# Identification of causes of high dose rate observed in the southeast area on the 1st floor of Unit 1 reactor building

## ■ 1. Introduction

In Unit 1, high dose rate of several thousand mSv/h were observed in the southeast area of the first floor (1st floor) of the reactor building (R/B) in surveys conducted in May, June, and July 2011 and 2012, as shown in Figures 1.1 and 1.2, and the cause is set as Unit-1/Issue-8 in this report.

As shown in Figure 1.3, a survey conducted in June 2011 confirmed that steam was leaking from the floor penetration in the southeast area. In addition, inert gas system (AC) piping used for the containment vessel (PCV) venting is laid in the vicinity of the southeast area, and this examination focused on these and other possible causes of the high dose rate observed in the southeast area.

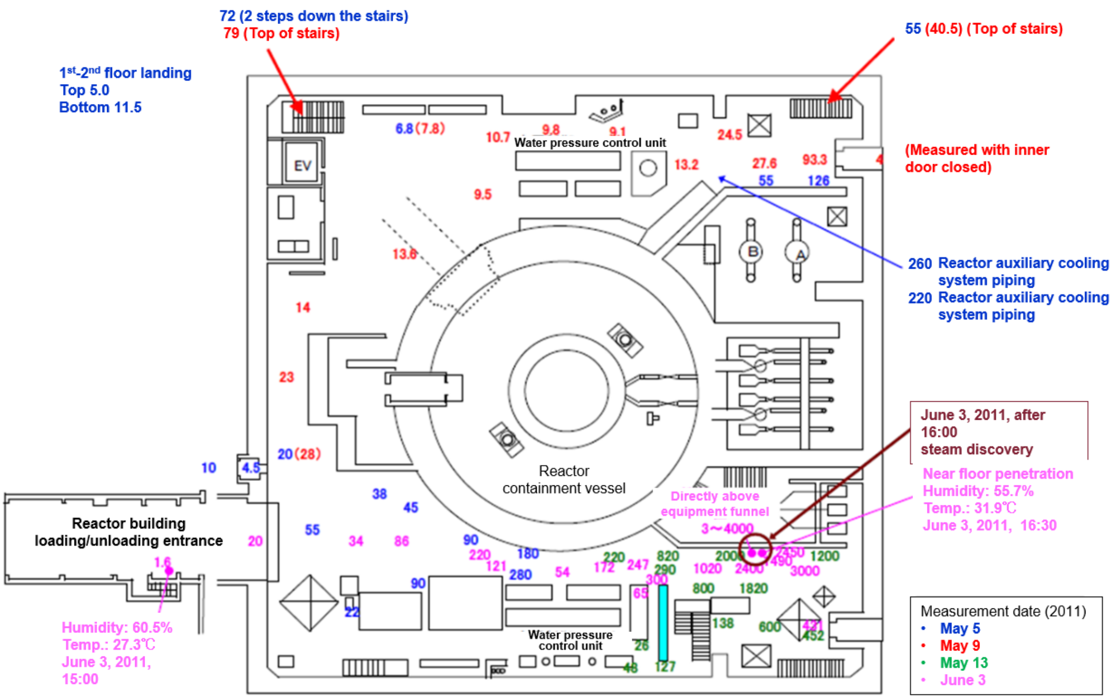



Figure 1.1 Air dose rate on the 1st floor of Unit 1 R/B (May-June 2011) [1]

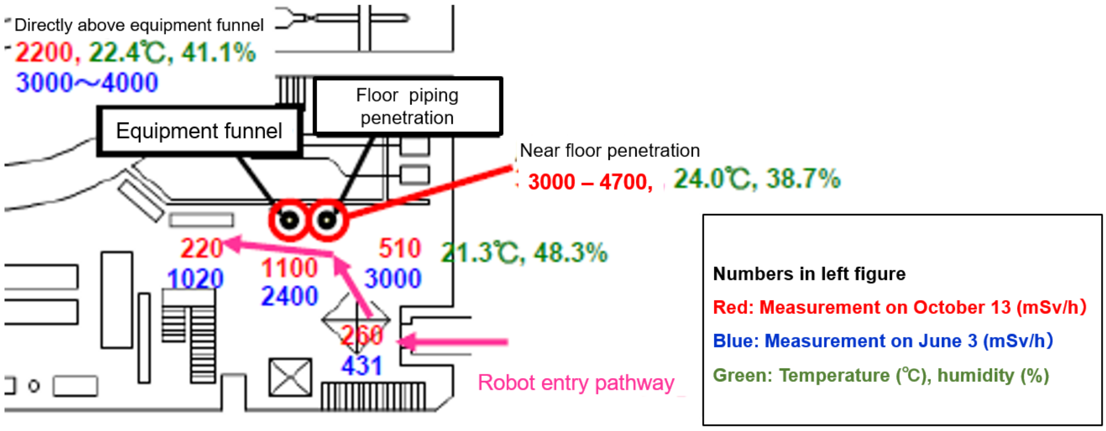



Figure 1.2 Air dose rate in the southeast area of the 1st floor of Unit 1 R/B (July 2012) [2]


Figure 1.3 Steam observed at the southeast floor penetration of the 1st floor of Unit 1 R/B (June 2011) [3]

■ 2. Identification of contamination sources to be considered

In addition to the effect of the steam observed in June 2011 and the contamination of the AC piping used in the PCV venting, other possible causes of the high dose rate observed in the southeast area include the effect of contamination sources with high dose rate that exist adjacent to the southeast area. Therefore, it is necessary to extract the equipment and systems that have been observed to have high dose rate in the vicinity of the southeast area as a cause of the high dose rate observed in this area. Based on these figures, the following four contamination sources were extracted as contamination sources to be considered.

① Contamination by steam and contamination of the torus room

In the southeast area, steam was observed leaking from the floor penetration leading to the torus room during the June 3, 2011 survey, and extremely high dose rate of several thousand mSv/h were observed in the vicinity of the floor penetration. Since the dose rate exceeding 1000 mSv/h was also observed in the torus room, it is necessary to estimate the cause of contamination in the torus room and the source of the outflowing steam; and to evaluate the effect of these contaminations on the southeast area, contamination of the torus room was extracted as a contamination to be considered.

② Contamination of inert gas system (AC) piping

AC piping used for PCV venting is laid in the southeast area. This piping is considered to be contaminated by radioactive materials in the vent gas that passed through the piping during venting, and the dose rate observed in the southeast area may be higher due to the contamination of the inner surface of the piping. In addition, if there is a damaged part in the piping, the vent gas released into the southeast area may have contaminated the southeast area. Therefore, contamination of the AC piping was extracted as a contamination to be considered.

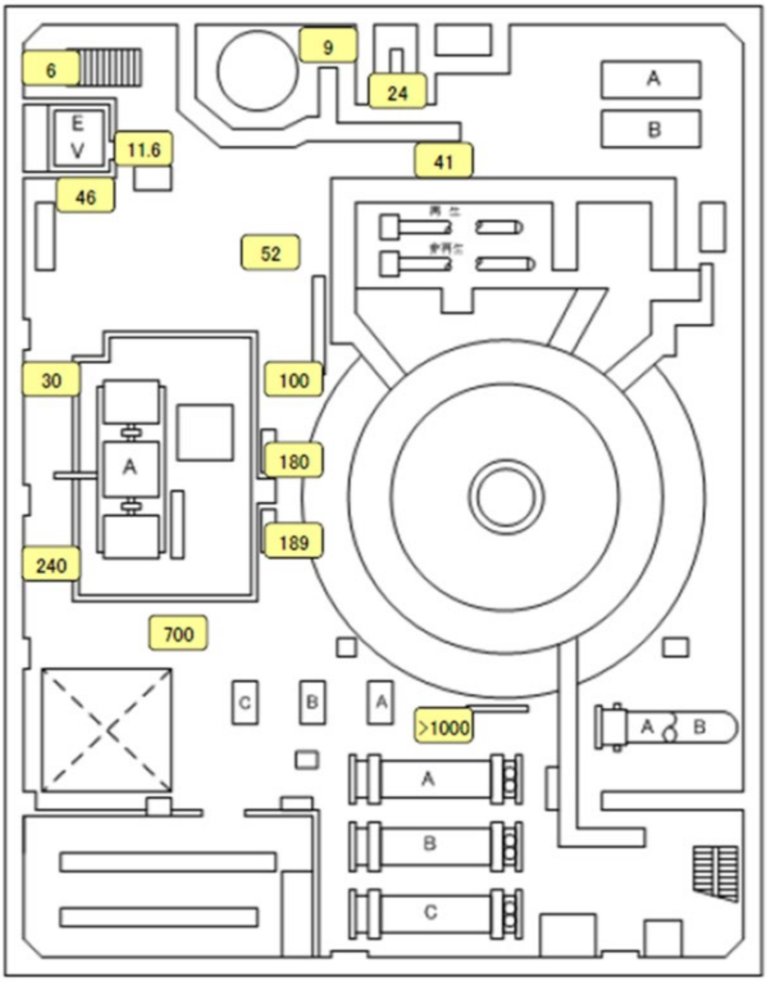
③ Contamination of reactor building cooling water system (RCW) piping

High air dose rate exceeding 1000 mSv/h have been observed near the RCW heat exchanger on the second floor (2nd floor). The cause of this is presumed to be that the molten fuel that fell to the bottom of the PCV during the accident damaged the RCW piping, and radioactive materials migrated and remained in the RCW piping (see Attachment 1-9). Therefore, it is necessary to consider the effect of RCW contamination on the southeast area, including the arrangement of RCW loads around the southeast area and the presence or absence of system water leakage. Therefore, contamination of the RCW piping was extracted as a contamination to be considered.

④ Contamination of traversing in-core probe system (TIP) room

The TIP room is located on the north side of the southeast area. During the accident, the core was exposed and overheated, and the fuel melted, causing the TIP instrumentation dry tube to break. Similarly, in Unit 3, where the reactor core melted down, during a survey in May 2012, the TIP room entrance door was found to have been blown outward, and high dose rate were reported around the TIP room entrance. Therefore, there is a possibility that the TIP room is contaminated in Unit 1 as well, and the TIP room investigation was conducted in September 2015 (see Attachment 4). Based on these findings, contamination of the TIP room was extracted as a contamination to be considered.

The four extracted contamination sources were evaluated from three perspectives to determine the cause of the high dose rate observed in the southeast area: (1) the cause of contamination; (2) the effect of radiation from the contamination sources; and (3) the presence or absence of migration of radioactive materials from the contaminations sources.




Unit : mSv/h

Figure 2.1 Air dose rate on the 2nd floor of Unit 1 R/B (April 2011-February 2013) [4]

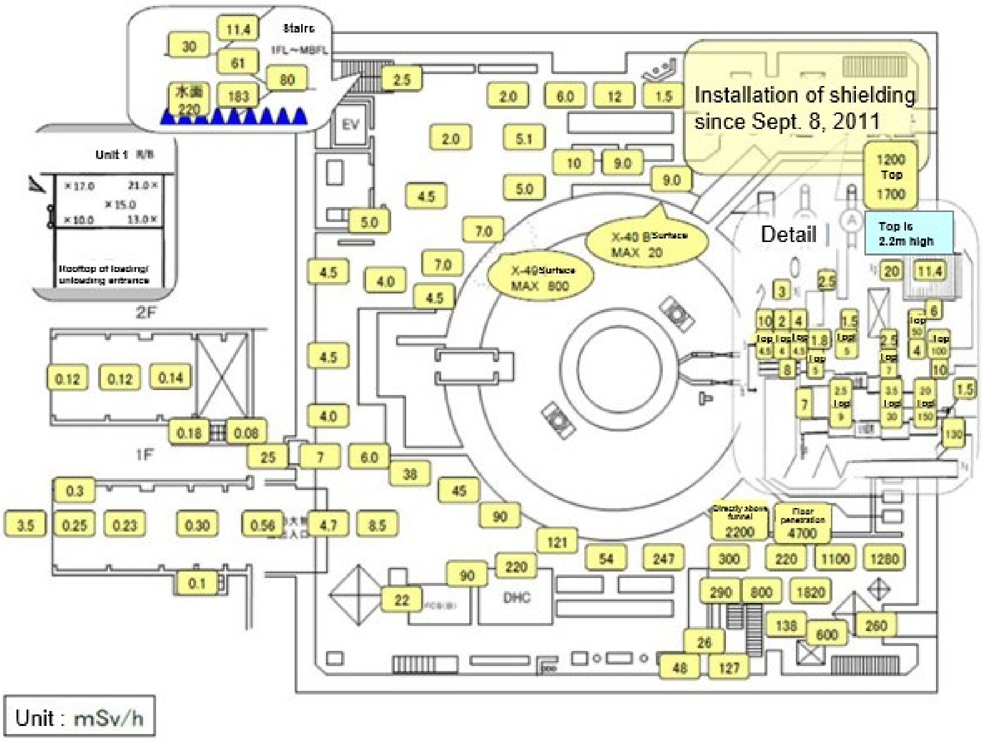



Figure 2.2　Air dose rate on the 1st floor of Unit 1 R/B (April 2011-February 2013) [4]

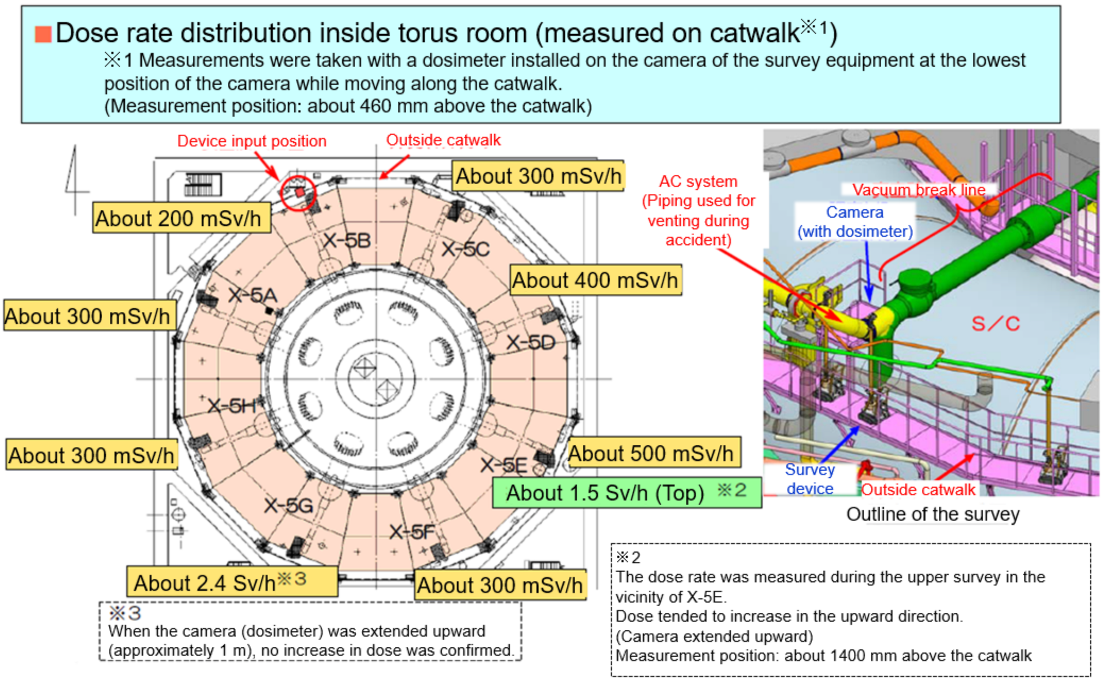



Figure 2.3　Air dose rate in the torus room on the basement floor of Unit 1 R/B (May 30, 2014) [5]

■ 3. Examination of possible contamination as the causes of the high dose rate observed

■ 3.1 Contamination by steam and contamination of the torus room

(1) Cause of contamination (cause of the high dose rate in the torus room)

The vent line (AC piping) used at the time of the accident was installed in the torus room in the form of a connection to the vacuum break line. The inside of the vacuum break line and S/C were contaminated due to the accident. In addition, seawater and groundwater have accumulated in the torus room, and it has been confirmed that water from the PCV leaked from the sand cushion drain piping (lower part of X-5B vent piping) and from the damaged expansion joint of the vacuum break line (upper part of X-5E vent piping) (see Appendix 4). The main sources of contamination in the torus room are considered to be the piping installed in the torus room, stagnant water in the S/C and the torus room, and contamination of the torus room itself due to the leakage.

(2) Effect of radiation from contamination sources (Effect of contamination in the torus room)

The distribution of air dose rate in the torus room is shown in Figure 2.3, and dose rate of several hundred to 2400 mSv/h have been observed on the catwalks. However, the effect of radiation from the contamination source inside the torus room is sufficiently attenuated in the southeast area of the 1st floor due to the shielding of the torus room ceiling concrete (650 mm thick), so the effect on the high dose rate observed in the southeast area of the 1st floor is considered small.

(3) Migration of radioactive materials from contamination sources (effect of steam)

The possibility of migration of radioactive materials to the southeast area due to steam was examined from two perspectives: a) the cause of the steam generation and b) the examination of the effect of the steam.

a) Cause of the steam generation

During a survey on June 3, 2011, it was confirmed that steam was leaking from the torus room through the floor penetration in the southeast area. The same area was also surveyed on May 13, 2011, but no outflow of steam was confirmed at that time. There are two possible sources of the steam: (i) stagnant water in the torus room and (ii) stagnant water in the PCV.

(i) Possibility of steam generation from stagnant water in the torus room

If steam was generated from the water stagnant in the torus room, it would have filled the entire torus room and flowed out from other floor penetrations on the 1st floor of the R/B. However, the investigation at that time did not confirm any steam except from the floor penetrations in the southeast area on the 1st floor. Considering the heat dissipation to the concrete frame, it is unlikely that the water in the torus room was still hot enough to generate steam two and a half months after the accident, and it is unlikely that steam was generated from the water in the torus room.

(ii) Possibility that stagnant water in the PCV has been leaking out of the PCV as steam

If the water in the PCV leaked out of the PCV as steam, a candidate location for the leakage would be the damaged expansion joint of the vacuum break line to the southeast of the torus room, where a liquid-phase leak has been observed.

The damaged part of the vacuum break line expansion joint is located above the X-5E vent piping in the southeast area of the torus room, almost directly below the 1st floor penetration where the steam was leaking, which is consistent with the fact that no steam was confirmed from other floor penetrations. At the time of the steam discovery date (June 3, 2011), decay heat was still high, and the D/W ambient temperature was 97.4 °C, as shown in Figure 3.1.1. Therefore, it is considered that the water in the PCV was evaporating due to the heat source of the fuel that migrated to the bottom of the D/W. The RPV water injection rate at the time of the steam discovery was 5 $m^3/h$, and the RPV water injection rate on May 13, 2011, when no steam was observed from the AC piping penetration, was 8 $m^3/h$. Therefore, it is possible that the PCV water level dropped as the water injection rate decreased, causing the gas phase to leak from the damaged expansion joint of the vacuum break line, resulting in the steam outflow.

Based on the above, it is highly likely that the steam observed in the southeast area of the 1st floor was generated from high-temperature stagnant water in the PCV and flowed out of the PCV from the damaged expansion joint of the vacuum break line located southeast of the torus room, passing through the floor penetration and into the southeast area of the R/B 1st floor.

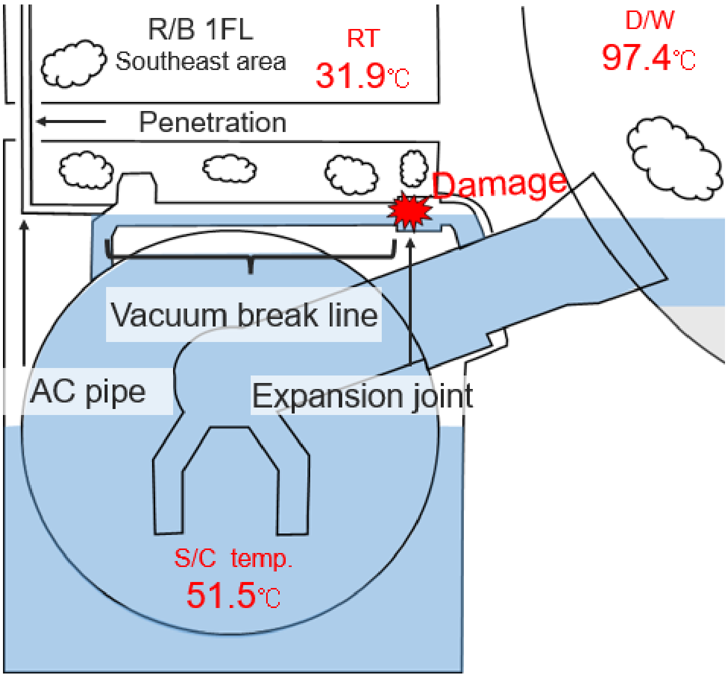



Figure 3.1.1 Temperatures around the torus room on the day the steam was discovered and the estimated path of the steam (June 2011) [1]

b) Examination of the effect of the steam

Figure 3.1.2 shows a gamma camera photo of the floor penetration in the southeast area of the 1st floor where the steam was outflowing. The piping where the high dose rate is confirmed in the center of the photo is AC piping. Contamination of AC piping is discussed in Section 3.2. If steam is the contamination source, there should be conspicuous contamination in the passages of steam, including AC piping penetrations, and in surrounding structures where steam would have adhered. However, from the gamma camera photo, it was found that the contamination along the AC piping was predominant, and no contamination comparable to that of the AC piping could be confirmed in the penetration and surrounding structures.

Figure 3.1.3 shows the floor sampling locations in the southeast area on the 1st floor, and Figure 3.1.4 shows the floor samples collected. Table 3.1.1 lists the surface dose rate measurement results for floor samples. Sample A was collected near the X-6 penetration and had a surface dose rate of 0.14 mSv/h, with no water marks on the surface. Sample B was collected near the AC piping penetration where the steam flowed out, and had a surface dose rate of 0.38 mSv/h, with water marks on the surface. The measured surface dose rate of sample B was

2.7 times higher than that of sample A, but it is not a significant enough value to cause the air dose rate of several 1000 mSv/h observed in the southeast area. In addition, the air dose rate in the southeast area measured in December 2013 shown in Figure 3.1.5 is characterized by being higher at 150 cm above the floor than at 5 cm above the floor. Given that floor contamination is the dominant contamination source in the southeast area, this cannot be considered to be the dominant contamination source because it is inconsistent with the contamination characteristics of this area.

Based on the above, although steam is thought to have flowed out from within the PCV, no significant contamination was confirmed in places where steam is expected to adhere, such as AC piping floor penetrations, surrounding structures, and floor surfaces. It is thought that there is almost no effect of contamination by steam.

From the examination results of (1), (2) and (3), both the outflow of steam confirmed at the floor penetration in the southeast area on the 1st floor and the high dose rate confirmed in the torus room have no dominant effect on the southeast area.

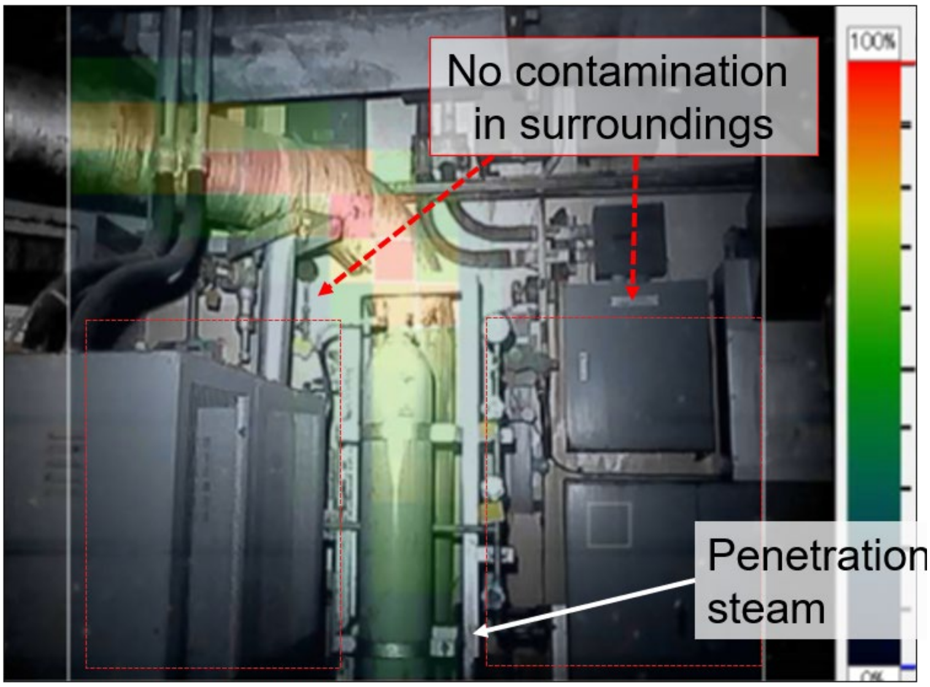



Figure 3.1.2 Gamma camera photo of the floor penetration in the southeast area of the 1st floor (partially modified from [6])

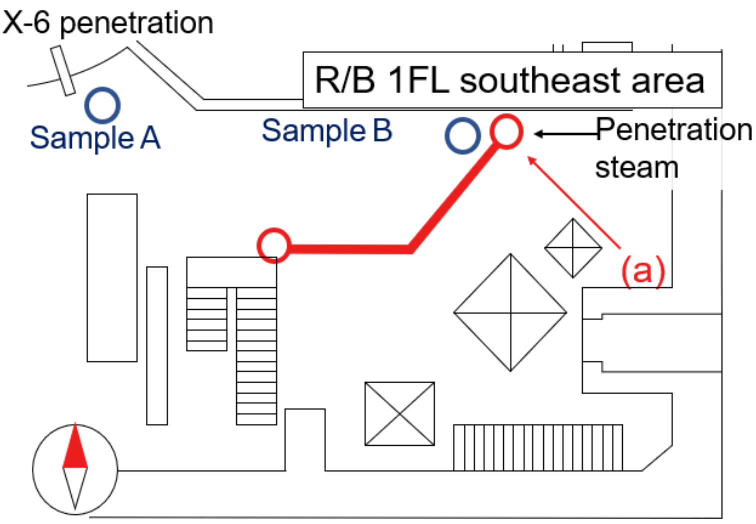
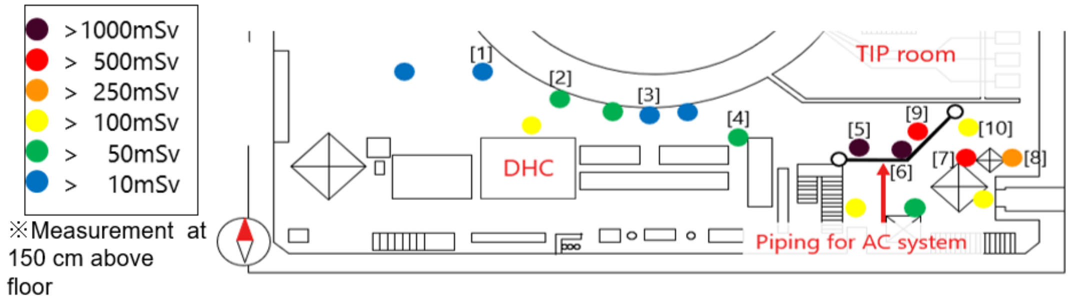



Figure 3.1.3 Locations of floor sample collection in the southeast area of the 1st floor
( (a) is the photo direction in Figure 3.1.2)

Figure 3.1.4 Floor samples collected in the southeast area of the 1st floor [7]
(left, Sample A; right, Sample B)

Table 3.1.1 Results of surface dose rate measurements for floor samples [7]

| Location | Sample | Surface dose rate (mSv/h) | | BG (mSv/h) |
|---|---|---|---|---|
| | | β + γ | γ | |
| Floor near X-6 penetration on the south side of the 1st floor | Sample A | 8 | 0.14 | 0.04 |
| Water mark near AC pipe root on the south side of the 1st floor | Sample B | 13 | 0.38 | 0.04 |




| Position | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 150 cm above floor | 31 | 62 | 26 | 52 | 1662 | 1097 | 511 | 314 | 659 | 203 |
| 5 cm above floor | 20 | 41 | 32 | 31 | 186 | 331 | 274 | 244 | 158 | 144 |

Figure 3.1.5 Air dose rate (December 2013) on the south side of the 1st floor (partially modified from [6])

## ■ 3.2 Contamination of inert gas system (AC) piping

### (1) Cause of contamination

In Unit 1, the PCV pressure rose above the maximum working pressure due to the loss of the cooling function of the PCV, and a depressurization operation using a PCV vent was performed to protect the PCV. Therefore, the AC piping used for venting was contaminated by radioactive materials that passed through the inside of the piping during venting.

### (2) Radiation effect from contamination sources

A contamination survey was conducted in December 2013 around the southeast area of the 1st floor where the AC piping is laid, as shown in Figure 3.1.5. Figure 3.2.1 shows the gamma camera measurement locations in the southeast area of the 1st floor, and Figures 3.2.2 and 3.2.3 show gamma camera photos of this area. According to the gamma camera measurement survey, the air dose rate due to the AC piping at 150 cm above the floor was estimated to be approximately 900 mSv/h, which is generally consistent with the air dose rate in the southeast area of the 1st floor. In addition, the AC piping used for venting was laid so that it rises from the 1st floor penetration where the steam was outflowed, passes 200 cm above the floor in the southeast area of the 1st floor parallel to the floor surface, and exits to the 2nd floor. Therefore, the air dose rate on the upper side of the 1st floor is expected to be higher, which is consistent with the characteristic that the air dose rate at 150 cm above the floor is higher than that at 5 cm above the floor shown in Figure 3.1.5.

(3) Migration of radioactive materials from contamination sources

From the gamma camera photos in Figures 3.2.2 and 3.2.3, no dominant contamination sources can be seen on the floor, walls, or structures in the southeast area, and only contamination along the AC piping can be seen. Therefore, there is no possibility that radioactive materials that passed through the piping leaked from the AC piping in the southeast area, and it is considered that the contamination is still inside the piping.

Based on the examination results of (1), (2), and (3), although there was no migration of radioactive materials from inside the AC piping to the southeast area, the contamination identified along the AC piping is consistent with the observed characteristics of air dose rate, suggesting that the high dose rate in the southeast area is dominated by the effect of contamination in the AC piping.

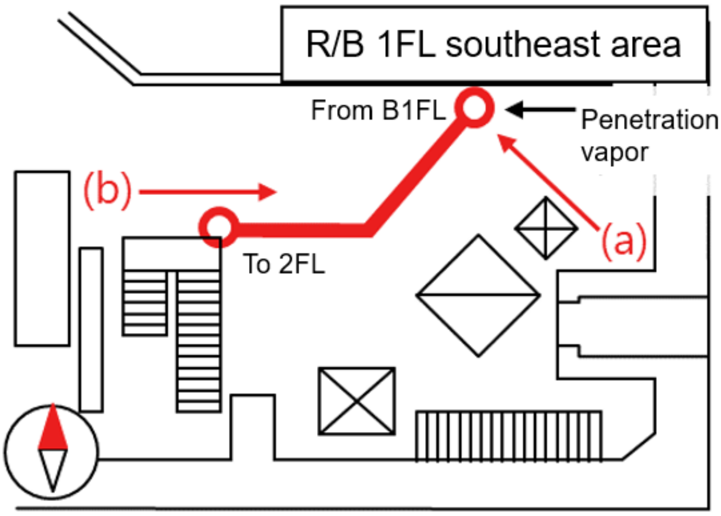



Figure 3.2.1 Locations of gamma camera measurements in the southeast area of the 1st floor (partially modified from [6])

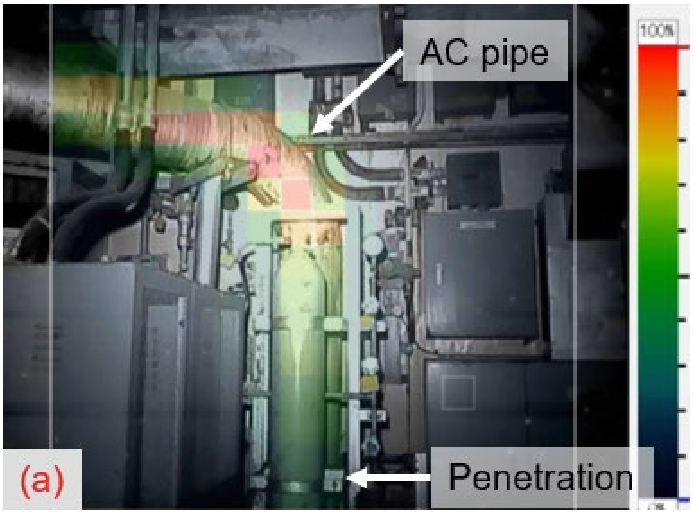



Figure 3.2.2 Gamma camera photo of the southeast area of the 1st floor (1) (December 2013) [6])


Figure 3.2.3 Gamma camera photo of the southeast area of the 1st floor (2) (December 2013) [6])

■ 3.3 Contamination of reactor building cooling water system (RCW) piping

(1) Cause of contamination

The molten fuel that fell to the bottom of the PCV during the accident damaged the RCW piping, and radioactive materials migrated and stayed in the RCW piping, which is assumed to have contaminated several RCW components (see Attachment 1-9). The effect of the RCW piping contamination was also included in the examination.

(2) Radiation effect from contamination sources

Figure 3.3.1 shows the RCW loads and respective dose rate on the 1st and 2nd floors of the R/B. The RCW load around the southeast area on the 1st floor is the drywell humidity control system (DHC), and dose rate of about 100 mSv/h have been observed around it, but they are not enough to be a dominant factor in the southeast area. On the other hand, high air dose rate equivalent to the air dose rate in the southeast area (about 1600 mSv/h) are observed around the heat exchanger (RCW-Hx) on the 2nd floor (over 1000 mSv/h) and in the shutdown cooling system (SHC) pump room on the 1st floor (about 1700 mSv/h). Therefore, the dose rate contribution from the contamination sources in the RCW-Hx and SHC pump room to the southeast area was discussed.

The concrete thickness of the R/B 2nd floor concrete is 600 mm, which indicates that the radiation from the 2nd floor RCW-Hx is sufficiently attenuated in the southeast area. The concrete thickness from the SHC pump room to the southeast area is shown in Figure 3.3.2, and it is clear that the radiation from the contamination source in the SHC pump room is sufficiently shielded by the frame.

Based on the above, it is considered that the effect of radiation from the high dose points in RCW do not explain the high dose rate in the southeast area.

(3) Migration of radioactive materials from contamination sources

The RCW is a closed-loop system, and system water is supplied to each device from the main piping that passes through the upper part of each floor. No damage has been confirmed to date in the R/B. If the RCW system water spills only from the damaged point in the PCV, the system water in the main piping will drain, but the system water will remain in the piping of each device. Figure 3.3.3 shows the assumed residual water situation in this case. Around the southeast area of the 1st floor, it is considered that the system water remains in the DHC on the 1st floor, and in the RCW-Hx and SHC-Hx on the 2nd floor. If residual high-dose system water leaked and flowed into the southeast area, it could cause a high dose rate in the southeast area; therefore, it is necessary to examine whether there is leakage to the southeast area.

However, as shown in Figures 3.1.3 and 3.1.4, and Table 3.1.1, floor sample B, which was collected near the AC piping floor penetration where high dose rate are observed in the southeast area, has a surface dose rate of 0.38 mSv/h, although water marks were observed on the sample surface. The surface dose rate is 0.38 mSv/h, which is not as significant as the 0.14 mSv/h surface dose rate of floor sample A collected in the vicinity of the X-6 penetration where no water marks are observed. Therefore, it is considered that the water marks were not caused by high-dose RCW system water, there was no leakage of RCW system water around the southeast area, and there was no radioactive material migration from the RCW.

Based on the examination results of (1), (2), and (3), it is considered that radiation from the high-dose area of the RCW is sufficiently shielded by the frame concrete, and that there was no migration of radioactive materials from the RCW; therefore, the effect of the contamination of the RCW piping on the southeast area is not considered dominant.

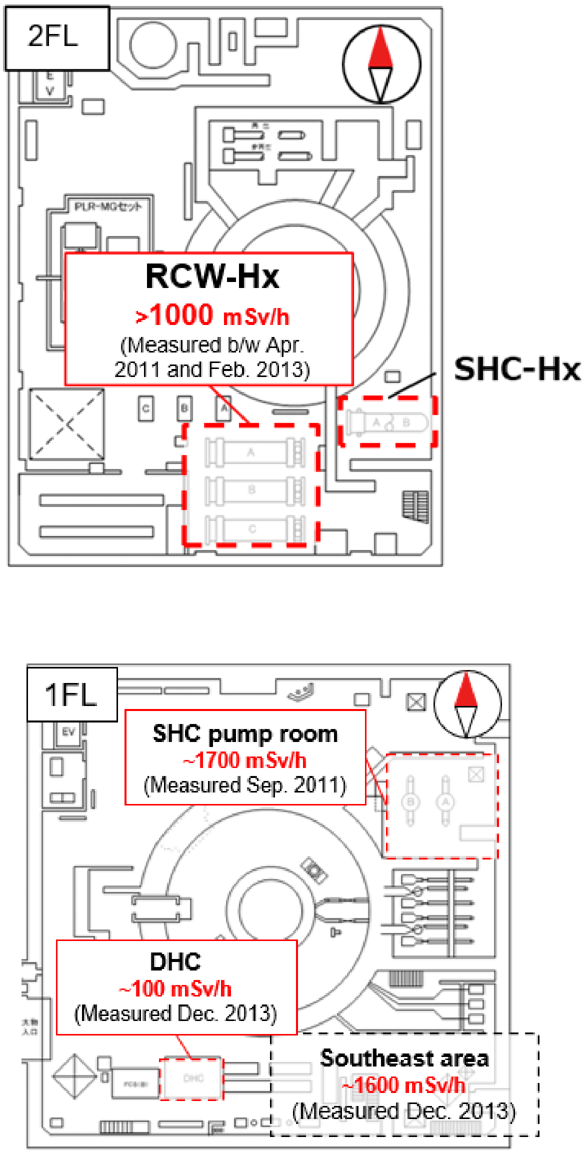



Figure 3.3.1 Load and nearby dose rate of RCW systems in the vicinity of the southeast area [4][6]

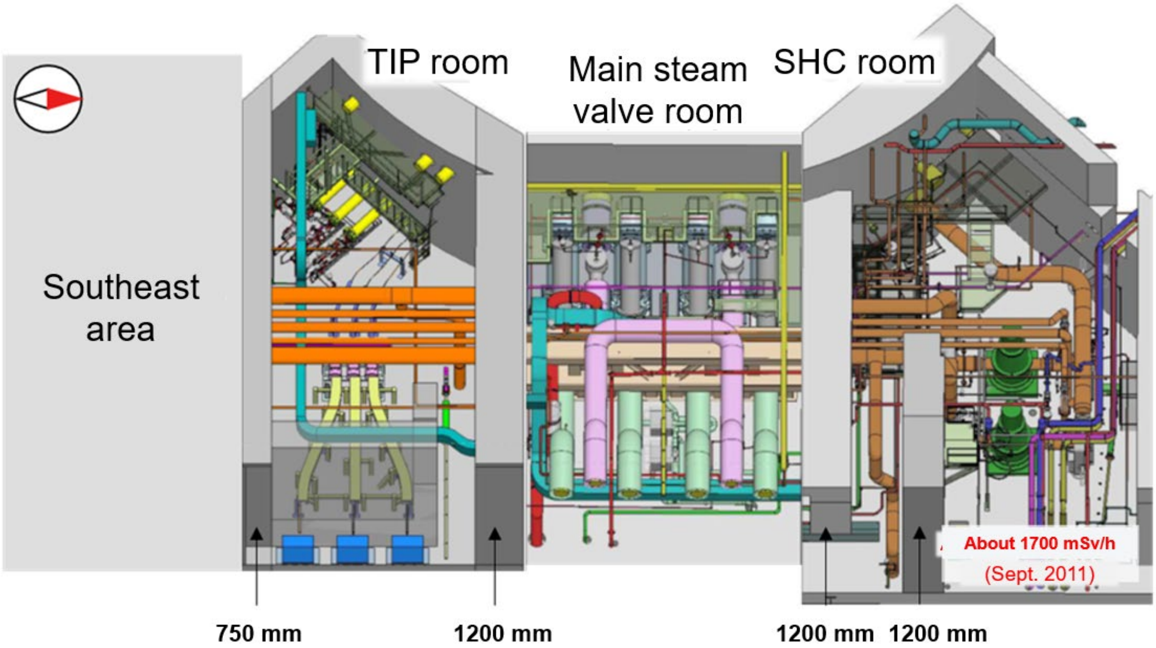



Figure 3.3.2 Locations of TIP room, main steam valve room, and SHC room (partially modified from [8])

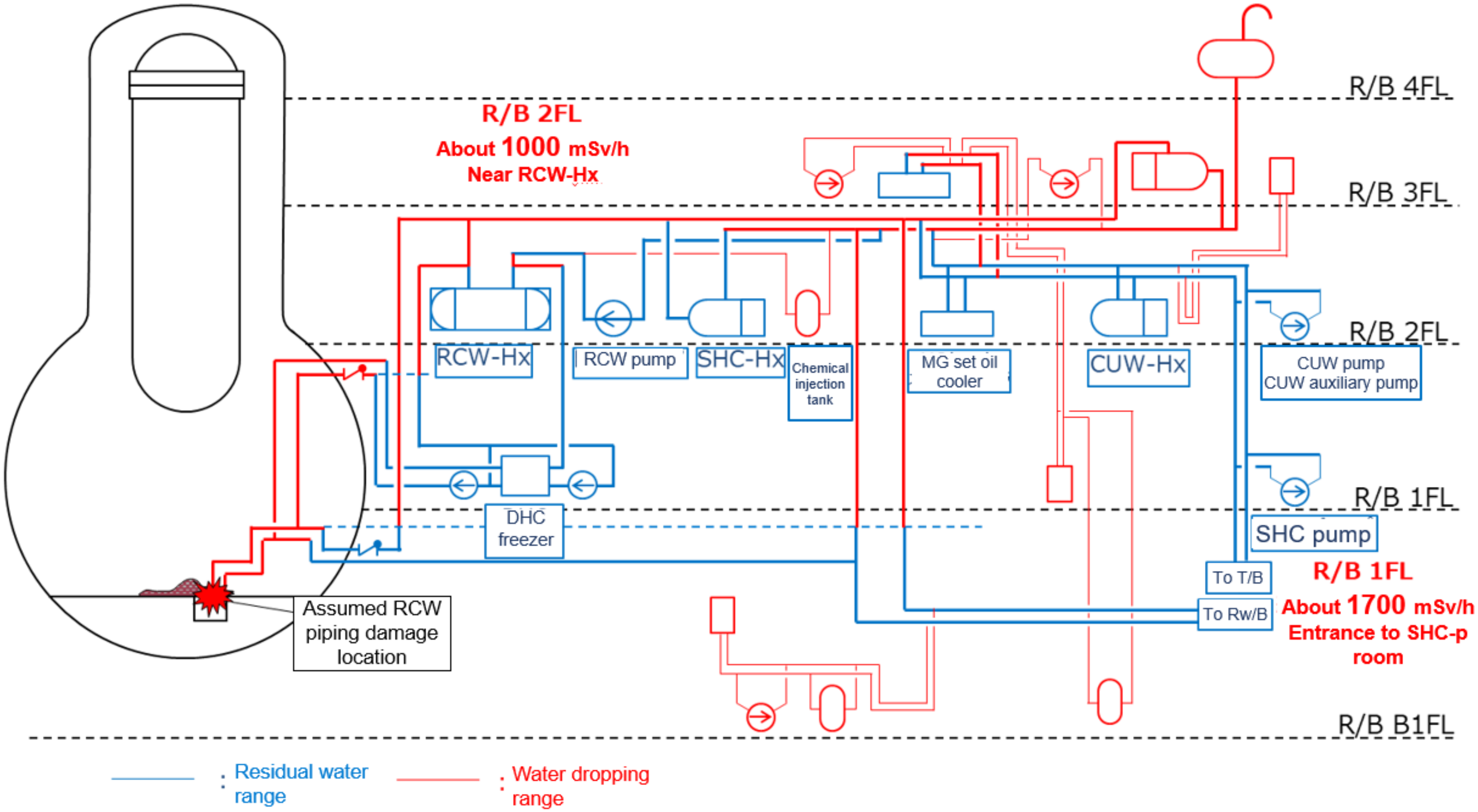



Figure 3.3.3 Residual water in RCW system assumed if water drops only from the damaged area in the PCV

## ■ 3.4 Contamination of traversing in-core probe system (TIP) room

### (1) Cause of contamination

During the accident, the core was exposed and overheated, and the fuel melted, which may have damaged the TIP instrumentation dry tube, causing radioactive material from the molten fuel to migrate into the TIP instrumentation, resulting in high contamination of the TIP instrumentation.

The air dose rate in the TIP room obtained during the Unit 1 TIP room survey from September 24, 2015, to October 2, 2015 are shown in Figure 3.4.1 and a gamma camera photo around the PCV penetration is shown in Figure 3.4.2. The TIP instrumentation penetrations (X-35A~D), which were initially feared to be contaminated, were not found to be contaminated, but the adjacent X-31 penetration was found to be contaminated at approximately 300 mSv/h. The main steam instrumentation and SHC instrumentation is installed in the X-31 penetration, but it is unclear which instruments are contaminated.

### (2) Radiation effect from contamination sources

The maximum air dose rate inside the TIP room is about 300 mSv/h (October 2015). On the other hand, the air dose rate in the southeast area is more than 1000 mSv/h, even when converted from the measured value in December 2013 to the air dose rate in October 2015, considering the half-life, and the dose rate in the TIP room is lower than that in the southeast area; therefore, the TIP room is not considered the dominant contamination source of the southeast area. Furthermore, the thickness of the frame concrete between the TIP room and the southeast area is 750 mm, indicating that the effect of radiation from the TIP room is sufficiently attenuated in the southeast area. Therefore, the effect of radiation from the TIP room is considered negligible.

### (3) Migration of radioactive materials from contamination sources

Figure 3.4.3 shows an image of the X-31 penetration and Figure 3.4.4 shows an image of the X-35 penetration. No leakage traces can be seen in the X-31 penetration, which is confirmed by the gamma camera to be contaminated. On the other hand, although brown marks can be seen in the lower part of the X-35A penetration, the gamma camera confirmed no contamination. In addition, Figure 3.4.1 shows that the air dose rate in the TIP room decreases on moving away from the X-31 penetration, suggesting that the contamination of the X-31 penetration was confined to the penetration area and that there was no migration of radioactive materials into the TIP room.

Based on the examination results of (1), (2), and (3), it is considered that radiation from high-dose areas in the TIP room is sufficiently shielded by the frame concrete, and that radioactive materials do not migrate into the TIP room, so the effect of contamination in the TIP room on the southeast area is not dominant.

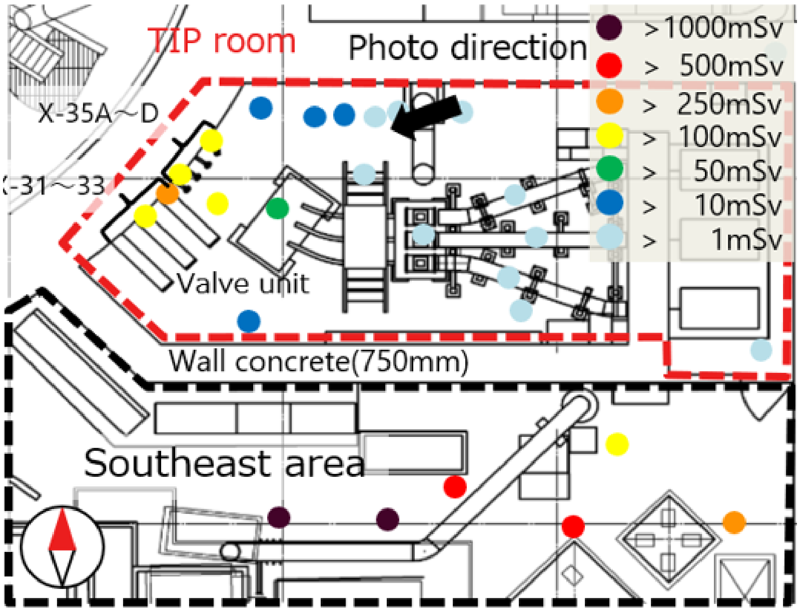



Figure 3.4.1 Air dose rate in the TIP room (September 2015) and in the southeast area (December 2013) (Modified from reference [6][8])

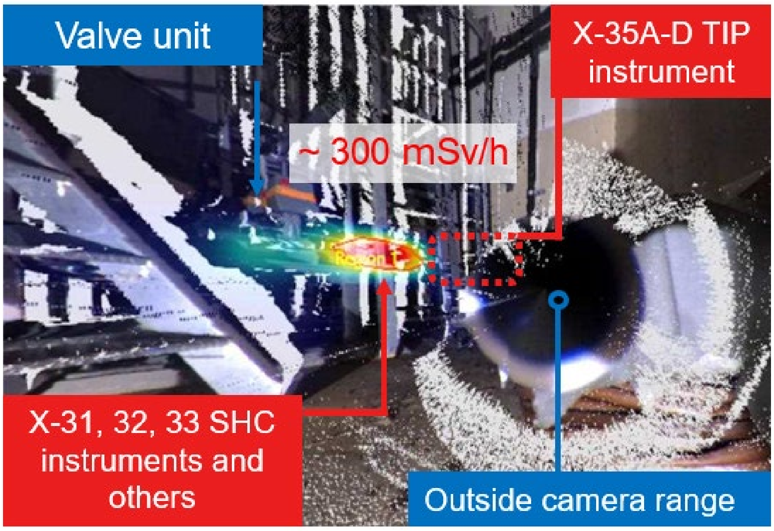



Figure 3.4.2 Gamma camera photo of the TIP room (partially modified from reference [8])

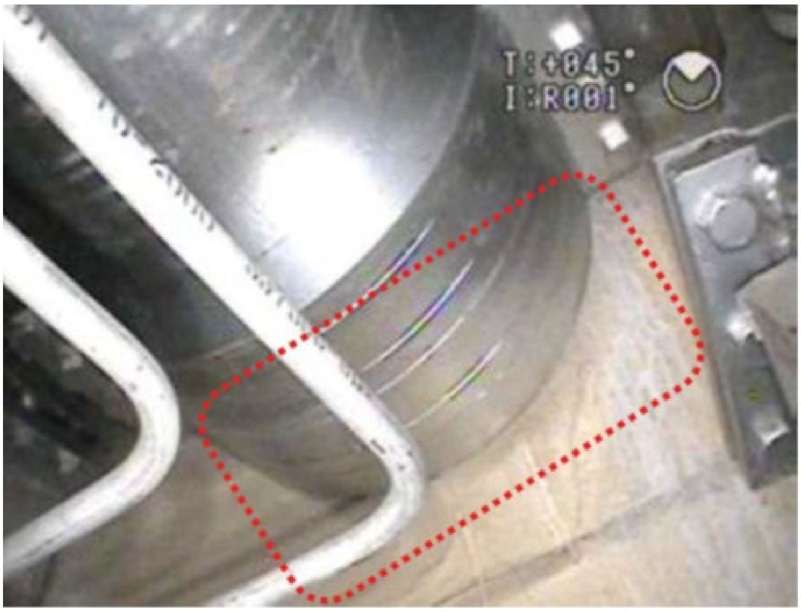



Figure 3.4.3　Image of X-31 penetration [8]

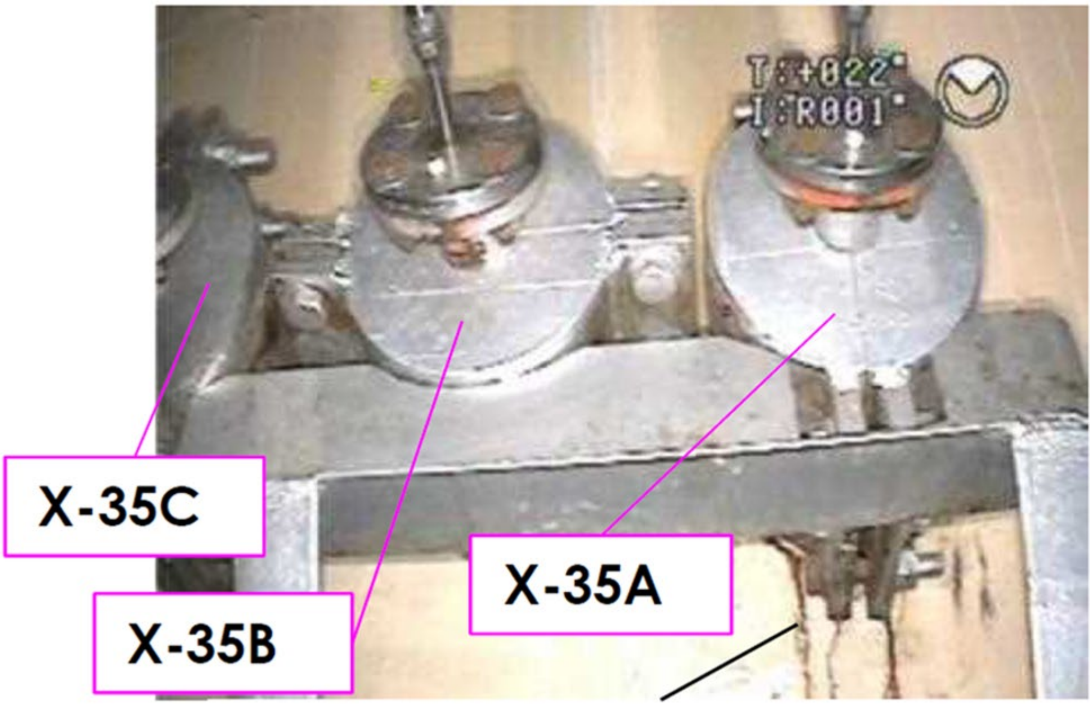



Figure 3.4.4　Image of X-35 penetration [8]

■ 4. Relation to safety measures at Kashiwazaki-Kariwa Nuclear Power Station (NPS)

Based on the previous discussion, the radiation from the AC piping used for PCV venting was identified as the dominant cause of the high dose rate observed in the southeast area on the 1st floor of Unit 1. Therefore, safety measures at the Kashiwazaki-Kariwa NPS should be taken to ensure that radiation from the vent line does not affect accident response operations.

At the Kashiwazaki-Kariwa NPS, in addition to implementing measures to prevent damage to the reactor core and to remove heat from the PCV while maintaining the PCV boundary using alternative circulation cooling, the following exposure reduction measures have been implemented in the event that PCV venting becomes necessary.

The valves that need to be opened during PCV venting can be operated remotely and electrically from the central control room, and a bypass line is provided to the secondary isolation valve to prevent PCV venting by remote electric operation from being disabled due to valve failure alone (Figure 4.1). In addition, the vent line valves are designed so that they can be opened and closed by remote operation from outside the secondary containment facility in the event of power loss, either manually or by using dedicated cylinders (Figures 4.1 to 4.4). Therefore, remote manual operation during venting operation after core damage can reduce exposure associated with the operation. Furthermore, the filter system, iodine filter, and outdoor piping connected to the filter system (on the inlet side of the filter system) are shielded to reduce exposure during outdoor operations. The evaluation has confirmed that the PCV venting operation after core damage is sufficiently feasible from the viewpoint of radiation dose.

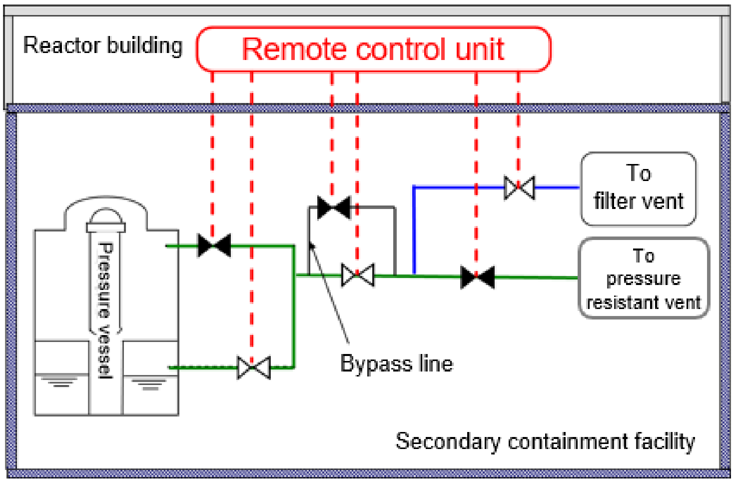



Figure 4.1 Outline of vent line

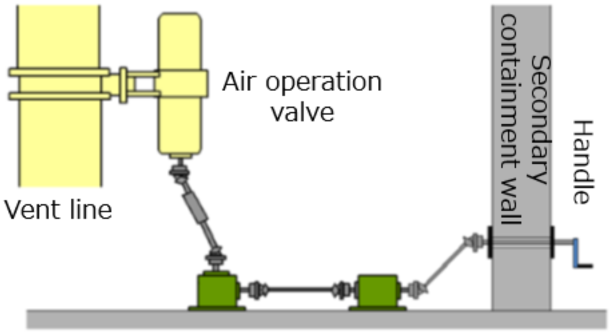



Figure 4.2　Outline of remote manual operation equipment

Figure 4.3　Operation of the remote manual operation equipment

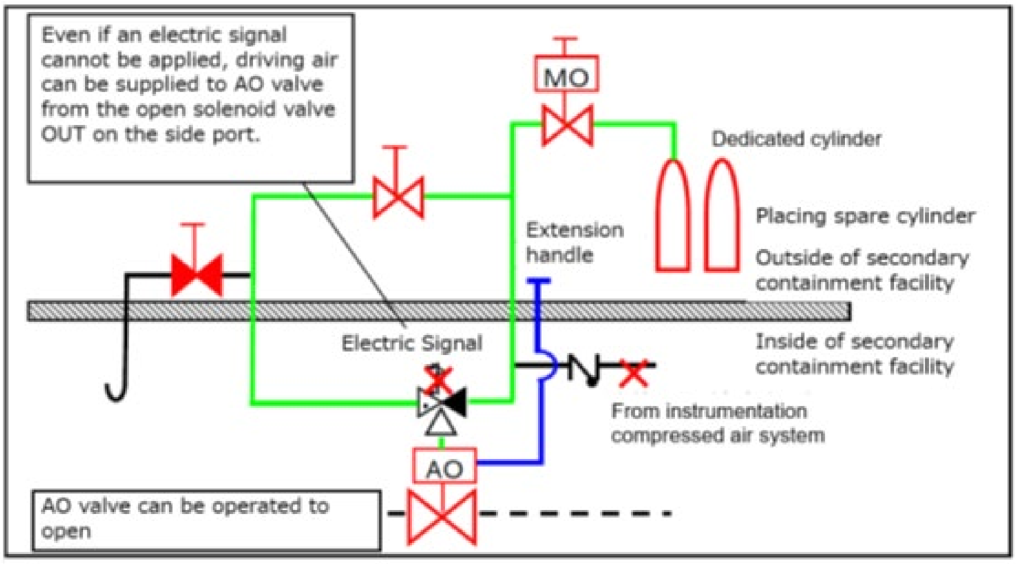



Figure 4.4 Outline of AO valve operation mechanism with dedicated cylinder

■ 5. Summary

In order to identify the cause of the high dose rate observed in the southeast area of the 1st floor of the Unit 1 R/B, this attachment extracted possible sources of contamination and examined the effect of each extracted contamination source on the southeast area in terms of (1) cause of contamination, (2) radiation effect, and (3) radioactive material migration. As a result of the examination, the radiation effect from the AC piping used for PCV venting was identified as the dominant source. The results of the examination are summarized in Table 5.1.

Table 5.1 Summary of examination results

| Possible contamination source | Result | Details of examination results | | |
|---|---|---|---|---|
| | | Radiation effect | Radioactive material migration | Content of examination |
| Contamination by steam and contamination of the torus room | × | × | × | ・ Steam from the stagnant water in the PCV was leaking out, but it was not a significant contamination.<br>・ Contribution from the torus room was limited due to attenuation by frame concrete shielding. |
| Contamination of inert gas system (AC) piping | ○ | ○ | × | ・ Dose rate in the vicinity of the AC piping were similar to those observed in the southeast area.<br>・ Contamination was distributed along the piping, there was no leakage. |
| Contamination of Reactor Building Cooling Water System (RCW) piping | × | × | × | ・ Contribution from RCW piping was limited due to attenuation by frame concrete shielding.<br>・ No leakage of RCW system water to the southeast area. |
| Contamination of Traversing In-core Probe System (TIP) room | × | × | × | ・ Contribution from TIP room was limited due to attenuation by frame concrete shielding.<br>・ No leakage into TIP room from the X-31 penetration, where high dose rate was observed. |

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