The guillotine breaking of the secondary piping in nuclear power plant

Dec. 9th, 1986, Virginia State United States

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(Summary)

At 14:21 on December 9th, 1986, the guillotine breaking accident shown in Fig.1 occurred at the secondary system piping in Surry Nuclear Power Plant Unit No.2. The Surry Unit No.2 was owned and operated by the Virginia Electric Power Company in Newport News, Surry County in the state of Virginia, the USA. The commercial operation started in May 1973 and continued for a total operating time of 76,600 hours prior to the accident. The pipe failed in a 90°elbow located in the 18 inch (457mm) feedwater suction line that feeds water to the feedwater pump as shown in Fig. 2. The material of the broken piping is carbon steel (ASTM A234) with a wall thickness of 0.5 inches (12.7mm). The cause of the failure is wall thinning due to erosion-corrosion. Four persons who were replacing thermal insulation nearby the line were killed and two persons were injured.

1. Event

(1) The main steam isolation valve failed to close while operating at 100% power on December 9th, 1986. Therefore, the nuclear reactor tripped and the auxiliary feedwater pump started as shown in the outline of the system given in Fig. 3.

(2) Since the auxiliary feed pump was also started in addition to the auxiliary feedwater pump after the main steam isolation valve had been closed, a large amount of water was supplied to the steam generator, and the primary system coolant temperature fell to 290℃ or less. In order to avoid subcooling of the primary coolant temperature, a main feedwater supply control valve was closed.

(3) Since the feedwater pump was working even though the main water supply control valve was closed, the pressure in front of and behind the feedwater pump rose. As a result, about 5 seconds after the main water supply control valve was closed, there was faint steam discharge sound, and the 90°elbow part of the 450mm piping that branches from a 600mm header piping at a feedwater pump suction line broke. Six of eight persons who were replacing thermal insulation nearby the fractured elbow part received serious burns. Four of them died, and two of them survived with serious burns.

2. Course

(1) After the accident, a time series analysis was executed based on the monitor record of a secondary system each equipment because of the clarification of the pressure increase situation of the part of concerned.

(2) In order to try to find the cause of the breaking of the part, several investigations including an

investigation of the material specifications, an integrity investigation of the material by metallography, an investigation of the inside surface conditions of the piping, a micro and macro investigation of the fracture surface, and a piping wall thickness investigation were made.

(3) Since the phenomenon of wall thinning by erosion-corrosion was suspected from the condition of the broken part, an investigation of the water chemistry record of the secondary system was conducted.

(4) Because a fracture had occurred, a fracture mechanics analysis was carried out.

(5) The Surry Unit No.1, that used a similar water chemistry management and had a similar piping layout to the Surry Unit No. 2, was shutdown because it had been predicted that wall thinning of the piping and elbow part by the phenomenon of erosion-corrosion had occurred as a result of the investigations of the failed part. A measurement of the pipe wall thickness at the Surry Unit No.1 was conducted, resulting in observation of wall thinning similar to the Surry Unit No.2.

(6) The piping around the part where particularly severe wall thinning had been observed was replaced.

3. Cause

The part in which the break occurred was carbon steel that was exposed to the secondary water chemistry environment of a pressurized water reactor. In the combination of the secondary system water chemistry (pH 8.8 - 9.2) by AVT (All Volatile Treatment), and carbon steel, it was not necessarily the water chemistry for maintaining the corrosion protection of carbon steel. Since a copper alloy was used in the system, proper corrosion protection of the carbon steel could not be maintained under the higher pH. Moreover, because the part that broke was not designated as an object of the in-service inspection, no inspection of the position where the break occurred had ever been conducted. In addition, the 90o elbow where the break occurred had been installed as a result of an improper piping layout. For this reason, a turbulent flow occurred in the elbow part resulting in the progression of severe wall thinning by erosion-corrosion. The break occurred after the scram of the nuclear reactor.

4. Immediate Action

After the fracture occurred, the Surry Nuclear Power Plant Emergency Plan* was put into effect immediately, and the notice of abnormal circumstances was issued. Then, this was changed to "Alert".

The owner of the plant started restoration activities immediately. The plant owner contacted the U.S. Nuclear Regulatory Commission (NRC) immediately after the accident. The NRC made the decision to dispatch an inspection team from a nearby NRC branch. A specialist of the water hammer phenomenon was added to the NRC inspection team, forming the augmented inspection team. The augmented inspection team by the side of this regulation carried out its own inspections independently from the electric power company that had caused the accident. On the other hand, the top level management of the Virginia Electric Power Company responded by setting up the adjustment management group in charge of investigating the cause of the break, the safety of the plant, the operation, and the safety of the industry as shown in Fig. 4.

After the accident occurred, the Virginia Electric Power Company regularly reported the situation and other details of the accident to the media, explaining that it was not a serious accident such as one in which a piping fracture causes the damage to the core of a nuclear reactor.

*: A plan maintained as correspondence to a serious accident that results in damage to the reactor core of a nuclear plant.

5. Countermeasure

(1) An inspection of the wall thinning in the piping of the secondary system at the Surry Unit No.2 that caused the accident was performed. The piping in the part where the generation of wall thinning had been observed was replaced.

(2) The piping was replaced according to the following conditions. (a) Adoption of stainless steel that has a higher erosion-corrosion resistance than carbon steel, for which the corrosion resistance under the water chemistry environment and flow velocity conditions was difficult to maintain, and (b) adoption of larger diameter piping in order to reduce erosion-corrosion and to improve the piping layout by decreasing the flow velocity.

6. Knowledge

Even when the AVT (All Volatile Treatment) water chemistry in which ammonia and hydrazine is added for the prevention of material corrosion is adopted, if carbon steel is used and a high flow velocity exists, erosion-corrosion cannot be prevented. In the part where the flow velocity becomes large, wall thinning must be measured periodically and the wall thinning trend must be predicted. When relatively large wall thinning is observed, it is necessary to prevent erosion-corrosion by (a) adopting a material with greater erosion-corrosion resistance, (b) replacing the piping with larger diameter piping, or (c) improving the pipe layout in order to avoid local occurrence of high flow velocity.

7. On the Side

The second design of the system of the pressurized water reactor was based on a design of the turbine equipment for a thermal power plant. Therefore, the main system material adopted was carbon steel, and copper alloys were used in the heat exchanger tube of the heat exchanger. Moreover, the second system water chemistry management was also based on the water chemistry control of a thermal power plant. Therefore, the method of water chemistry control using the addition of hydrazine to phosphoric acid soda in order to limit the decrease in pH even if the second seawater leaking from the condenser tube entered the system.

The design of the secondary system of a pressurized water reactor was based on the design of turbine equipment of a thermal power plant. For this reason, a copper alloy was adopted as the material for the heat exchanger tube of a heat exchanger, and carbon steel was mainly used for the material of the secondary system. Moreover, the secondary system water chemistry control was also based on the water chemistry control of the thermal power plant so that, even if sea water leaked into the secondary system from the condenser tube, the pH would not easily decrease. Since wall thinning was observed in steam generator heat exchanger tube by using the phosphoric acid soda, generally AVT processing which added hydrazine to ammonia came to be carried out. However, it was necessary to adjust the water chemistry control with AVT processing of corrosion resistance so that both carbon steel and the copper alloy might be satisfied. In order that to be referred to as high pH is required in order to improve corrosion resistance more for carbon steel, but a copper alloy may dissolve, it is in the situation which is not made to high pH. As a result, if the flow velocity in the secondary system is high, wall thinning will occur in carbon steel. It is in the situation which is not high pH, and it has been common sense as maintenance activities of the power plant that wall thinning occurs in carbon steel on the conditions that the flow velocity is high. For this reason, the part that the flow velocity becomes high observes the wall thinning situation intentionally. Generally surveillance is thickness measurement of piping. It is necessary to carry out thorough wall thickness measurements during periods when the power plant is shut down. Since the material and water chemistry control of the secondary system in the Mihama Unit No. 3 are the same, wall thinning management was determined to be necessary, and thickness measurements of piping were carried out during the plant shutdown. The pipe rupture occurred in the Mihama Unit No. 3 because the time to put a fracture part on a maintenance list of wall thinning to decide the part where the measurement of the pipe wall thickness was delayed.

In general, if a material that does not have excellent corrosion resistance properties is used for the part where the flow velocity is high, erosion-corrosion will occur. The part in which this erosion-corrosion occurs most strongly is the part where the flow velocity changes suddenly. Moreover, when severe wall thinning is observed, it is good to inquire so that more suitable corrosive protection may be ready in the combination of the material currently used, since it may be possible to improve the water chemistry control. Moreover, another effective countermeasure is to adopt a material with excellent corrosion resistance properties so that erosion-corrosion will not occur.

*1: "a guillotine failure" involves "a fracture in which piping breaks into two separate parts and flows out of both of fracture sides without a coolant interfering, respectively" (from the nuclear dictionary of Nikkan Kogyo Shinbun and the nuclear library of the Internet library of the Japan Science and Technology Agency JST http://mext-atm.jst.go.jp.) This technical term is currently used officially. "Guillotine" is a tool for execution that was invented in France. Many people were executed by guillotine during the time of terrorism that followed the French Revolution. Joseph Guillotine, a member of the National Assembly and a physician, proposed the use of the guillotine as an execution device in which the person executed did not suffer and persons of all positions could be executed in a similar way, and his proposal was adopted in the National Assembly.

Although the device was initially called "Louisette" or "Louison" after the name of Louis, the designer of the device, Guillotine, who greatly advertised the humanity and equal nature of this device, became famous, and the name "Guillotine" was given to the device. The official name of the guillotine is "Bois de Justice (pillar of justice)" in German reading. In addition, "Guillotine was executed by the guillotine" is a mistake.

8. Information Source

(1) USNRC Information Notice No. 86-106 Supplement 1: Feed Water Line Break 1987.

(2) Dr. Shibata, Dr. Miyazono, Ueda et al, "Piping failure accident of Surry Nuclear Power Plant" Atomic Energy Society of Japan, Vo.29, No.11, and p952-969 (1987).

9. Primary Scenario

01.Insufficient Analysis or Research
02. Insufficient Prior Research
03. Project Diversion
04. Ignorance
05. Insufficient Knowledge
06. Erosion/Corrosion
07. Production
08. Hardware Production
09. Machine/Component Production
10. Improper Piping
11. Usage
12. Maintenance/Repair
13. No Inspection
14. Failure
15. Abration
16. Erosion/Corrosion
17. Failure
18. Large-Scale Damage
19. Guillotine Failure
20. Leak
21. Bodily Harm
22. Death
23. Accidental Death

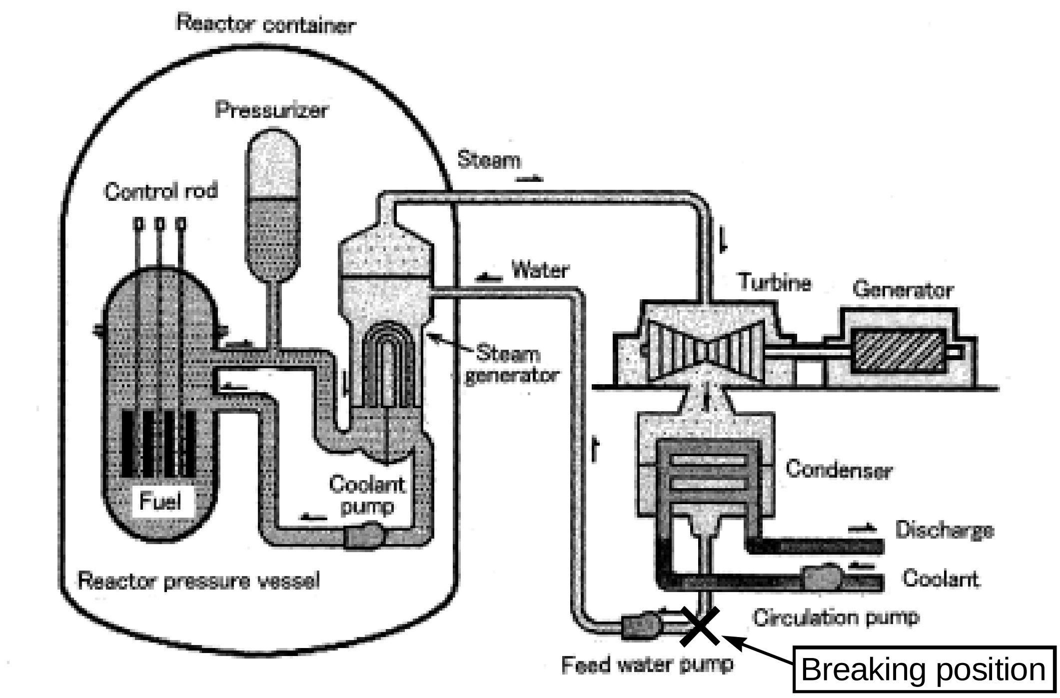

Fig. 1 Primary and Secondary Systems of Pressurized Water Reactor and Braking Portion.

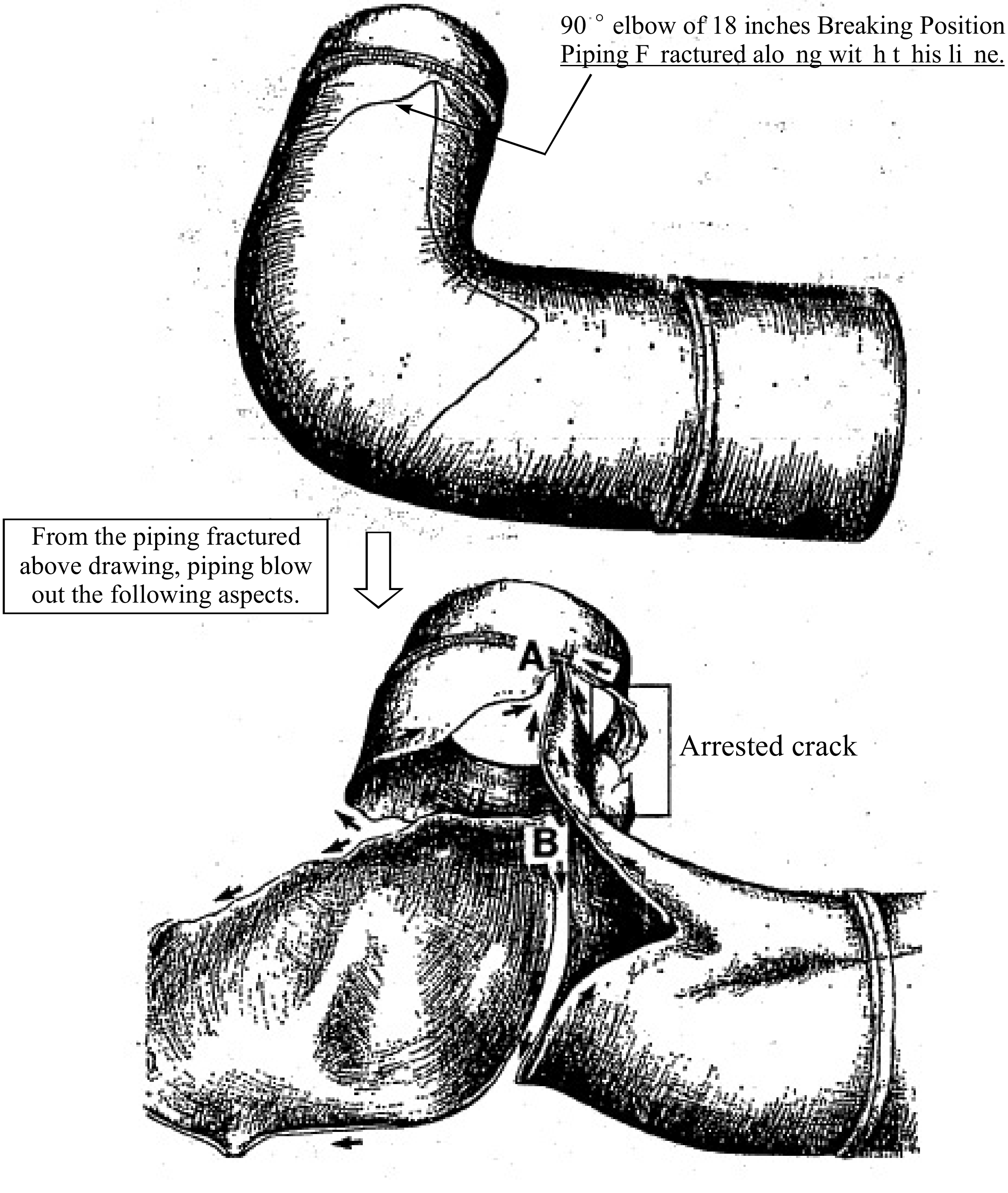

Fig. 2　Detail Drawing of the Breaking Portion.

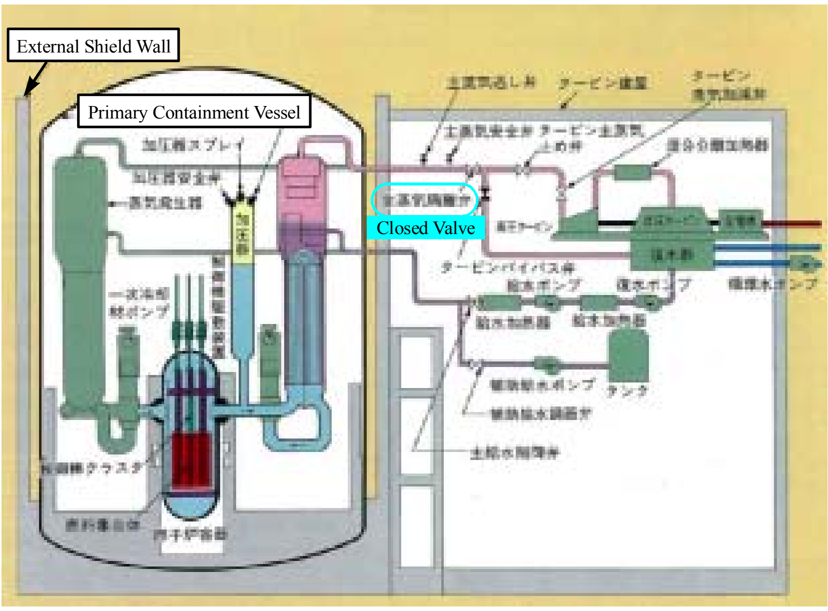

Fig. 3 Schematically System Drawing of Pressurized Water Reactor.

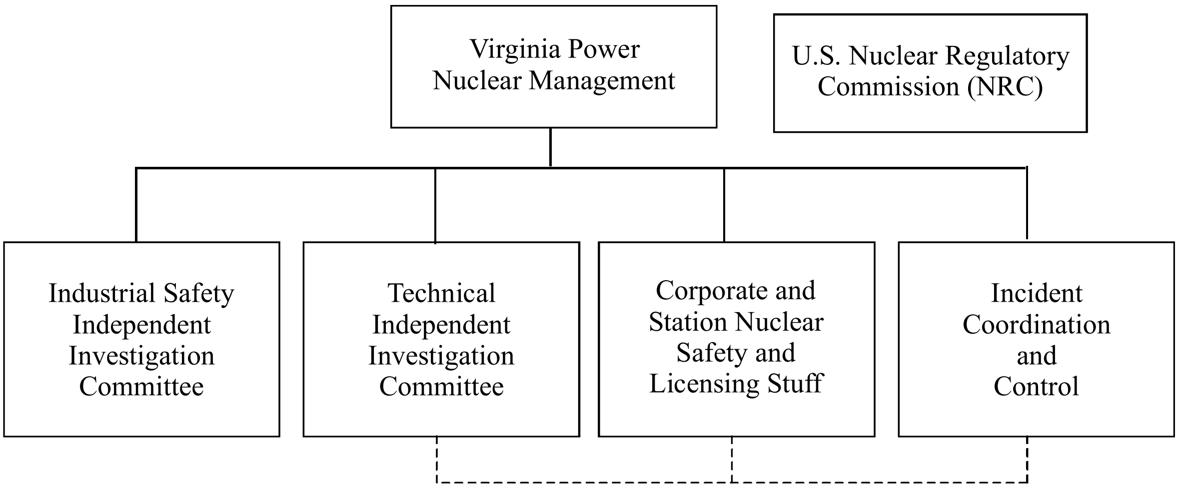

Fig. 4 Incident Response Organization Chart of Virginia Power.