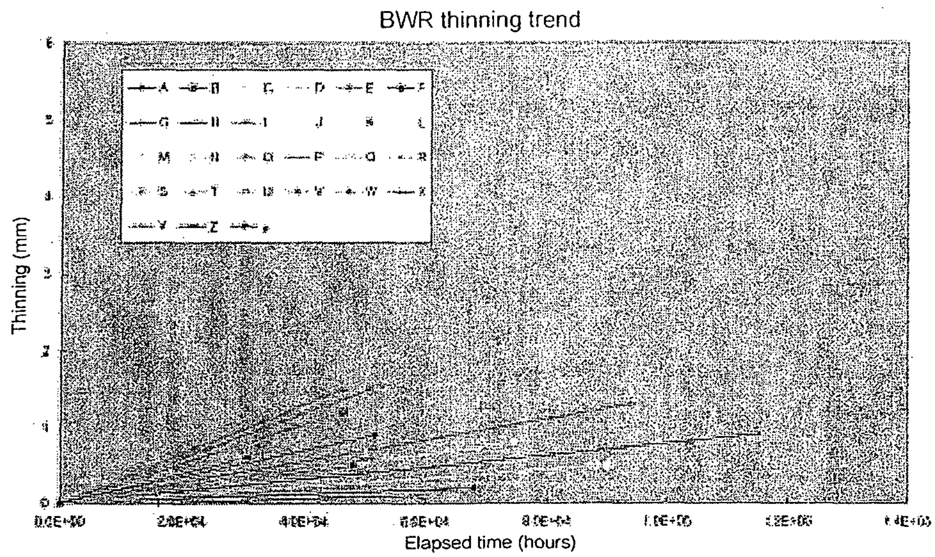


Figure 5 Measured results of Mihama Unit 3 (example)



* Elapsed time is the time after an initial inspection.

No.	Inspection part	Material	Temperature (°C)	Flow velocity (m/s)	Wetness fraction	Thinning rate ($\times 10^{-4}$ 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

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.

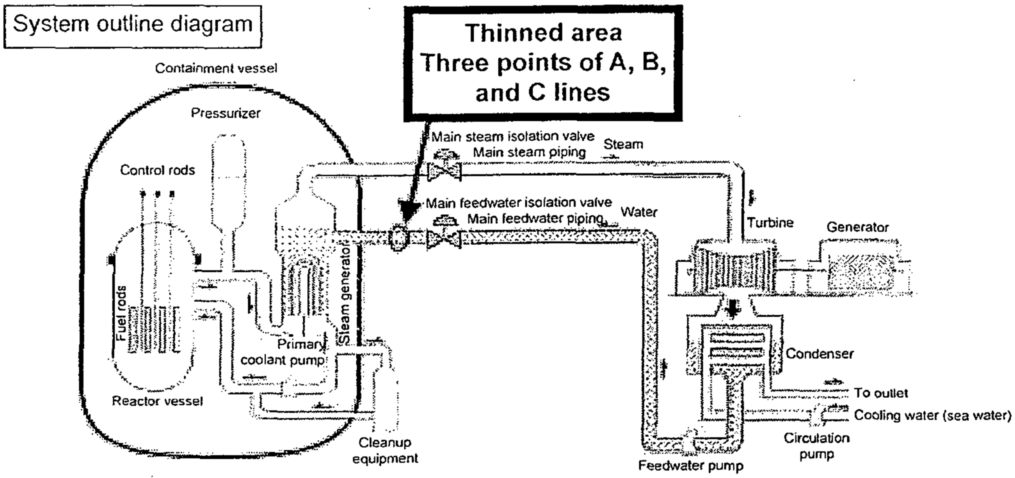
1) To replace the elbow area concerned with piping manufactured at the same dimensions using the same material.

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 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



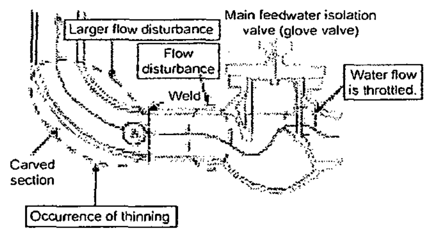
Measurement results

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

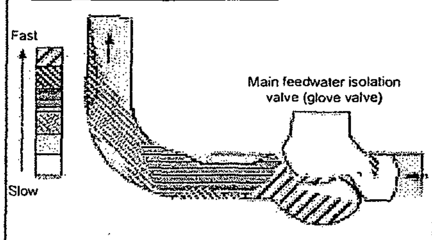
Outer diameter: about 410 mm
Thickness: about 21 mm
Maximum internal pressure: about 8 MPa
Maximum temperature: about 230°C
Material: Carbon steel pipe
Flow rate: about 1,700 t/h, loop

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.

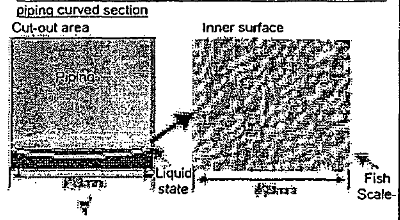
Flow pattern analysis



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

Enlarged view of "A" area

Example B: Expanded observation result of main feedwater piping curved section



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

Appendix 6 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.

Regulation of thinning control in the United States

Troubles

'76 Millstone, Unit 3
'82 Oconee, Unit 1 and 2
Vermont Yankee
Trojan
Zion
'85 Trojan
'85 Haddam Neck

1986
Feedwater piping of Surry, Unit 2 was ruptured.

Many thinning and rupture phenomena occurred.

Main phenomena noticed in NRC's IN, etc.
IN: Information Notice for information communication of safety issues

'87 Trojan
'88 Surry, Unit 2
'89 ANO 2
'90 Millstone, Unit 3
San Onofre, Unit 2
Surry, Unit 1
Loviisa, Unit 1
'91 Millstone, Unit 2
'92 Catawba, Unit 2
Susquehanna
'94 Sequoyah, Unit 1
'97 Fort Calhoun
'99 Callaway, Unit 1
'01 Callaway
'02 Columbia
'03 Millstone, Unit 2
Watts Bar, Unit 1

Damages due to erosion/corrosion (E/C) are often generated at the turbine system.
E/C: Erosion/Corrosion

NRC's response

NRC: Nuclear Regulatory Commission
BL: Bulletin
Notice on emergency issues
GL: Generic Letter
Notice on generic issues
IP: Inspection Procedure
NRC's inspection procedure

1987
BL 87-01
Regarding thinning of piping

1989
GL 89-08
Regarding thinning of piping due to erosion/corrosion

Finally issued GL 89-08 requiring all licensees to submit information on monitoring program for piping thickness of carbon steel piping at high-energy single-phase and two-phase flow.

1992
Staff Inspections
Inspections on execution of monitoring program for erosion/corrosion (5 plants)

IP 49001
Inspection procedure of erosion/corrosion monitoring program

1998
IP 49001
Revision

- This monitoring-type inspection continuously monitors the licensee's activity responding to erosion/corrosion in licensed plants.
- Additional inspections conducted as needed.
- Items indicated in outlined characters are used at present.

Approved private codes

Response by U.S. industry concerned

1985
EPRI's report (NP3944) explains primary causes of erosion and corrosion and guideline of inspection program.

EPRI: Electric Power Research Institute

1987
NEI
Erosion/corrosion guideline for single-phase flow in carbon steel piping

NEI: Nuclear Energy Institute
ASME: American Society of Mechanical Engineers

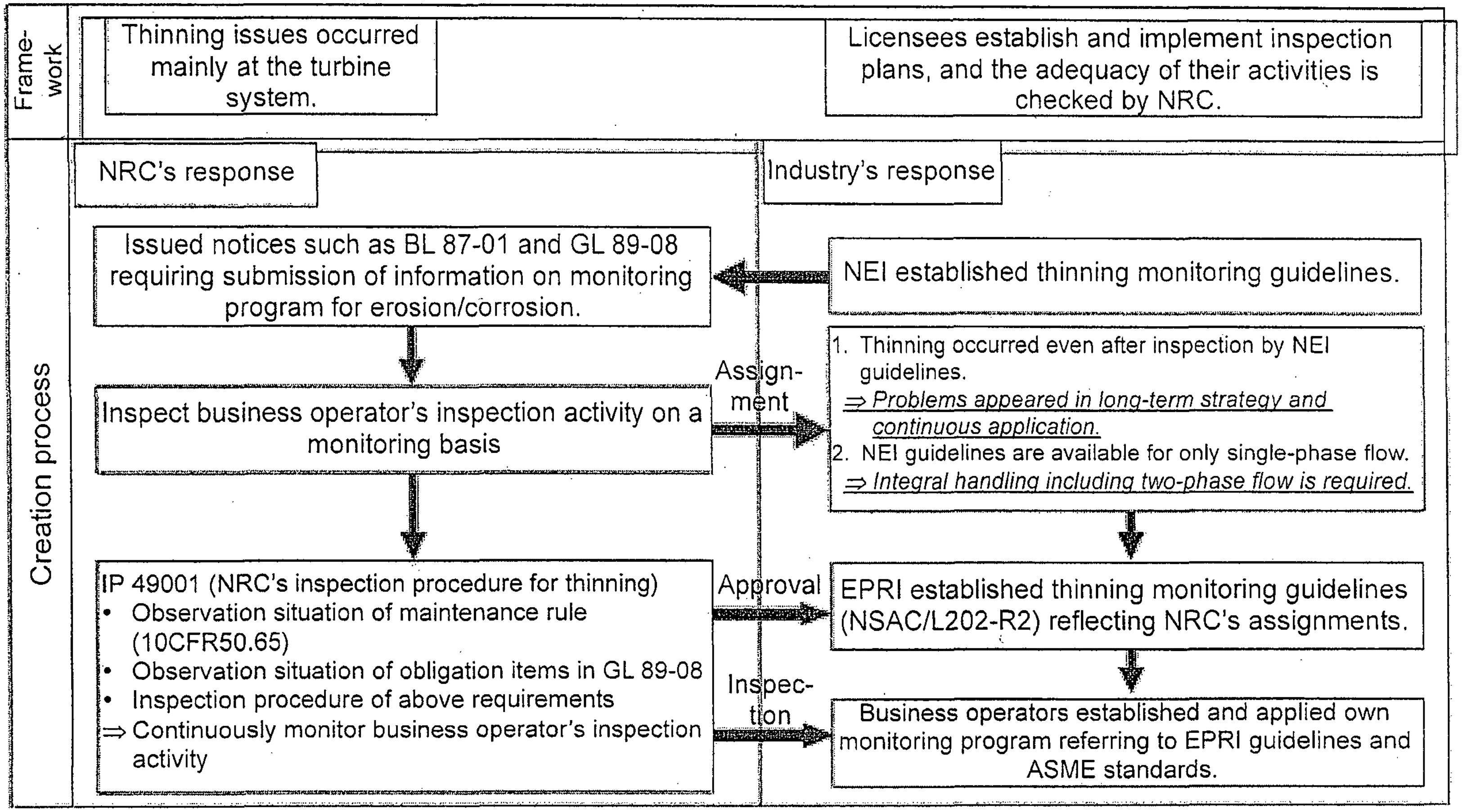
EPRI: Development of thinning estimating code available for single/two-phase flow (finally integrated to CHECWORKS)

ASME: Establishment of the erosion/corrosion guidelines in ASME Sec. XI. According to NRC requirement

1999
EPRI (NSAC/L202-R2)
Recommended program effective for flow acceleration corrosion (FAC)

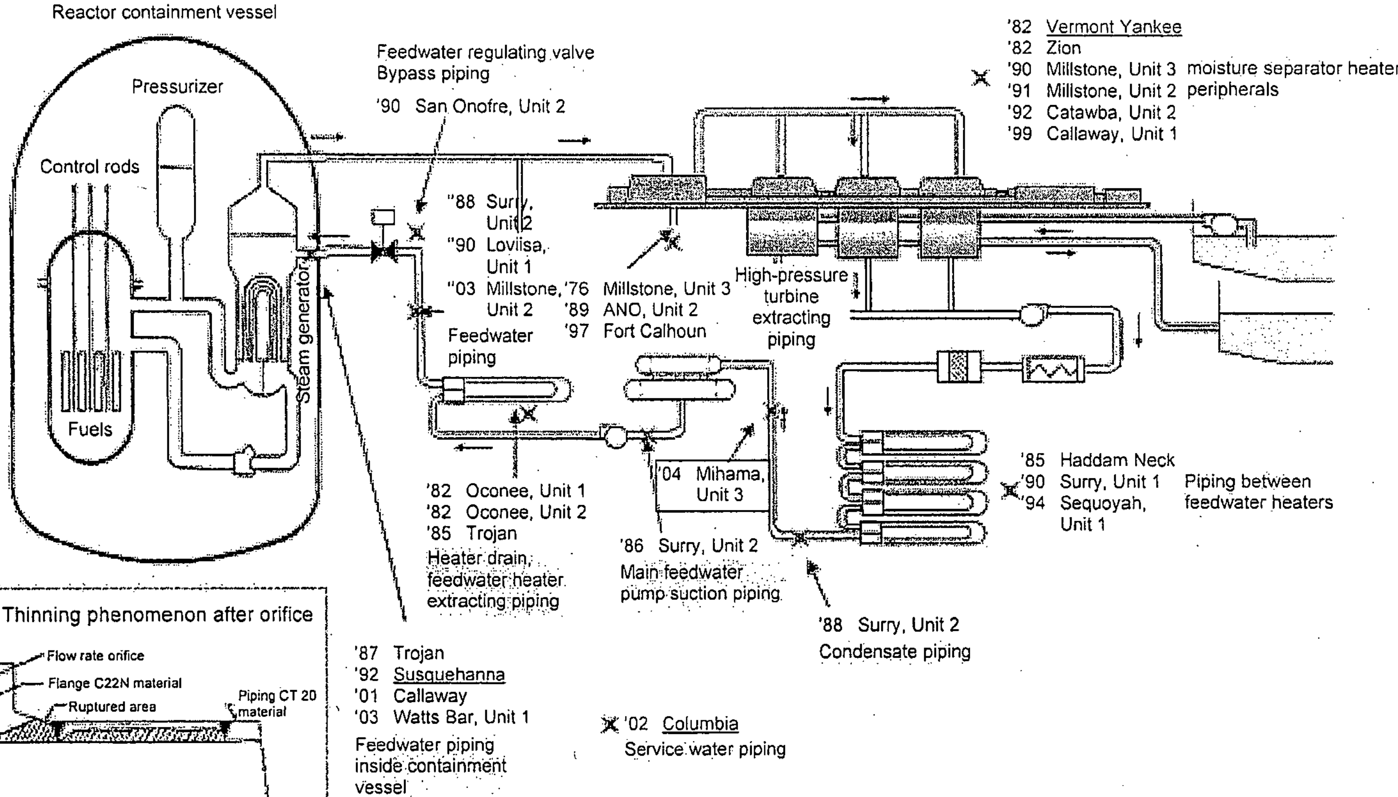
1998
ASME
(Code Cases N 597-1)
Analytical requirements of piping thinning

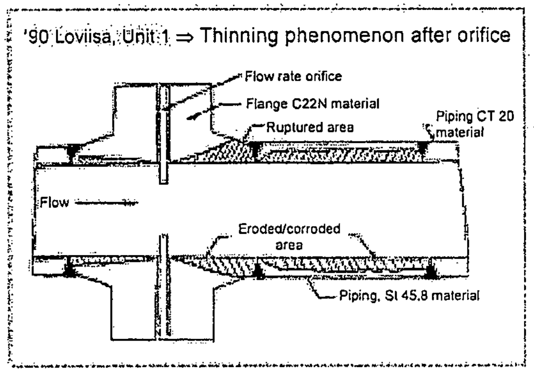
Framework of regulations on thinning and its creation process



* Maintenance rules
- Required self-controlled monitoring for effectiveness of maintenance management (10CFR50.65)
- Licensees established own maintenance program based on above private codes and NRC inspected it.

(Reference) Piping thinning occurred at overseas plants





'YY plant name ⇒ occurrence year and PWR
'YY plant name ⇒ occurrence year and BWR
The above diagram shows PWR, but BWR data are also indicated at corresponding areas.