Steam Eruption from Secondary System Piping in Nuclear Power Plants

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(Summary)

On 9th August 2004, piping ruptured and a steam eruption occurred in the turbine building (3 stories) of the nuclear power plant under operation. An inspection team on the 2nd floor suffered the eruption, resulting in 4 deaths, 2 severe injuries and 5 injuries. One of the 2 severe injuries died later. As an accident of the nuclear power plant under operation, it was the worst ever happen. As the ruptured piping was secondary system piping, there was no radioactive contamination.

The cause of the eruption was localized metal loss of piping due to erosion and/or corrosion. In order to measure the coolant flow rate in the piping, an orifice flow meter was installed. This caused a localized metal loss in cross-sectional area of the piping year-to-year, and the stress level became higher, at last, plastic collapse was occurred and the piping ruptured. As a result, large quantities of high temperature water became steam, and blew off.

This part of the piping was widely recognized as a suspected part for erosion and/or corrosion, and it should be inspected periodically. However, the pipe thickness was not checked for 27 years due to oversights.

1. Component

Pressurized Water Reactor (PWR), a turbine for an electric power generation, a condensate pipe which connects a condenser and a steam generator

2. Event

On 9th August 2004, a piping ruptured and a steam eruption occurred in the turbine building (3 stories) of the "mihama nuclear power plant No.3" under operation, which belongs to The Kansai Electric Power co., inc, Japan. An inspection team on the 2nd floor suffered the eruption, resulting in 4 deaths, 2 severe injuries and 5 injuries. One of the 2 severe injuries died later. As an accident of the nuclear power plant under operation, it was the worst ever happen. As the ruptured piping was secondary system piping, there was no radioactive contamination.

The rupture occurred at the carbon steel pipe which was connecting the condenser and steam generator. The specifications are as follows; outer diameter: 560mm, thickness: 10mm, coolant pressure: 10 MPa, temperature: 142 degrees Celsius. Eruption makes maximally 570mm fissure, which resulted in blow off of 800 tons coolant from the pipes. The thickness of the ruptured pipe was reduced to 2〜3mm. The minimum thickness was about 0.4mm. In order to satisfy safety standards, the cross-section should have had a thickness of at least 4.7mm.

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This part of the piping is widely recognized as a suspected part for erosion and/or corrosion, and it should be inspected periodically. The bylaw of The Kansai Electric Power Company orders to inspect the thickness of a fourth of all secondary piping every ten years. Inspection of all secondary piping, therefore, complete by 40 years. The burst section of pipe has never been inspected for 27 years since the plant started operation. On the other hand, The Kansai Electric Power Company inspected other eight nuclear power plants which have identical system of secondary piping from 1990 to 2003. As a result, they found reduction of thickness of pipe in "Ohama nuclear plant No.1" and "Takahama nuclear plant No.2" which have same orifice at same position to "Mihama nuclear plant No.3". Those pipes were replaced with the pipe made of an Austenite stainless steel. In the case of the Mihama nuclear power plant, because of oversights by The Kansai Electric Power Company and the inspection companies (Mitsubishi Heavy Industries and Nihon Arm), the thickness of the pipe was not inspected.

Investigation headquarters of Tsuruga station, Fukui prefectural police, opened a criminal investigation of fatal professional negligence.

3. Course

In the latter half of 1975, thickness reduction of pipes due to erosion and/or corrosion was occurred in some pressurized water-reactor (PWR) and wall-thickness investigations were conducted. Subsequent to this, Sally nuclear plant accident was occurred in the U.S. in December 1986, then power plant companies investigated a management method for the thickness reduction of pipe by evaluating the inspection results of all PWR plants. As a consequence of this study, in May 1990, a management guideline for PWR's secondary piping was decided. Although the guidelines were decided in 1990, it has not revised more than ten years even though they got many data regards thickness reduction.

From 1985 to 1989, The Kansai Electric Power Company had outsourced the pipe wall-thickness measurement and data collection to Mitsubishi Heavy Industries. This data was used for formulating the PWR's maintenance standard in 1990. The section which caused the accident was erroneously omitted on the inspection list of Mihama nuclear power plant No.3 made by Mitsubishi Heavy Industries. A total of three sections, two sections at condensation orifice flow meter at downstream and one part at steam converter heating steam orifice flow meter at downstream, out of 39 sections in Mihama nuclear plant No.3 were erroneously omitted on the inspection list. It is unknown why those three parts were not listed. The Kansai Electric Power Company did not check the inspection list, either.

In 1996, The Kansai Electric Power Company changed the contract of an inspection service from Mitsubishi Heavy Industries to Nihon Arm. However, even at the time, the inspection list had still not been revised.

Nihon Arm carried out maintenance of the inspection list from 2001 to 2002. In April 2003, a maintenance worker found the omitted section and revised the mistake of the inspection list. Nihon Arm put the omitted section into their 20th periodic inspection report and proposed 21st periodic inspection plan which contains the omitted section to the Kansai Electric Power Company (November 2003). The Kansai Electric Power Company did not recognize that the ruptured pipe section erroneously had not been in the inspection list before.

In summary, although the ruptured section was known to be important to monitor wall-thickness, it was erroneously omitted on the inspection list. As a result, wall-thickness had not been inspected for 27 years. Ironically the omission was found in the previous year of the accident and the wall thickness inspection was scheduled in the year which just caused the accident.

4. Cause

The central system of PWR and location of the damaged section is shown in Fig 1. The damaged section of piping was situated near the downstream of orifice flow meter in "A" system condenser piping. Two condenser piping system labeled "A" and "B" were installed, which connect low pressure water absorption heater No.4 near ceiling to deaerator in the 2nd floor turbine room. Orifice is a mechanism which reduces cross sectional area of pipe to measure the fluid flow.

The detailed appearance of the damage is shown in Fig. 2. The material used for the piping was Carbon Steel (SB42), having an outer diameter of 538.8mm, a nominal thickness of 10mm, a temperature of around 140 degrees Celsius, a pressure of around 0.93 MPa, and a flow rate of 1700 m^3/h. The reduction of thickness was significant at upper part. The maximum size of fissure was 515mm in axis direction and 930mm in radial direction. The thinnest wall-thickness was 0.4mm.

Later investigation reported that the thickness of pipe was penetrated, and reduction of thickness of flange which supports the orifice was also observed at the downstream of a vent. The situation of the downstream of the vent is shown in Fig. 4. The vent is installed at upper part of orifice to release air. In this case, the diameter was 4mm.

The scale pattern, a feature of erosion and/or corrosion, was observed at downstream of orifice except for the lower part of a pipe. On the other hands, a nominal thickness was remained at the lower part of a pipe and the section had the thick surface coating (0.4mm). The scale pattern was not observed there.

The results of investigation can be summarized as follows.

- ○ The damaged piping was made by easily eroded/corroded carbon steel. The damaged part is at downstream of the orifice at which turbulent flow was often occurred.
- ○ Data related to water quality (pH, percentage of dissolved oxygen, etc.) in feeder and condenser was kept within the specified value.
- ○ At the area of eventual rupture, the temperature was around 140 degrees Celsius, which is ideal for erosion and/or corrosion.
- ○ Large thickness reduction was observed inside the pipe. The scale pattern was also observed entirely.

- ○ Large thickness reduction and scale pattern were also observed at downstream of orifice of "B " system.

It can be supposed that the pipe rupture was caused by the plastic collapse at thinner part by pressure in service as a result of reduction of pipe thickness reduction due to erosion and/or corrosion. Here, reduction of pipe thickness due to erosion and/or corrosion at downstream of vent occurred before the reduction of pipe thickness at downstream of orifice. Fortunately, the leakage was not happened at downstream of the vent because the flange was installed to support the orifice. This was typical case of the localized metal loss and the rate of reduction is very high. The part is not in the inspection list because the inspection of this part is impossible. The cause of erosion and/or corrosion at downstream of vent must be clarified. The localized metal loss at downstream of vent indicates the other parts of erosion and/or corrosion which were not realized. Furthermore, it is supposed that the turbulent flow that caused erosion and/or corrosion at downstream of the vent combined with the flow that caused erosion and/or corrosion at downstream of the orifice, hence accelerating the erosion and/or corrosion.

From a technological point of view, the cause of the problem was reduction in thickness due to erosion/corrosion. However, the direct cause of the accident was negligence by The Kansai Electric Power Company, Mitsubishi Heavy Industries, and Nihon Arm. There was a fault in inspection list of secondary piping and it could not be revised until the accident happened. The poor quality assurance and maintenance of The Kansai Electric Power Company resulted in the accident.

Main cause of the accidents is as follows.

- ○ The damaged section was erroneously omitted on the inspection list.
- ○ This has not been revised for a long time.
- ○ Even after the omitted section on the inspection list was realized, inadequate liaison with relevant persons led to the lack of an appropriate inspection plan.

5. Immediate Action

The Nuclear and Industrial Safety Agency established an accident analysis committee of secondary piping of Mihama power plant No.3 after the accidents. In a series of meetings between 11th August 2004 and 27th September 2004 (1st to 6th meetings), committee submitted an interim report.

The report shows about the current management method for wall-thickness of piping in PWR's nuclear power plants, BWR's nuclear power plants, and thermal power plants. They proposed following revised management plan.

○Reduction of pipe thickness in PWR

The maintenance method of PWR was examined. Validity of the guideline of PWR maintenance was investigated. The problems of the guideline were indicated.

○Reduction of pipe thickness in BWR

Thickness reduction in BWR piping due to erosion and/or corrosion was also recognized. Oxygen was injected to feed and condensed water to improve the water quality. Hematite coating (Fe203) was applied on the surface of the pipes in order to help prevent erosion and/or corrosion.

The accident of secondary piping of Sally reactor plant gave a motivation to electric power companies to measure the reduction of pipe thickness. The electric power companies uniquely established the maintenance rule based on the data.

If the maintenance rules of BWR's by each electric power company are compared with those of PWR's, the inspection range is wider in BWR's and the inspection frequency is higher in PWR's.

The rate of reduction of pipe thickness is less in a BWR's than in a PWR's. It is considered that the difference is caused by the difference of the water quality. The secondary piping of PWR employs a deaeration alkali treatment. Oxide layer of magnetite (Fe_3O_4) is also made on the surface of carbon steel.

○Reduction of pipe thickness in thermal power plant

By the report submitted by electric power companies (8th August 2004), out of the 1467 units in 802 power plants, 704 units enforced pipe thickness measurement and 763 did not.

The report submitted by electric industries (21 September) shows that, by the public wall-thickness inspection plan for 20-year-olds thermal power plants, about 249,000 sections should be inspected, although, 213,000 sections has not yet been inspected. They will sequentially inspect these remaining sections.

6. Countermeasure

Many data about the reduction of pipe thickness has been accumulated by the inspection which based on guidelines for PWR plants. It is supposed from the data that the guideline is almost appropriate. However, in order to make assurance doubly sure, nuclear power plant companies and concerned parties should make new guideline. The guideline should be made by a neutral 3rd party and the process of making the guideline must be released to the public. The accumulated data in Japan and other countries are of great value to refer. The following factors should also be considered.

- ○ Thickness reduction rate should be supposed from past measurement
- ○ The range to be inspect should be supposed from past measurement
- ○ The classification of inspected sections into complete inspection and sampling inspection, and the number of sampling points.
- ○ The frequency of inspection in accordance with the evaluation results of the remaining lifetime.
- ○ The required minimum thickness and the integrity evaluation method based on the new knowledge such as the minimum thickness, the maximum rate of thickness reduction, and the change ratio of thickness reduction rate regarding localized metal loss phenomenon.
- ○ The measurement method (addition of the detailed measurement method to the guideline).

Since it is hoped that every power company conduct an inspection accordance with the unified management method, BWR companies and concerned parties should consider the management method in cooperating with PWR companies.

Furthermore, even though at the present time there are no common technical guidelines covering pipe thickness in thermal power plants, from now on all measurement data taken by every company should be colleted and used to set technical guidelines for appropriate management of pipe thickness.

Under present measurement techniques, 8 or 4 points are selected to measure the thickness of every cross section. If the thickness fails to meet the specified criteria, more detailed measurements are performed and the minimum thickness was measured. If the minimum thickness is less than technical standards, it will be replaced. This maintenance method is supposed that the reduction of the pipe thickness is progress uniformly in circumference.

Although this maintenance method is effective if the measured point is thinnest point, in practice it has been found that the rates of localized metal loss vary greatly from point to point in a cross section.

It is necessary to extract the section which localized metal loss tends to occur and develop the measurement method response to the extract result. Integrity evaluation method for the piping with localized metal loss should be also considered. These points must be confirmed when the neutral 3rd party is organized.

When considering the direct cause of the secondary piping accident by The Kansai Electric Power Company, Mitsubishi Heavy Industries and Nihon Arm, it is clear that there were failures in quality assurance and maintenances by The Kansai Electric Power Company.

By the revision of inspection regulation system in October 2003, concrete requirements to quality assurance and maintenance were regulated by a law. It was also decided to conduct a periodical operator inspection. The commissioners are required to develop quality assurance and maintenance system by complying with the law. Nuclear and Industrial Safety Agency is commissioned to inspect the commissioners' duties by maintenance inspection and periodic safety management inquisition. From the view point of quality assurance and maintenance for the wall-thickness reduction of piping, following countermeasures are required.

○ Preparation of Inspection lists and unified maintenance system

○ Proper subcontract management system

○ Regulations on pipe thickness maintenance

○ Information sharing in order to prevent accidents before happen

7. Knowledge

○ What is erosion and/or corrosion?

The wall-thickness of piping with flowing fluid is reduced and this leads to a leakage of fluid or an eventual rupture of piping. The wall-thickness reduction mechanisms are corrosion and erosion. One representative example of erosion is "cavitation erosion".

Erosion and corrosion occur at the same time, and it is difficult to determine which one is dominant. Therefore, the term, "erosion and/or corrosion," is used. In the atomic energy field, the terms "Flow Accelerated Corrosion (FAC)" and "Flow Induced Corrosion (FIC)" are also used. This means the mechanism that an oxidized layer (Fe3O4) on carbon steel is dissolved by water flow. This is similar to corrosion. Erosion and/or corrosion do not reduce the pipe thickness uniformly in circumference, but reduces accumulatively in specific point in a cross section. This is the characteristics of erosion and/or corrosion.

○ Localized metal loss is a defect

Thickness reduction is classified into "general metal loss" and "localized metal loss". On the other hands, defect is classified into "crack-like flaws" and "localized metal loss". Then, localized metal loss is defect, and the localized metal loss should be inspected as well as fatigue crack and stress corrosion cracking to keep structural integrity.

○ Difficulty of prediction of localized metal loss rate

The rate of localized metal loss is much higher than the rate of general metal loss. Localized metal loss only occurs at particular section (flow turbulence) under particular operation condition (temperature, chemical species, flow velocity). The rate of localized metal loss cannot be predicted by general corrosion data because it is very sensitive to the changes in process condition and material, which is just same to stress corrosion cracking.

○ The situation of thickness reduction control

For the light water reactor, thickness reduction of carbon steel piping in secondary system of PWR and feed-condenser system of BWR should be monitored and controlled. It is controlled by changing water quality (temperature, dissolved oxygen, pH) and materials (low alloy steel, austenitic stainless steel). Localized metal loss is caused if carbon steel is used while stress corrosion cracking is caused if austenitic stainless steel is used. Completely safe cannot be realized with materials.

○ Current situation of inspection.

Wall-thickness at representative point of a pipe is measured by the ultrasonic inspection. There is no discrimination between general metal loss and localized metal loss in the inspection. Measured thickness is compare with required thickness of permissible level.

○ Problem of localized metal loss

Localized metal loss should be listed in the standards of integrity evaluation in the fitness for service. Permissible level (decided by plastic collapse) should be regulated dependent on the shape and size of localized metal loss. The major section which sustains localized metal loss easily should be clarified. Improvement in accuracy of localized metal loss rate estimation is required for the accurate remaining life predictions. The structural heath monitoring can be applied tentatively.

○ Similar accidents

The accident of the H-II F6 rocket on 29th November 2003 was caused by localized erosion. Due to a turbulence of combustion gas, a rocket booster nozzle made by carbon fiber reinforced plastic was eroded away leading to a hole eventually opening in the nozzle wall through which the combustion gas escaped. The rate of local erosion is very difficult to predict.

8. Sequel

(a) The case of Tohoku-Electric Power Co., Inc

On 29th September 2004, a report was submitted by Tohoku-Electric Power Company to the Nuclear and Industrial Safety Agency concerning the thickness reduction of pipe at orifice downstream of the vent of high pressure feed water heater in the Onagawa nuclear plant No.1 and No.2.

At the Onagawa nuclear plant No.1, the pipe repeatedly replaced due to thickness reduction. The pipe in the Onagawa nuclear plant No.2 was also recognized the thickness reduction and replaced.

The details of the inspections and record of replacements are presented below (1st and 2nd high pressure feed water heater systems have two heaters respectively, those are labeled A and B)

〇Onagawa nuclear power plant No.1

- The 5th inspection in 1989 led to the replacement of pipes at A and B in 1st high pressure feed water heater system. (Carbon steel → Carbon steel)
- The 6th Inspection in 1990 led to the replacement of pipes at A and B in 1st and 2nd high pressure feed water heater system. (Carbon steel → Low alloy steel)
- The 9th inspection in 1993 led to the replacement of pipes at A in 1st and 2nd high pressure feed water heater system. (Low alloy steel → Low alloy steel)
- The 11th inspection in 1997 led to the replacement of pipes at A and B in 1st and 2nd high pressure feed water heater system. (Low alloy steel → Stainless steel)

〇Onagawa nuclear power plant No.2

- The 2nd inspection in 1997 led to the replacement of pipes at A and B in 1st and 2nd high pressure feed water heater system. (Low alloy steel → Stainless steel)

Onagawa nuclear power plant No.1 could not stop the reduction in pipe thickness although it was replaced with carbon steel and low alloy steel. Austenite stainless steel was used finally. The piping in the Onagawa nuclear power plant No.2 could not be stopped the reduction of pipe thickness, either. On the other hands, Onagawa nuclear power plant No.3 has been using austenitic stainless steel since it started operation. The reduction of the pipe thickness has not yet been observed in No.3. In "Kashiwazaki Kariwa nuclear power plant No.1" (Tokyo Electric Power Company), the reduction of pipe thickness has not yet been observed, although the carbon steel pipe were replaced with low alloy steel pipe.

Although above reduction of pipe thickness was localized metal loss, the cause was not erosion and/or corrosion but erosion due to jet blast of condensed water. The mechanisms leading to the erosion are shown below;

1. There was a vent in the feed water heater to draw in steam and condensable gas. The vent also drew in condensed water.
2. The condensed water arrived at orifice with steam flow in vent.
3. The condensed water which arrived at orifice is erupted as droplets to downstream of orifice. Its speed was close to the sound speed.
4. As the droplets were erupted along the orifice direction (at 45 degree angle), the pipe thickness was eroded, causing a belt shaped section of erosion.

The taper of the orifice edges in Onagawa nuclear power plant No.1 and No.2 are 45 degree whereas the orifice edge in Onagawa nuclear power plant No.3 is straight. The 45-degree of taper is one of the reasons of localized metal loss.

The pipes in Onagawa nuclear power plant No.1 and No.2 have already replaced to Austenite stainless steel pipes. Tohoku-Electric Power Company is going to do the remaining life assessment by every periodic inspection. The shape of orifices is also going to be considered.

The main cause of the Kansai Electric Power Company accident was FAC (corrosion is dominant), whereas that in the Tohoku-Electric Power Company accident was erosion. The fact that the above two diametrically opposite accidents were occurred means that many in-between erosion and/or corrosion, although it has not yet recognized, have been occurring. It is, therefore, important to consider fundamental counter-measures against the problems.

(b) The case of thermal power plant

After the accident at the Kansai Electric Power Company, another accident occurred on 15th August 2004. "Shinchi thermal power plant No.2" in Shinchi, Fukushima Prefecture stopped operation after the leak of steam due to the burst of piping in turbine building. The burst location was at the downstream of valve of carbon steel pipe (300mm diameter and 10mm thick). The pipe thickness of the burst location was reduced to approximately 1.4mm. The localized metal loss was due to a typical erosion and/or corrosion.

This rupture had occurred while the Nuclear and Industrial Safety Agency was investigating the inspection conditions for piping of thermal power plant in Japan. The piping that ruptured had started operation in 1995 and the plant has never experienced an inspection.

Erosion and/or corrosion problems are not limited to nuclear power plants but also to thermal power plants, petrochemical plants, oil refining facilities, general chemical factories, etc.

9. On the Side

The investigation of the damage examples of erosion and/or corrosion except for nuclear power plants were conducted

Under several laws and regulations (High Pressure Gas Safety Law , Petroleum Use Law, Fire Defense low, Industrial Safety and Health low, etc.) accidents such as leakage, rupture, and fire disaster must be reported to the government. Corrosion is most often the cause of these accidents. 53 accident due to corrosion and 19 potential accidents due to were reported from 1971 to 1997. Out of these 72 cases, 22 were erosion and/or corrosion. It is considered that erosion and/or corrosion is directly related to the accidents.

Figure 4 shows the results of all 22 erosion and/or corrosion cases. The ordinate indicates the pipe thickness, and the abscissa indicates the duration of service in year. If it is assumed that the localized metal reduction penetrates the entire thickness and the accident occurs, the gradient in Fig. 4 indicates the rate of thickness reduction. The rate of thickness reduction (mm/year) that can cause accidents is in the following range.

- General corrosion: 0.15-0.3 mm/year
- Accelerated corrosion: 0.3-0.5 mm/year
- General erosion and/or corrosion: 0.5-1.0 mm/year
- Accelerated erosion and/or corrosion: 4 mm/year

The accelerated corrosion represents stress corrosion cracking or the corrosion that affected by seawater or groundwater. The accelerated erosion and/or corrosion represent the erosion and/or corrosion under the condition that the structure or the material is inappropriate. At any rate, the rate of thickness reduction caused by erosion and/or corrosion is much higher than that caused by corrosion only. In the general design, although the applicable corrosion allowance is taken into account, although the reduction rate of few mm per ten year is not take into account.

The causes of erosion and/or corrosion are classified as follows:

- Position (T-junction, curve, joint elbow, downstream of valve, downstream of an orifices etc.)
- Fluid events (water injection, collision, and hot water flushing)
- Design (inappropriate structure, unsuitable materials)

Erosion and/or corrosion are rarely caused by just one of the above factors. It is most often caused by a combination of several factors. Some of these combination causes are described below:

- Inappropriate structure composite, e.g T-junction and water injection
- Fluid-position composite, e.g. hot water flushing through an orifice
- Unsuitable structure and unsuitable materials

Figure 5 shows a combination example of water injection and an elbow part. The position of water injection was structurally inappropriate. The turbulent flow of the injected water stream accelerated the erosion and/or corrosion at the elbow part. In addition to the environmental affect, the rate of thickness reduction was at 4 mm/year. By analogy with this case, the accident occurred at Kansai Electric Power Company was supposed that the vent performed as water injection and the injection accelerated the erosion and/or corrosion at the orifice downstream.

Figure 6 shows an example of hot flushing combined with an orifice. Under the condition that the hot water flushing (separation between liquid and gas phases) occurs, erosion and/or corrosion were accelerated at downstream of the orifice. Compared this example and the Kansai Electric Power Company accident, the opening appearance caused by the rupture and the thickness reduction at downstream orifice was analogous to each other.

In general, the localized metal loss due to erosion and /or corrosion occurs preferentially at the specialized equipment and part. The question arises why the Kansai Electric Power Company accident was occurred prior to other plants which involve similar equipments and parts. Through the analysis of case studies focused on histories of operating condition, it was found that changes in operating condition (intentional changing) cause the changes in the flow velocity and the environment, and it accelerate the rate of thickness reduction (unintentional changing or accumulative changing). Although the localized metal loss due to erosion and/or corrosion itself is probabilistic event, changes in operating condition is also major factor of the problems.

10. Information Source

(1) Nuclear and Industrial Safety, "Kansai Electric Power Company number 3 turbine secondary cooling accident interim report", 27th September 2004

(2) Hideo Kobayashi, "Standardized Procedures necessary for accurate Technical Control", Nuclear

energy Culture 35-10, 11-13, October 2004

(3) Tohoku Electric Power Company, "On the Onnagawa plant high pressure feed water heaters wall thickness reduction," 29th September 2004

(4) Hideo Kobayashi et al, "Research into stressed component damage due to corrosion and corrosion speed," High Pressure Gas 35-3, 203/214 (1998)

(5) Hideo Kobayashi et al, "Research into stressed component erosion/corrosion," High Pressure Gas, 36-8, 720/728 (1999)

11. Primary Scenario

01. Organizational Problems
02. Poor Management
03. Insufficient Analysis or Research
04. Insufficient Prior Research
05. No Inspection Register
06. Usage
07. Maintenance/Repair
08. Inspection/examination
09. Lack of inspection
10. Usage
11. Operation/Use
12. Piping
13. Bad Event
14. Thermo-Fluid Event
15. Fluid Phenomenon
16. Fluid turbulence
17. Orifice
18. Failure
19. Abrasion
20. Erosion and/or corrosion
21. Failure
22. Fracture/Damage
23. Burst
24. Steam Eruption
25. Bodily Harm
26. Death
27. Accidental Death
28. Loss to Organization
29. Social Loss

30. Loss the Confidence

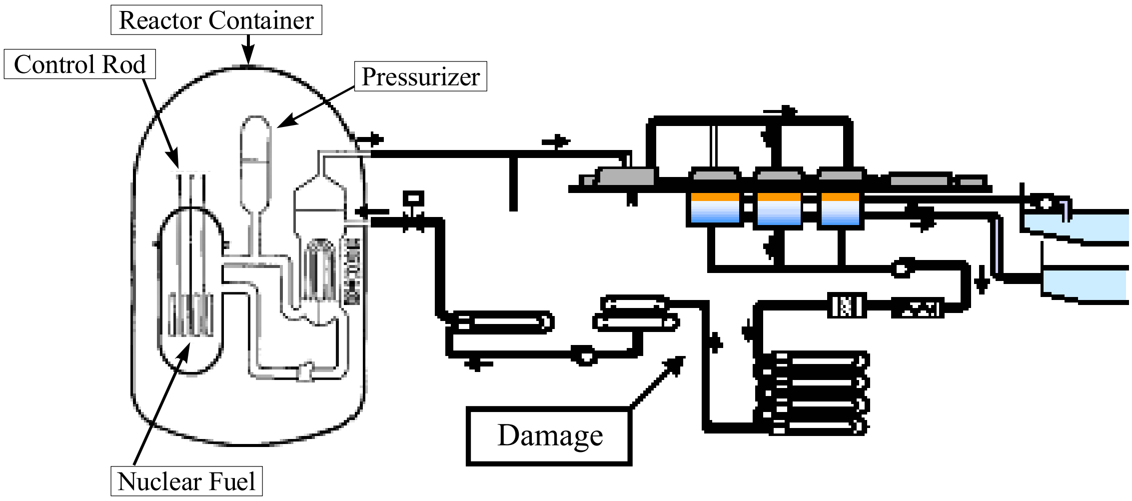


Fig. 1 Main damaged area of PWR.

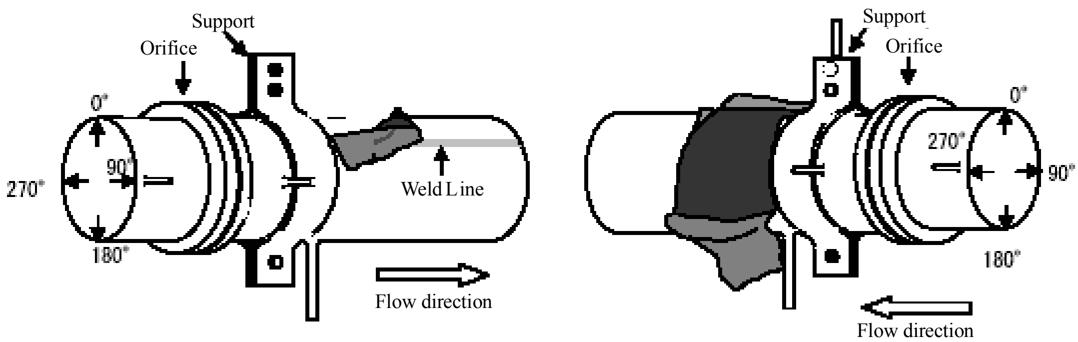
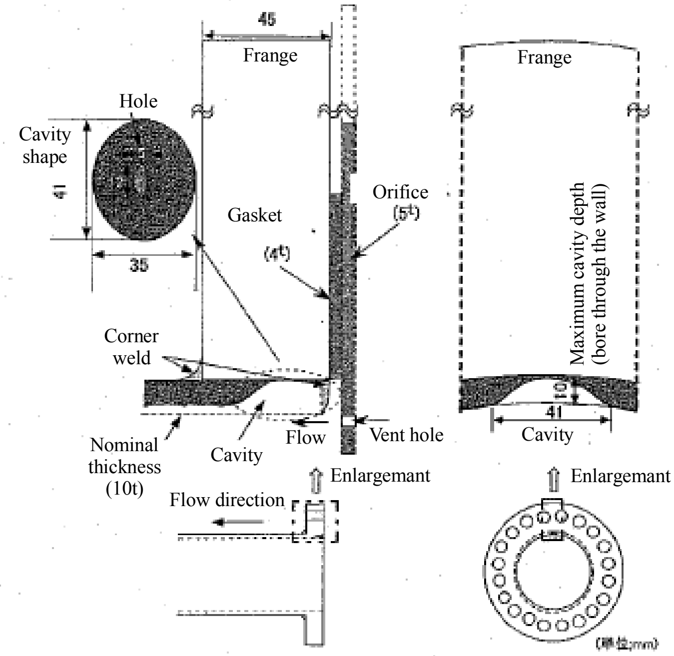
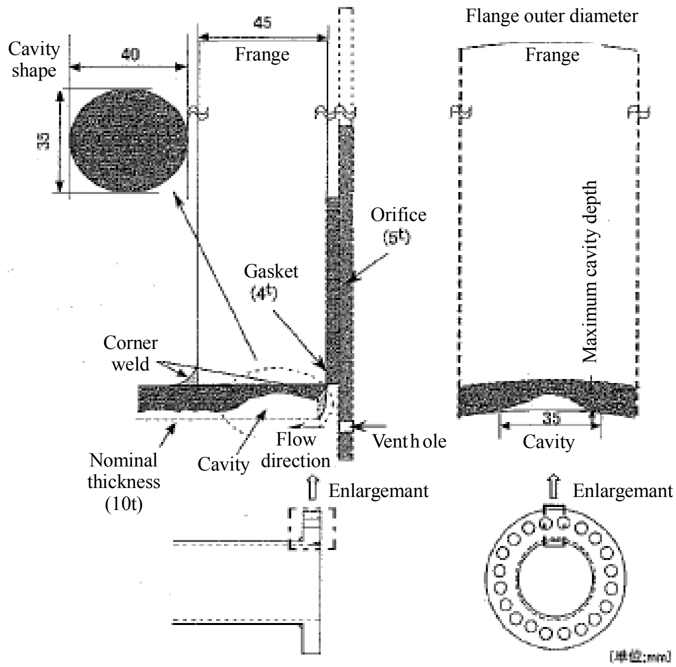


Fig. 2 Piping Damage.



A line's downstream frange



B line's downstream frange

出典：第５回事故調査委員会 資料５－１－２（別添１）
（日本原子力研究所、原子力安全基盤機構からの提出資料）より抜粋

Fig. 3 Downstream of Vent.

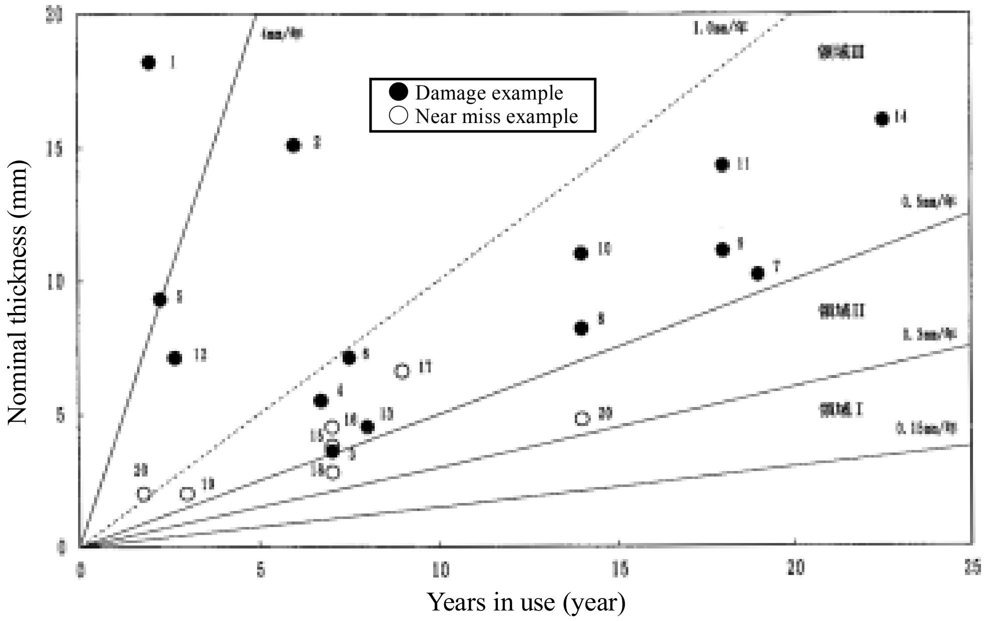


Fig. 4 Erosion/Corrosion Reduction Speed.

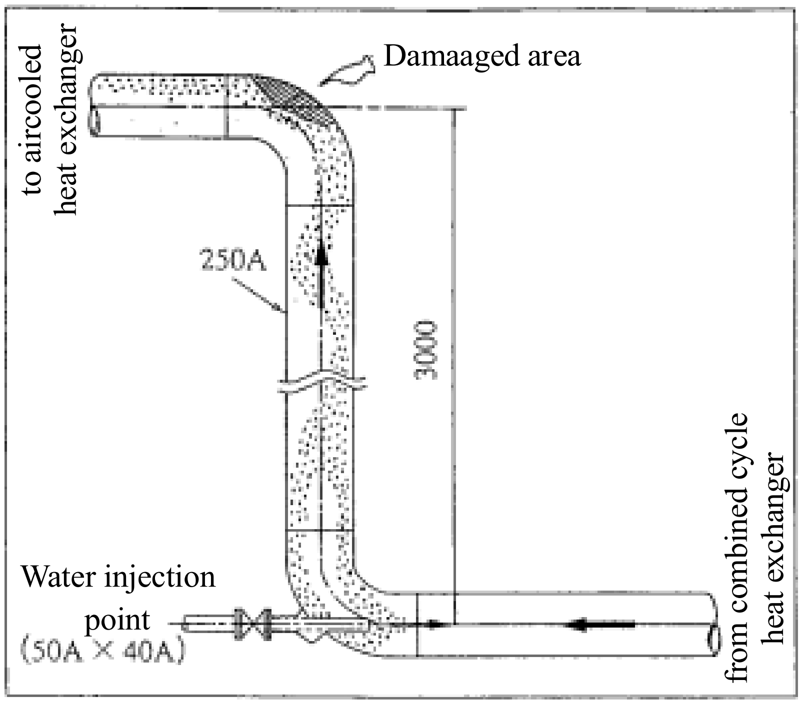


Fig. 5 Damage from cold water Injection.

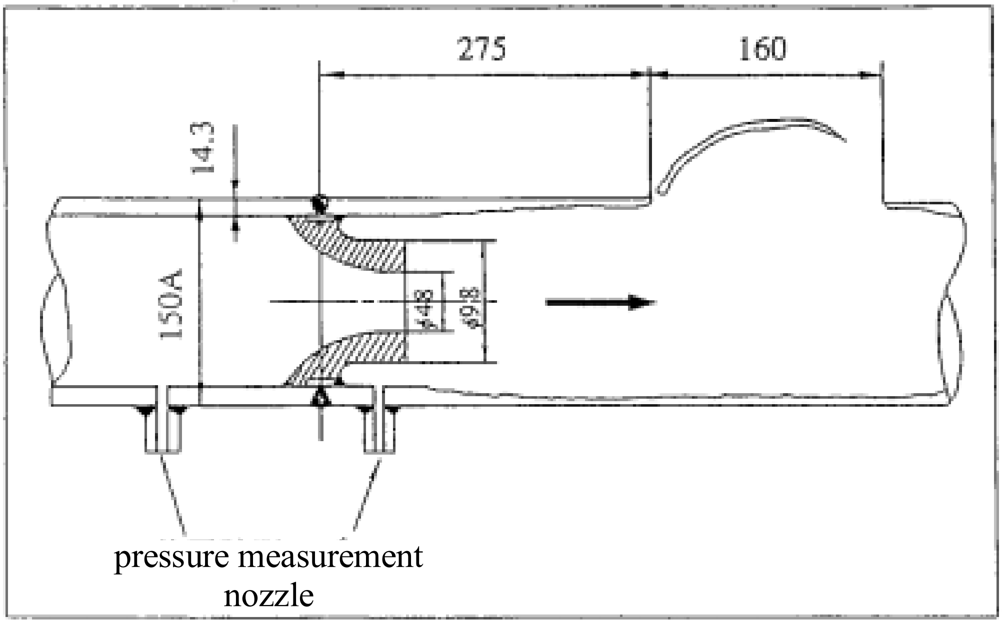


Fig. 6 Damage from hot water flushing.