

Status of investigation on estimating situation of cores and containment vessels

1. Introduction

The conditions of Unit-1 and Unit-3 containment vessels (PCVs), and the situation of damaged and fallen fuel were estimated, at a technical workshop held on November 30<sup>th</sup>, 2011, based on comprehensive evaluation of then-available knowledge, such as temperature changes, etc. due to water injection by the core spray systems. The workshop (organized by the former Nuclear Industry and Safety Agency) was for estimating the conditions of core damage at Unit-1 to Unit-3 of the Fukushima Daiichi Nuclear Power Station.

The latest illustrations for the estimated core and in-containment conditions incorporating new knowledge obtained thereafter by field investigations, etc., are summarized in Figures 1-1 to 1-3. The information added to the estimated illustrations as of November 30<sup>th</sup>, 2011, is summarized in the following chapters.

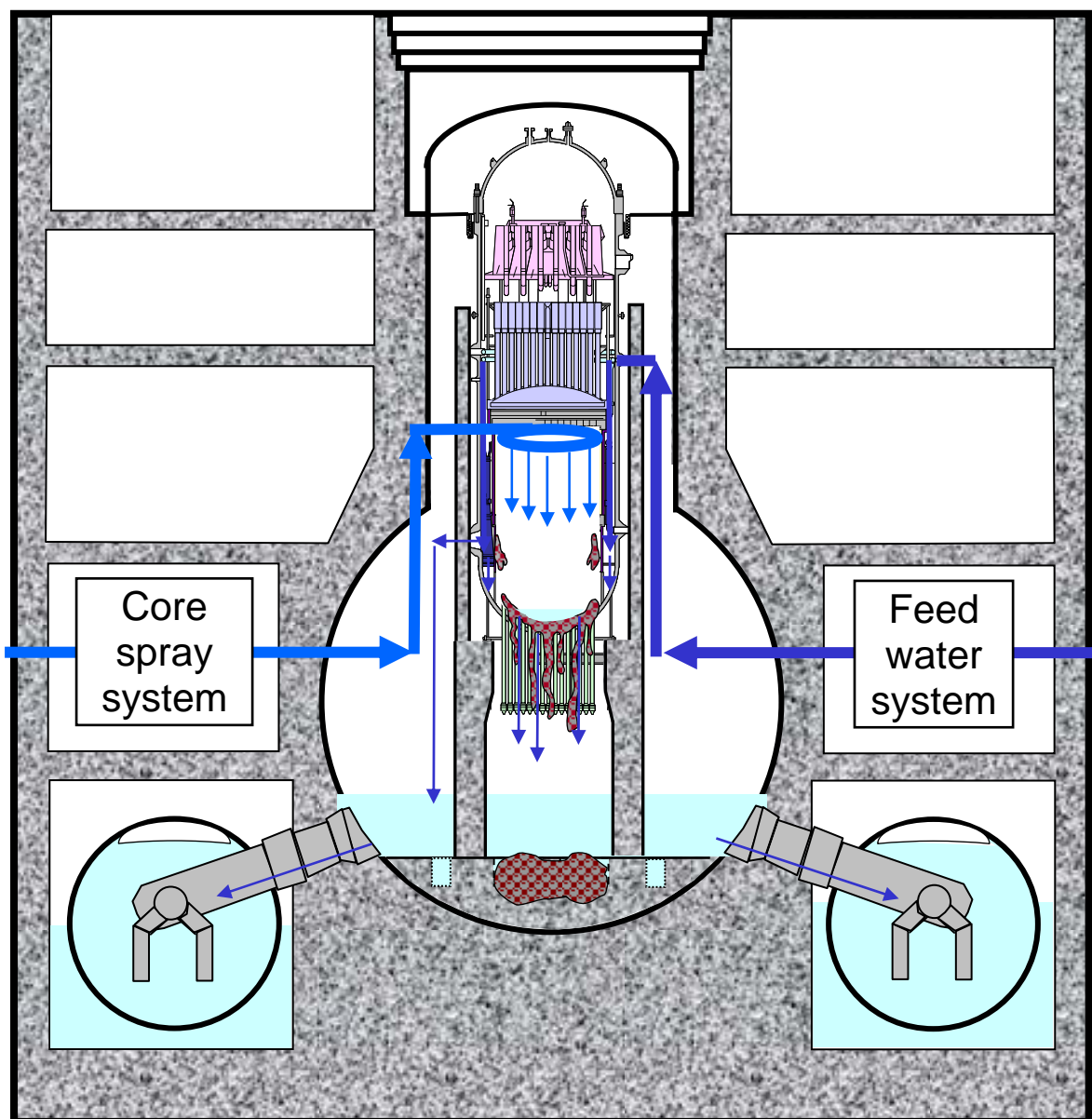


Figure 1-1 Estimated conditions of the core and PCV of Unit-1

(Note) Estimated conditions of the core and PCV are not updated from the previous report. The illustration does not accurately represent a quantitative image for the size, etc. of debris

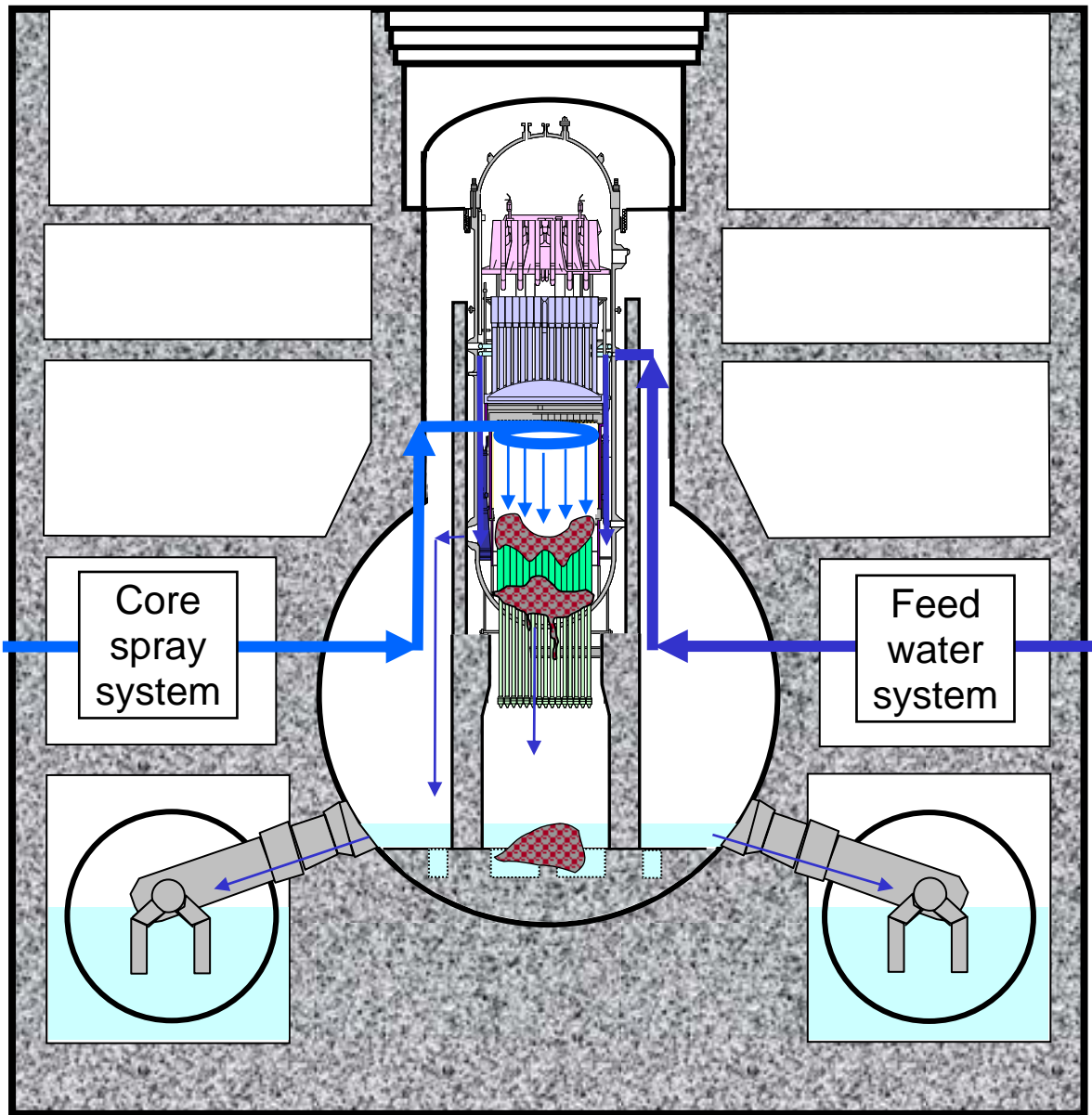


Figure 1-2 Estimated conditions of the core and PCV of Unit-2

(Note) Estimated conditions of the core and PCV are not updated from the previous report. The illustration does not accurately represent a quantitative image for the size, etc. of debris

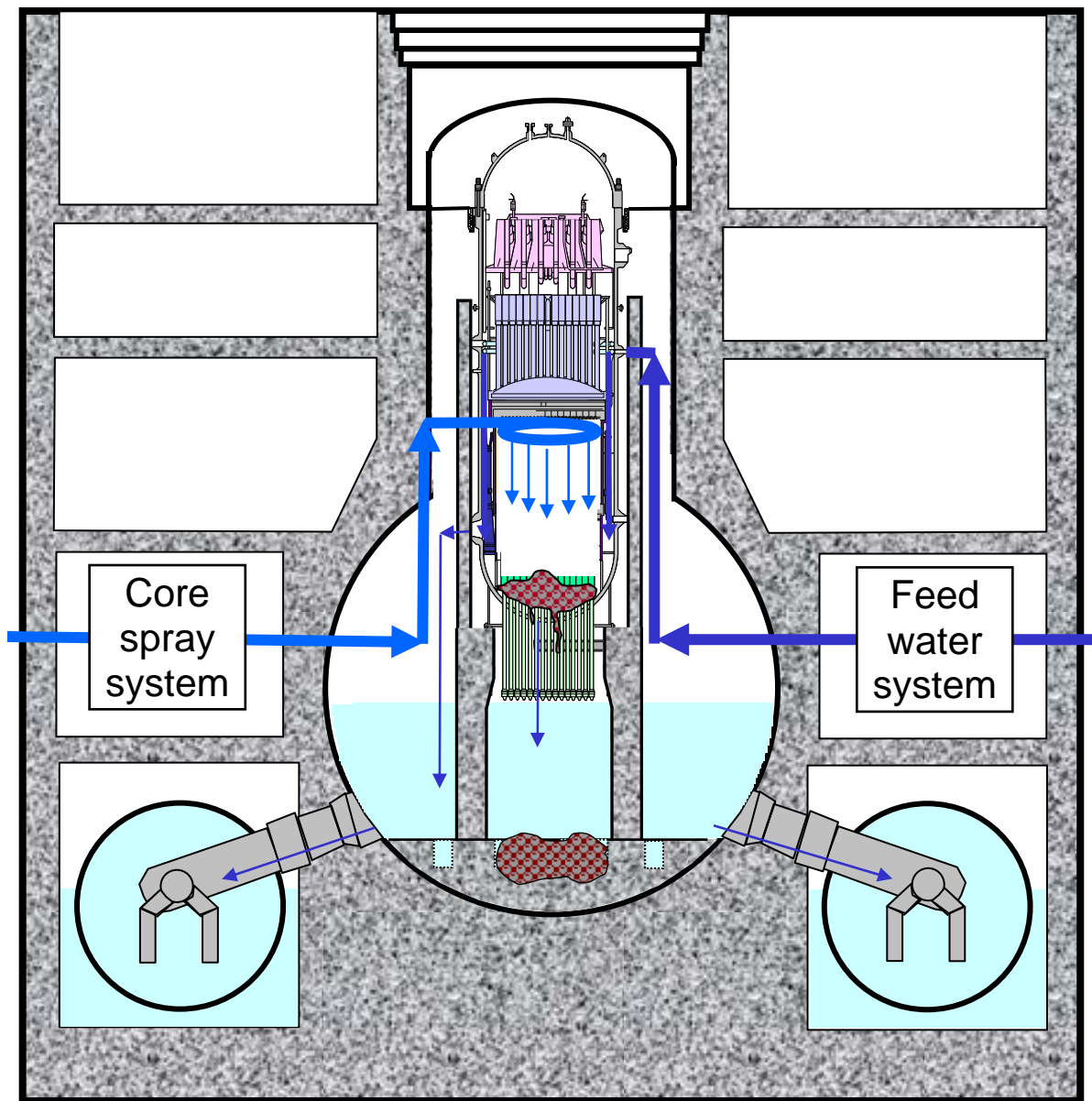


Figure 1-3 Estimated conditions of the core and PCV of Unit-3

(Note) The fallen debris on the PCV pedestal was shown larger this time, incorporating the analysis results of the case that sufficient water injection to the reactor had not been possible before the operator manually stopped the HPCI. The illustration does not accurately represent a quantitative image for the size, etc. of debris.

2. Conditions of Unit-1 core and PCV

(1) In-containment water level measured

In October 2012, an investigation was conducted into the status of the PCV of Unit-1, when photos were taken by cameras, the level of water retained in the PCV was confirmed, dose rates and temperatures were measured, and retained water was sampled and analyzed [1] by inserting survey devices into the containment through a hole dug at the PCV penetration (X-100B, on the first floor of the reactor building).

The level of water retained was measured by lowering the CCD camera cable down to the water surface through the grating above in the PCV. The water level was found to be about 2.8m above the D/W floor (as of October 10<sup>th</sup>, 2012) (Figure 2-1).

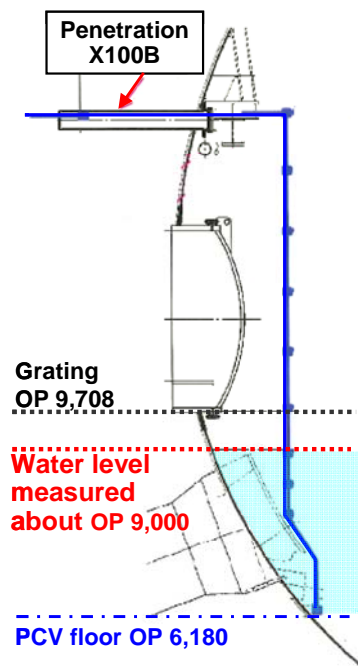


Figure 2-1 Measured level of water retained in Unit-1 PCV

(2) Test results of injecting nitrogen gas into the suppression chamber of Unit-1

In September 2012, a nitrogen gas injecting test was conducted into the suppression chamber (S/C), in which the theory was demonstrated that hydrogen gas and Kr-85 generated in the early stage of the accident and retained in the S/C upper space pushed down the S/C water level and were discharged to the D/W through the vacuum breakers. This helped to confirm that the S/C was currently almost filled with water (the level at around the lowest end of the vacuum breaker tube [2] (Figure 2-2).

This test was conducted with an intention to explain the phenomenon of the intermittent increase of hydrogen gas concentration and Kr-85 radioactivity measured by the containment gas control system of Unit-1 that has been seen since April 2012. This intermittent increase was assumed to occur in the following sequence: When the S/C water

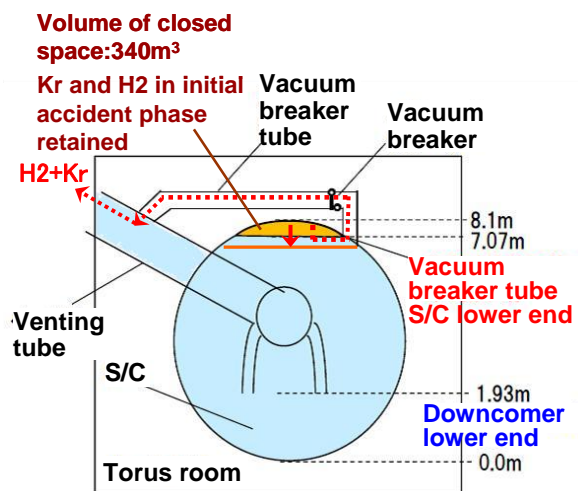


Figure 2-2 Closed space in gaseous phase inside S/C of Unit-1

[1] Handout document, 11th Steering Committee, Government – TEPCO Joint Board on Mid- and Long-term Response Policy, October 22, 2012

[2] Handout documents, 9th and 10th Steering Committees, Government – TEPCO Joint Board on Mid- and Long-term Response Policy, August 27 and September 24, 2012

level drops, residual gas left in the closed space in the upper S/C is discharged to the D/W through vacuum breakers, and then the S/C water level rises and stops the gas discharge. In this hypothesis, Kr-85 is understood to originate in the early phase of the accident, because Kr-85 is a long half-life fission product and its amount cannot be explained as being newly produced by spontaneous fission, etc.

In the test to verify the mechanism hypothesis, the S/C pressure (being monitored by the existing instrumentation) rose after the injection of nitrogen gas started into the S/C, the hydrogen gas concentration and Kr-85 radioactivity monitored by the containment gas control system started to increase, which decreased when nitrogen gas injection was halted. This is interpreted to be that the nitrogen gas injection pressurized the closed space of the S/C upper part, which lowered the S/C water level and formed a gas discharge channel to the D/W through the vacuum breakers, thus the retained gas in the space was discharged together to the D/W by the injected nitrogen gas.

Most of the hydrogen gas retained in the S/C has been purged by continuously injecting nitrogen gas into the S/C since October 2012. Further tests are now underway to verify a mechanism of hydrogen production in the S/C by water radiolysis.

### (3) Investigation of the torus room of Unit-1

The torus room was investigated in February 2013, when photos were taken by cameras, dose rates and temperatures were measured, and retained water was sampled and analyzed by inserting thermometers, dosimeters and cameras through a  $\phi$  200 hole dug on the northeast corner on the first floor of the reactor building [3].

No water leaking position in the S/C has been located yet. At least, no leak was confirmed on the flange of one of the eight vacuum breakers, as far as the camera photos showed (Figure 2-3).



Figure 2-3 Camera photo of an S/C vacuum breaker in the torus room of Unit-1

### (4) **[UPDATE]** Investigation of the situation at the bottom of the vent tubes in the torus room of Unit-1

In the torus room investigation in November 2013, a compact automated instrumentation boat,

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[3] Handout document, Progress in preparations for decommissioning of Units-1 to 4 of the Fukushima Daiichi Nuclear Power Plant, Decommissioning Measures Steering Panel, March 7, 2013

on which a camera and dose meters were mounted, was lowered into the torus room through a 510mm diameter hole drilled into the flooring of the first floor of the Unit 1 reactor building in the northwest corner. The boat was lowered to check visually for water leaks from the vent tube sleeve terminals, to check visually the condition of the sand cushion drain tubes, and to make dose measurements [4].

Camera imaging confirmed water leaks at the following locations (Figure 2-4).

- Vent tube X-5B (① in the figure): water flowing from the displaced sand cushion drain pipe\*
- Vent tube X-5E (④ in the figure): water flowing down on the S/C surface with 2 streams around both sides of the vent tube

\*Water leaks at ① were confirmed since the vinyl chloride pipe (connecting the sand cushion drain tube and drain funnel with an insertion-type joint) had been displaced. Water leaks could not be confirmed at locations ② to ⑧, since the drain tubes had not been displaced. The concrete seams (joints) below the sand cushion drain piping were observed to be wet all around on the concrete wall.

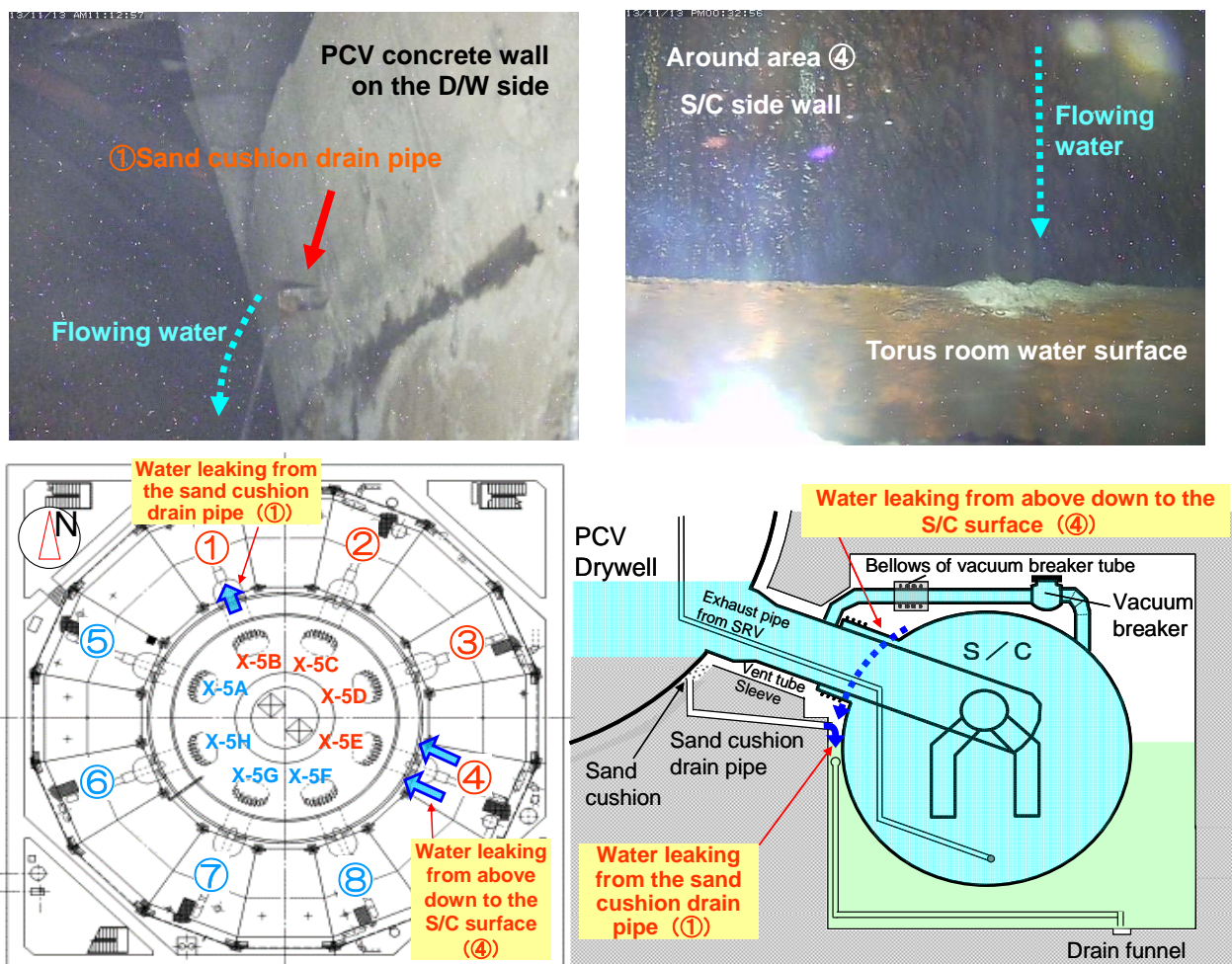


Figure 2-4 Camera images taken below the vent tubes in Unit 1 torus room (part)

[4] Handout document, Progress in preparations for decommissioning of Units 1 to 4 of the Fukushima Daiichi Nuclear Power Station, 10th Decommissioning Measures Steering Panel, November 28, 2013

Water leaks into the sand cushion occur only when water leaks directly from the drywell. The leakage is probably from a low position of the drywell below the water level (for example, the containment vessel shell, pipe penetrations, etc.). The low location of the water leaks in the drywell would indicate the possible influence of molten fuel that fell to the PCV bottom. This information is of critical significance in estimating the conditions of the core and PCV.

Meanwhile, the water leakage down to the S/C surface around both sides of the vent tube X-5E indicates the possibility of water leaks from the vacuum breaker tube (its bellows, for example) immediately above the vent tube. This elevation of the vacuum breaker tube is about the same level as that of the upper limit of PCV water level which was reached in an attempt to flood the PCV by increasing the amount of water injected in May 2011; where the PCV water level was calculated from the injected nitrogen gas pressure. The nitrogen gas pressure was stopped from changing at a specified level, which means the PCV water level was leveled off, i.e., an indication of leak hole existence at the level (Figure 2-5) [5].

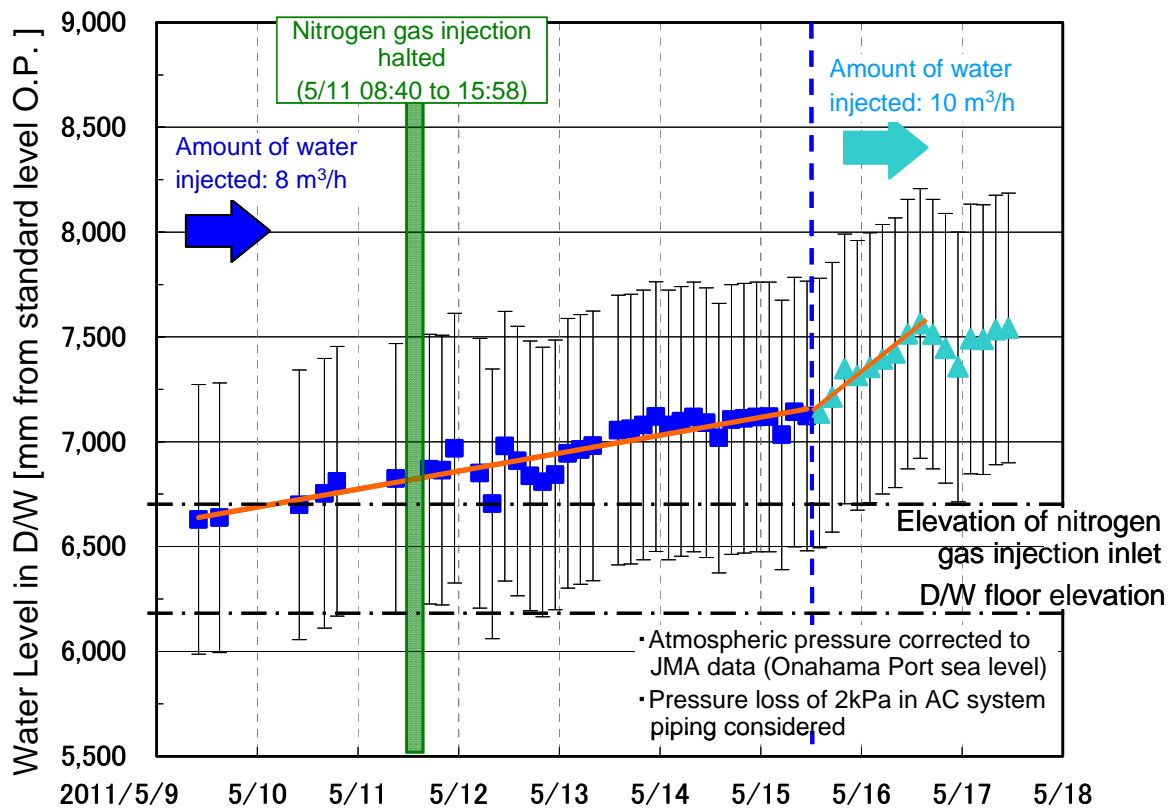


Figure 2-5 Estimated PCV water level changes during flooding operation of Unit 1 (May 2011)

The vertical distribution of radiation doses measured when lowering the instrumentation boat in November 2013 was similar to that measured in February 2013 (in the area surrounding the torus). Dose distribution along the boat traveling route was about 1 to 2 Sv/h, and the highest spots were in the southeast area (Figure 2-6).



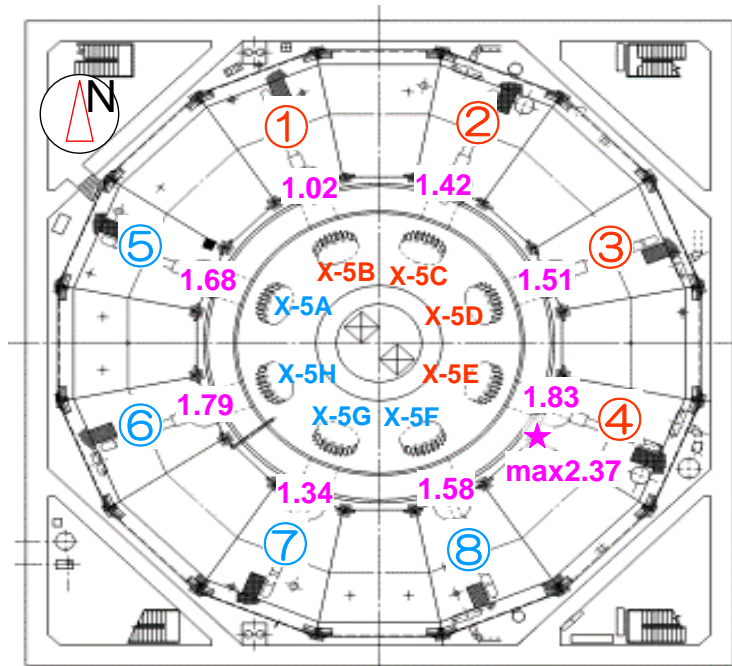


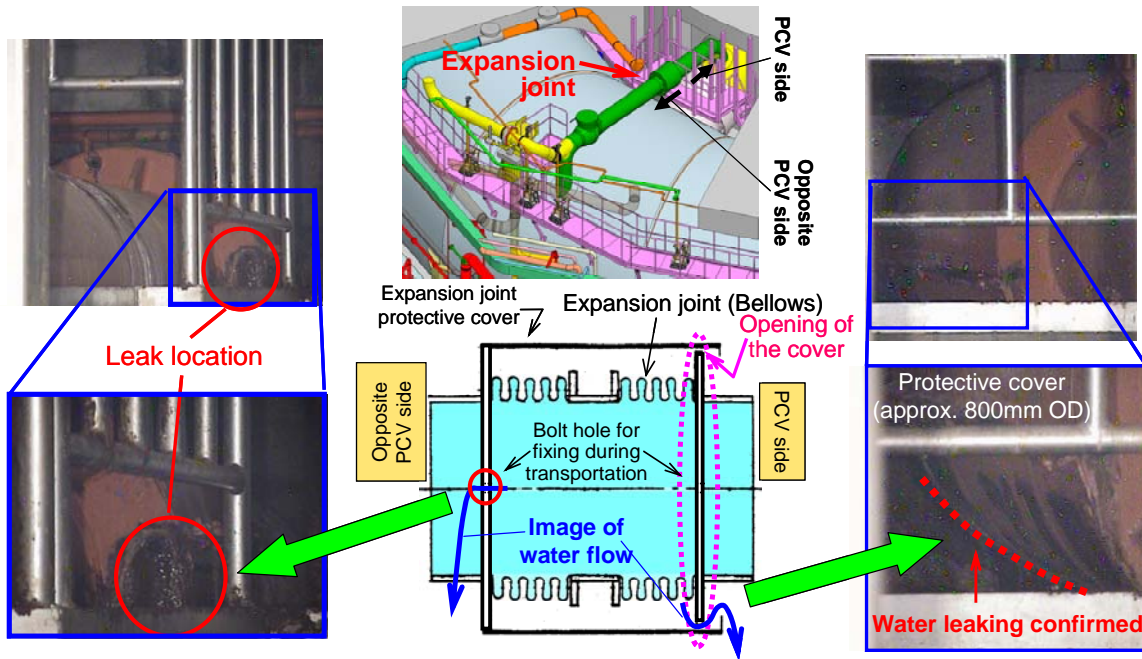
Figure 2-6 Dose distribution measured during the torus room investigation underneath vent tubes of Unit 1

In June 2011, steam blown from the pipe penetrations was witnessed at the southeast corner of the first floor of the reactor building. This would mean that radioactive materials carried by the steam were blown to the torus room after the accident and they deposited on the walls and structure surfaces there. The dose distribution in the torus room is considered to be the sum of doses due to these contamination sources. The estimated radiation dose levels on the water surface due to water-retained radionuclides ( $7.3 \times 10^4$  Bq/cm<sup>3</sup> of Cs-134 and  $1.5 \times 10^5$  Bq/cm<sup>3</sup> of Cs-137, sampled on February 22, 2013) are about 100 mSv/h and not a dominant contributor to the 1 to 2 Sv/h dose measured [6].

In May 2014, survey instrumentation robot was introduced through a drilled hole in the northwest area of the first floor of the Unit1 reactor building to explore the S/C top area in order to locate the leak source near the vent tube X-5E, where leaking had been confirmed. By using the outer catwalk, the instrumentation robot made a camera survey around the vent tube X-5E, and the water leak was confirmed to be from the protective cover of the expansion joint on the vacuum breaker line. No leaks were noticed from the vacuum breaker valve, torus hatch, Shutdown cooling system (SHC) piping or Atmospheric control system (AC) piping (Figure 2-7) [7].

[6] Handout document: Consideration of dose measurement results in the torus room of Unit-1, 7th Meeting of Specific Nuclear Facilities Survey and Examination, March 29, 2013.

[7] Handout document: Consideration of dose measurement results in the torus room of Unit-1, 6th Meeting of Specific Nuclear Facilities Survey and Examination, May 29, 2014



**Illustration of Expansion joint (Bellows) for vacuum breaker tube**

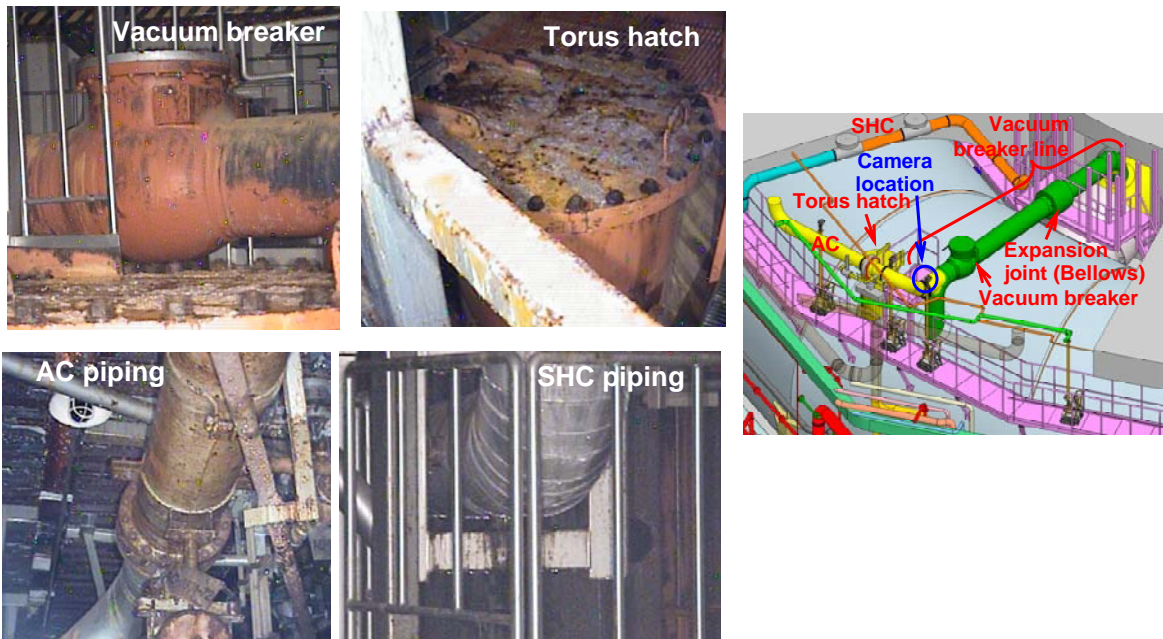


Figure 2-7 Camera images of Unit-1 S/C top area exploration (around vent tube X-5E) (Part)

(5) **[UPDATE]** Contamination survey on the Unit-1 reactor building first floor

In December 2013, contamination was surveyed on the first floor of the Unit-1 reactor building by radiation dose measurements and gamma camera images taken using a robot. It was found that contamination was relatively high on the Atmospheric control system (AC) piping and Drywell humidity control system (DHC) piping (Figure 2-8) [8].

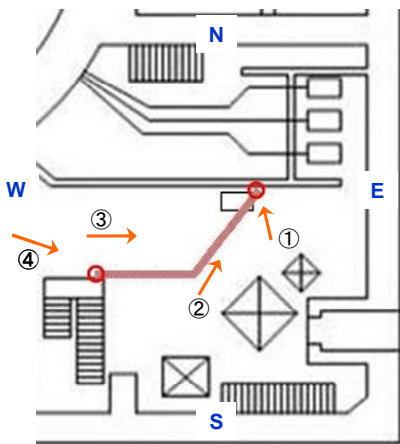


Figure 2. AC system piping route (about 2m elevation)

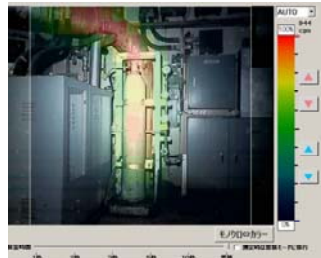


Figure 3. Photo from ①

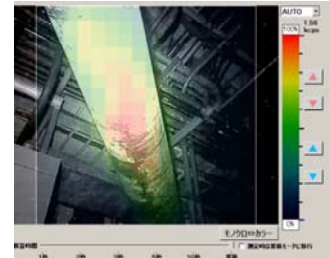


Figure 4. Photo from ②



Figure 5. Photo from ③



Figure 6. Photo from ④

(Gamma camera image taken near the AC system piping in the reactor building 1st floor)

Hot spots confirmed along piping

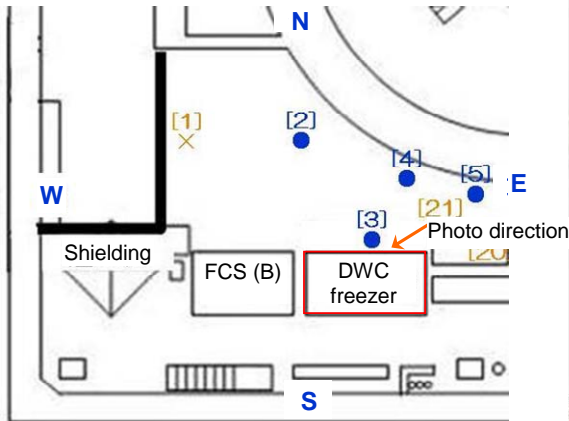


Figure 9. Layout

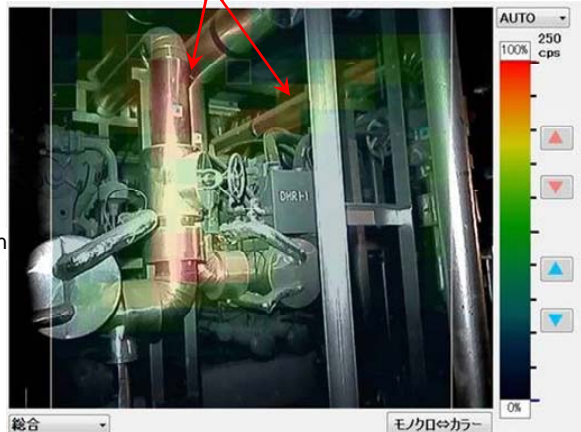


Figure 10. Gamma camera image taken near the DWC freezer

(Gamma camera image taken near the DWC system piping in the reactor building 1st floor)

Figure 2-8 Gamma camera images in the southern area of Unit 1 reactor building 1st Floor (part)

The AC piping is where the steam passed through when the wetwell (W/W) venting was carried out during the accident. Its high contamination is considered to be due to venting flows, and the situation was similar to that for the area near the standby gas treatment system (SGTS) train entrance room or near the SGTS piping connected to the main stack, where high dose rate had

[8] Handout document: Action progress towards decommissioning of Units 1 to 4 of Fukushima Daiichi Nuclear Power Station, 2nd Decommissioning and Contaminated Water Response Team Joint Meeting, January 30, 2014  
Attachment 4-11

been already confirmed.

The DHC piping is connected to the Reactor building closed cooling water system (RCW), and therefore its high dose is considered to be due to the same mechanism as that of RCW piping, where high dose rate had been already confirmed.

3. Conditions of Unit-2 core and the PCV

(1) In-containment water level measured

In March 2012, investigation was conducted into the PCV of Unit-2, when photos were taken by cameras, the level of water retained in the PCV was confirmed, and dose rates and temperatures were measured [9] by inserting survey devices into the PCV through a hole dug at the PCV penetration (X-53, on the first floor of the reactor building).

The level of water retained was confirmed to be about 60 cm above the D/W floor by the video image scope (as of March 26<sup>th</sup>, 2012) (Figure 3-1).

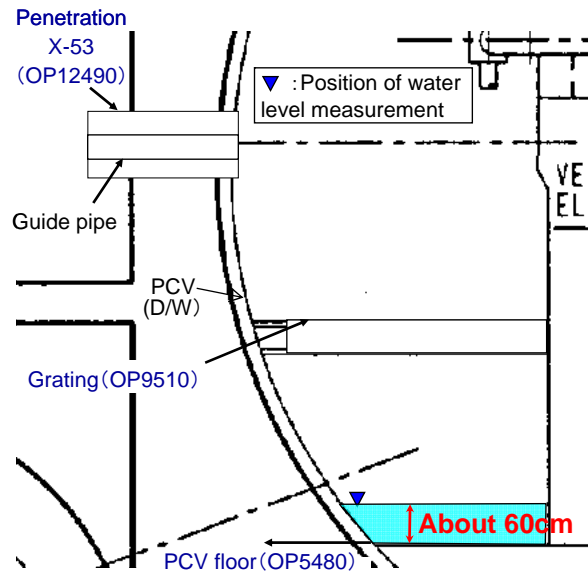


Figure 3-1 Measured level of retained water in Unit-2 PCV

(2) **[UPDATE]** Survey results near the PCV pedestal opening of Unit-2

In July and August 2013, a survey was conducted inside the PCV of Unit-2, when instrumentation was introduced through the PCV piping penetration X-53 (reactor building first floor) to take camera images and make dose and temperature measurements in the vicinity of the control rod drive mechanism (CRD) replacement rail and pedestal opening (Figure 3-2) [10].

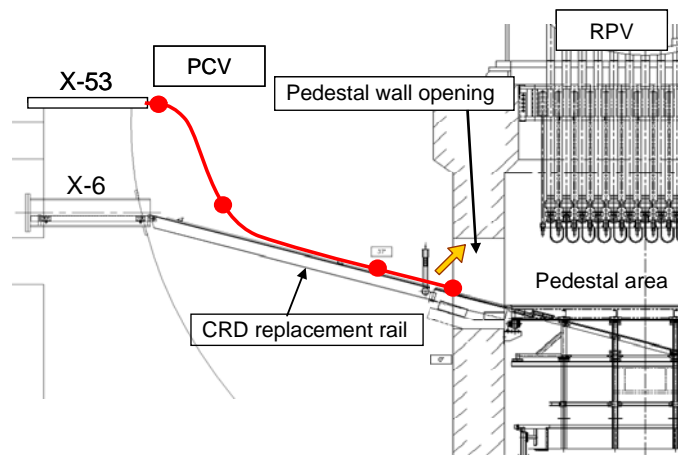


Figure 3-2 Survey areas inside Unit-2

Camera images were taken at the pedestal opening into its inside and after

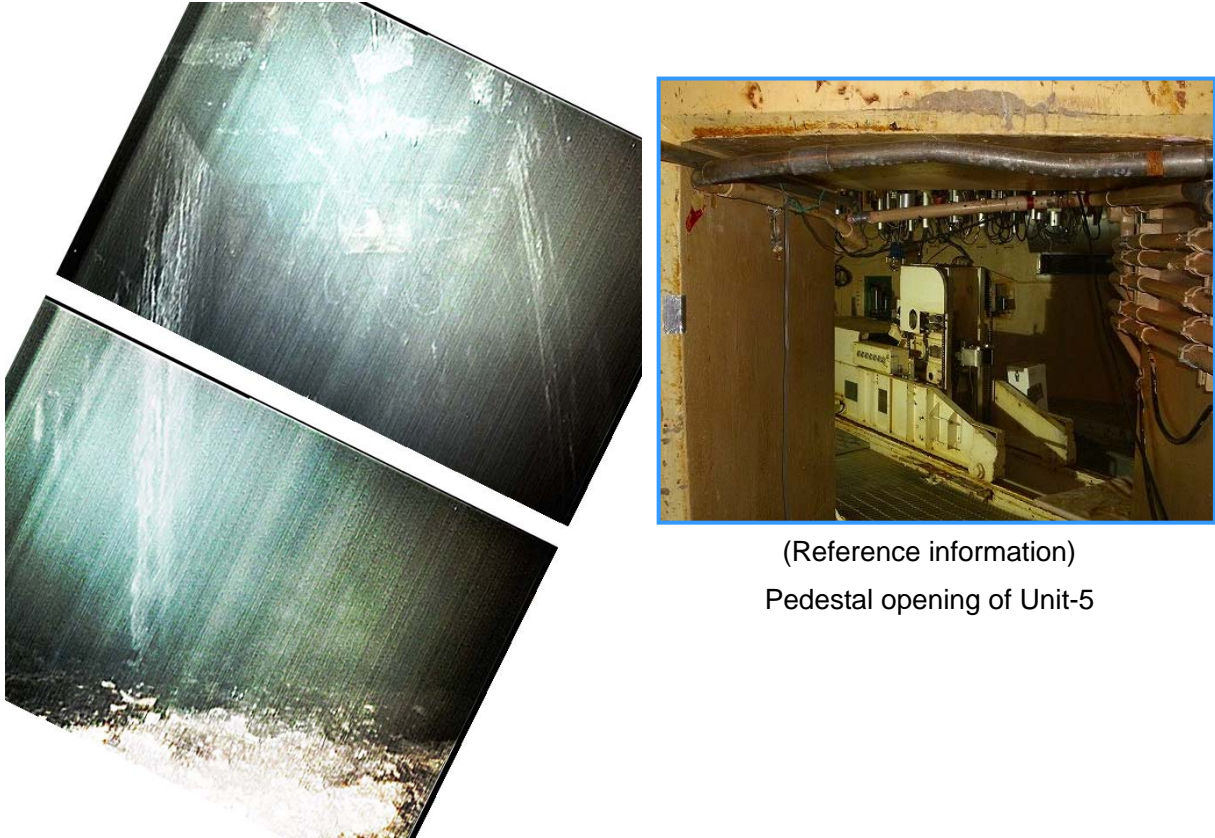
photo processing for noise and contrast, they confirmed the position of the control rod position indicator probe (PIP) cables in the upper part of the pedestal opening, but no clear information was obtained regarding what was in the lower part inside the pedestal (Figure 3-3).

Dosimeters measured the dose rates as far as the top of the CRD replacement rails. The values were about 45 – 80 Sv/h. As supplementary information, dose rates were estimated from the camera image noises; they were about 30 Sv/h near the landing point in replacement rail and

[9] “Results of PCV investigation and plan for identifying leak path”, Technical workshop for Fukushima Daiichi accident, July 24, 2012

[10] Handout document, Progress in preparations for decommissioning of Units 1 to 4 of the Fukushima Daiichi Nuclear Power Station, 7th Decommissioning Measures Steering Panel, August 28, 2013

about 36 Sv/h near the pedestal opening. No clear indication was obtained about gaining access to fuel debris, even via the pedestal opening on the CRD replacement rail because access to fuel debris will result in rapid dose rate increase.



(Reference information)  
Pedestal opening of Unit-5

Figure 3-3 Photos inside the PCV pedestal taken at the pedestal opening (processed image)

(3) **[UPDATE]** Test results of injecting nitrogen gas into the S/C of Unit-2

The S/C pressure was confirmed to be 3 kPag (as of May 14<sup>th</sup>, 2013) in a nitrogen gas injecting test into the S/C done in May 2013. The absolute water level in the S/C was not accurately known, but it was confirmed to be approximately on the level of the nitrogen gas inlet (O.P. 3780), because some reasonable pressure due to the water head should exist at the inlet if the S/C were almost filled with water. If the low water level in the

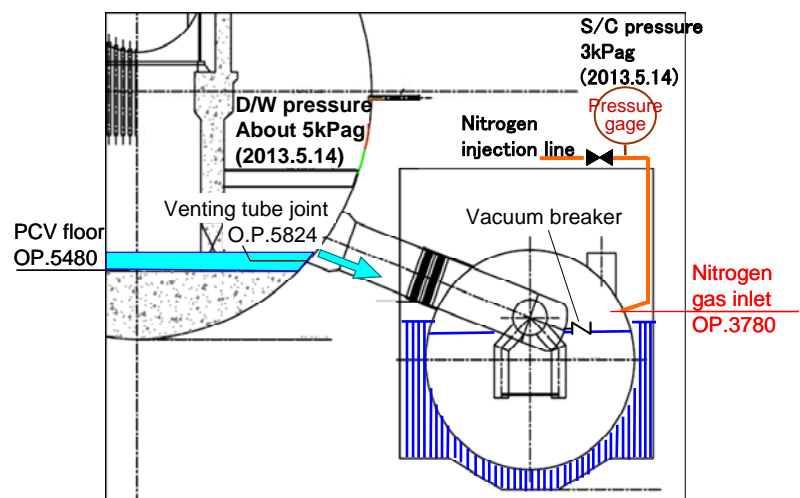


Figure 3-4 Closed space assumed in Unit-2 S/C

D/W is considered in combination, the water injected into the reactor vessel is considered to have reached the S/C via the D/W and venting tubes. If this hypothesis is correct, the current S/C water level will be on the same level as that of water retained in the torus room [11] (Figure 3-4).

Since December 2011, the hydrogen gas concentration and Kr-85 radioactivity measured by the containment gas control system of Unit-2 increased as a consequence of D/W pressure decreasing operations. This test was conducted to check if hydrogen and Kr-85 remained that had originated in the early phase of the accident as in the Unit-1 S/C.

The gradual pressure increase of the S/C from 3kPag to 7kPag before and after the injection confirmed that nitrogen gas had been injected into the S/C. But no change was observed in the hydrogen gas concentration and Kr-85 radioactivity measured by the PCV gas control system. Further tests were conducted to check if this was because there was no flow path from the S/C to the D/W or the hydrogen gas concentration in the S/C was already too low to send response signals.

In July 2013, upon injecting nitrogen gas into the D/W, a D/W pressure increase and an accordingly slight increase of S/C pressure were confirmed. Also in October 2013, upon injecting nitrogen gas into the S/C, the S/C pressure increased to the level of the D/W pressure, after that, both pressures showed similar increasing trends in conjunction. When the nitrogen gas injection to S/C was terminated, the S/C pressure decreased concomitantly with the D/W pressure [12].

From these findings, it was confirmed that nitrogen gas injected into the S/C was flowing to the D/W. And also from findings of nitrogen gas injection into the S/C flowing to the D/W with no change in hydrogen gas concentrations observed in the PCV gas control system, it was concluded that no more hydrogen gas remained in the S/C. It is considered, in this situation, that the vacuum breaker valve (OP. 3305) was not flooded and the nitrogen gas was flowing through this valve, because the water level in the reactor building was below about OP. 3400 during the tests and the S/C water level would follow the torus room water level (torus room water level minus level decrease due to internal pressure)

#### (4) Investigation of the torus room of Unit-2

In the Unit-2 torus room investigation in April 2012, a robot accessed the gallery inside. Videotaping, dose rates measurement, acoustic checks, etc. were carried out to the extent possible [13].

No water leaking position in the S/C has been located yet. At least, no leak was confirmed on the flange, etc. of the S/C manholes, as far as the camera photos show (Figure 3-5).

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[11] Handout document, Progress in preparations for decommissioning of Units 1 to 4 of the Fukushima Daiichi Nuclear Power Station, 3rd Decommissioning Measures Steering Panel, May 30, 2013

[12] Handout document, Action progress towards decommissioning of Units 1 to 4 of Fukushima Daiichi Nuclear Power Station, 1st Steering Committee towards Decommissioning, December 26, 2013

[13] Handout document, 5th Steering Committee, Government – TEPCO Joint Board on Mid- and Long-term Response Policy, April 23, 2012

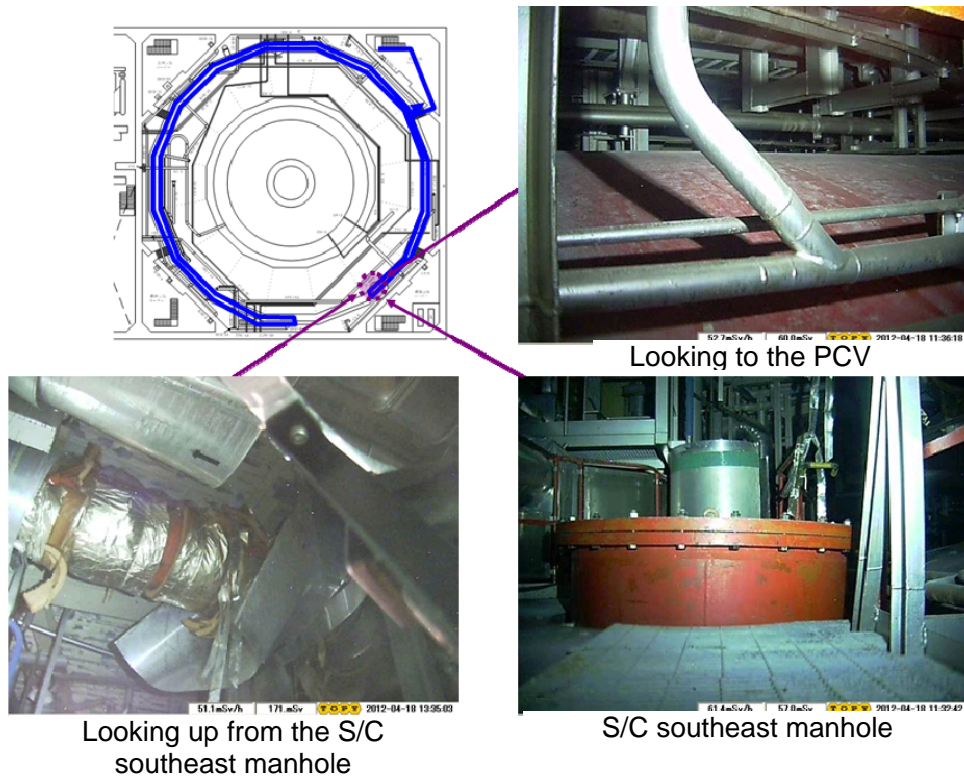


Figure 3-5 Camera photos in the torus room of Unit-2 (part)

(5) Investigation of the situation at the bottom of the vent tubes in the torus room of Unit-2

In the Unit-2 torus room, further investigations were made in December 2012 and March 2013, and the area around the lower end of venting tubes was surveyed by a robot. A small patrol vehicle, which was mounted on the tip of an arm of a four-leg robot, was set on the S/C, from which it accessed the lower end of the venting tube and took photos [14].

No water leaking position in the S/C has been located yet. At least, no leak was confirmed from the lower end of venting tubes within the visible range (Figure 3-6).

[14] Handout document, Progress in preparations for decommissioning of Units 1 to 4 of the Fukushima Daiichi Nuclear Power Station, 1st Decommissioning Measures Steering Panel, March 28, 2013



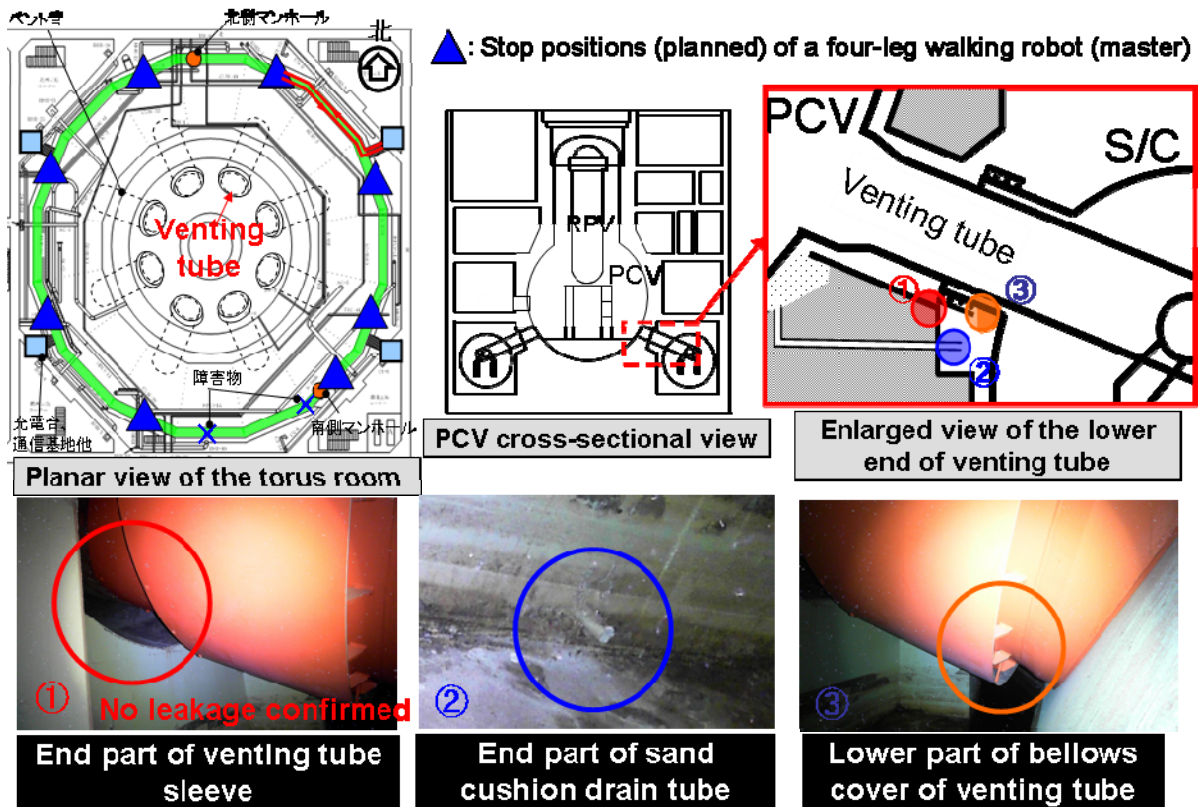


Figure 3-6 Camera photos around the lower end of the venting tubes in the torus room of Unit-2 (part)

(6) **[UPDATE]** S/C water level measurements of Unit-2

In January 2014, the S/C water level was remotely measured using ultrasonic techniques from the chamber outer surface. That is, the ultrasonic waves reflected by the S/C internal structures (as well as the opposite wall) were continuously measured. The water level could be estimated by observing where the reflective waves disappeared (Figure 3-7) [15].

The S/C water level is in correspondence with the level of water retained in the torus room. This is consistent with the water level estimated earlier by the nitrogen gas injection tests. This information confirms that water leaks occurred at the S/C lower position (including piping).

[15] Handout document: Action progress towards decommissioning of Units 1 to 4 of Fukushima Daiichi Nuclear Power Station, 2nd Decommissioning and Contaminated Water Response Team Joint Meeting, January 30, 2014.

Measurement date	Jan. 14, 2014	Jan.15, 2014	Jan. 16, 2014
<b>S/C water level</b>	<b>About OP. 3210</b>	<b>About OP. 3160</b>	<b>About OP. 3150</b>
<b>Water level retained in the torus room (reference info.)</b>	<b>About OP. 3230</b>	<b>About OP. 3190</b>	<b>About OP. 3160</b>
<b>Level difference</b>	<b>About 20mm</b>	<b>About 30mm</b>	<b>About 10mm</b>
<b>Method of measurement</b>	<b>Direct distance measurement between underwater structures</b>		

(Note) S/C water level seems to be affected by water level retained in the torus room



Measurement scene

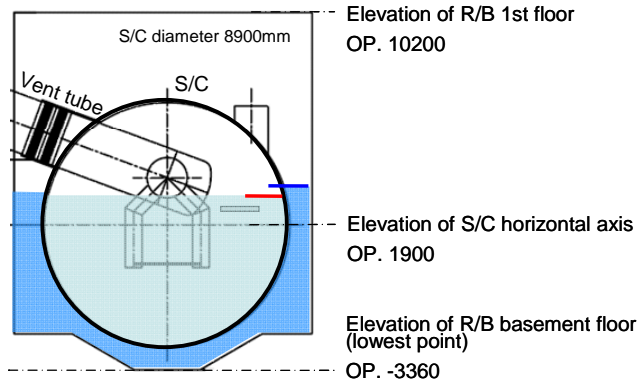


Figure 3-7 S/C water level measurements of Unit-2

#### 4. Conditions of Unit-3 core and PCV

##### (1) Investigation of torus room

In the Unit-3 torus room investigation in July 2012, a robot accessed the gallery inside. Videotaping, dose rates measurement, acoustic checks, etc. were also carried out to the extent possible [16].

No water leaking position in the S/C was located yet. At least, no leak was confirmed on the flange, etc. of the S/C manholes, as far as the camera photos show (Figure 4-1).

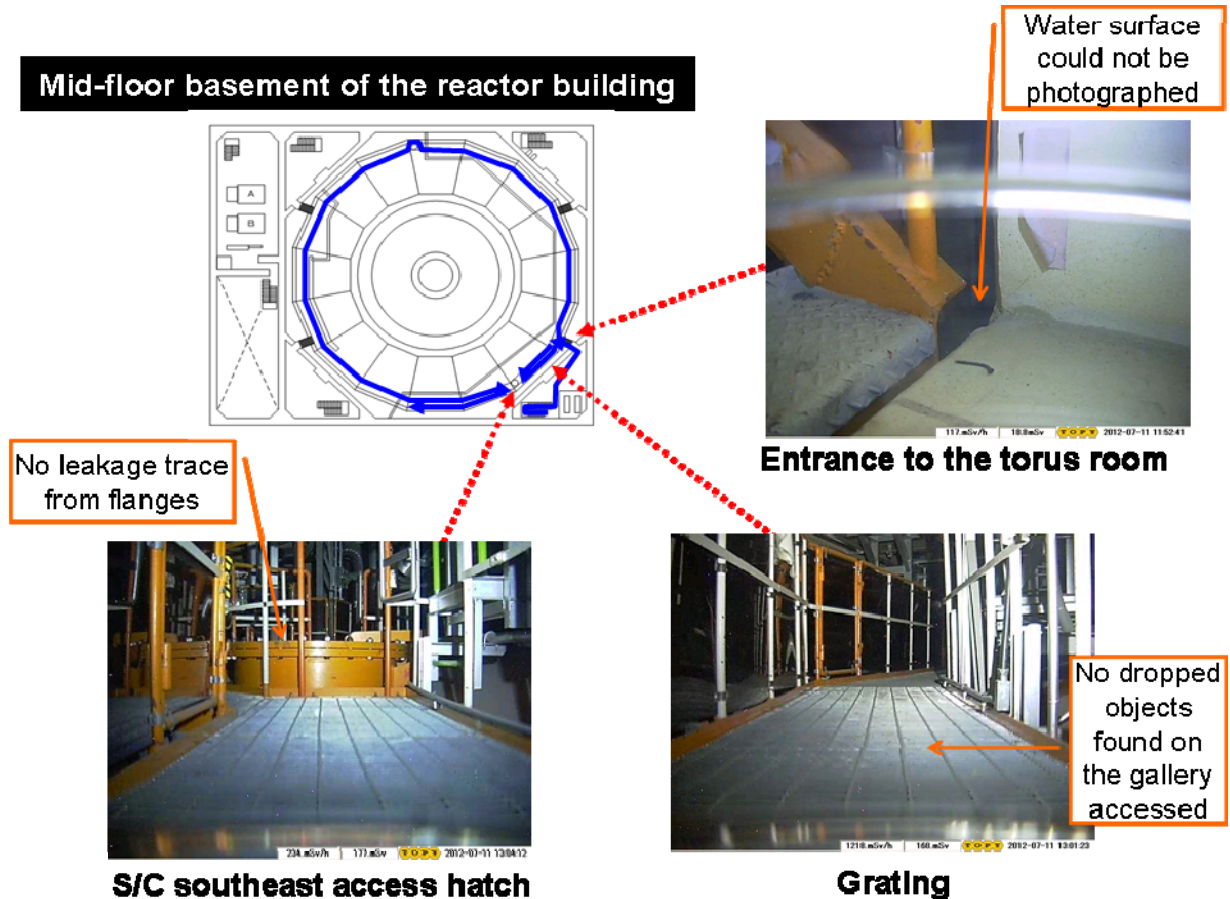


Figure 4-1 Camera photos in the torus room of Unit-3 (part)

##### (2) Oxygen concentrations in the PCV

Nitrogen is being sent to the PCV in order to maintain an inert atmosphere, while the containment gas control system discharges the same amount of gas from the PCV. It was confirmed through analyzing the discharged gas that the oxygen concentrations in the PCVs of Unit-1 and Unit-2 were nearly zero, while that in Unit-3 was about 8% (July 2012 [17]), analyzed again in March and April of 2013). Containment pressures of Unit-1 and Unit-2 PCVs are at

[16] Handout document, 8th Steering Committee, Government – TEPCO Joint Board on Mid- and Long-term Response Policy, July 30, 2012

[17] “Conditions in the containment vessels based on the measurements of the atmospheric gases”, Technical Workshop for the Accident of the Fukushima Daiichi Nuclear Power Plant, July 23, 2012

several kPa, and remaining positive, while the pressure of the Unit-3 PCV is almost constantly at the level of the atmospheric pressure. Consequently, the gas leak rate of the Unit-3 PCV was confirmed to be the highest.

(3) **[UPDATE]** Survey results of leaked water in the MSIV room of Unit 3

In January 2014, while camera photos taken by the rubble and wreckage removal robot in the Unit 3 reactor building were being checked, water was seen to be flowing from near the main steam isolation valve (MSIV) room door in the northeast area of the reactor building first floor. The water was flowing towards a nearby floor drain funnel (Figure 4-2) [18].

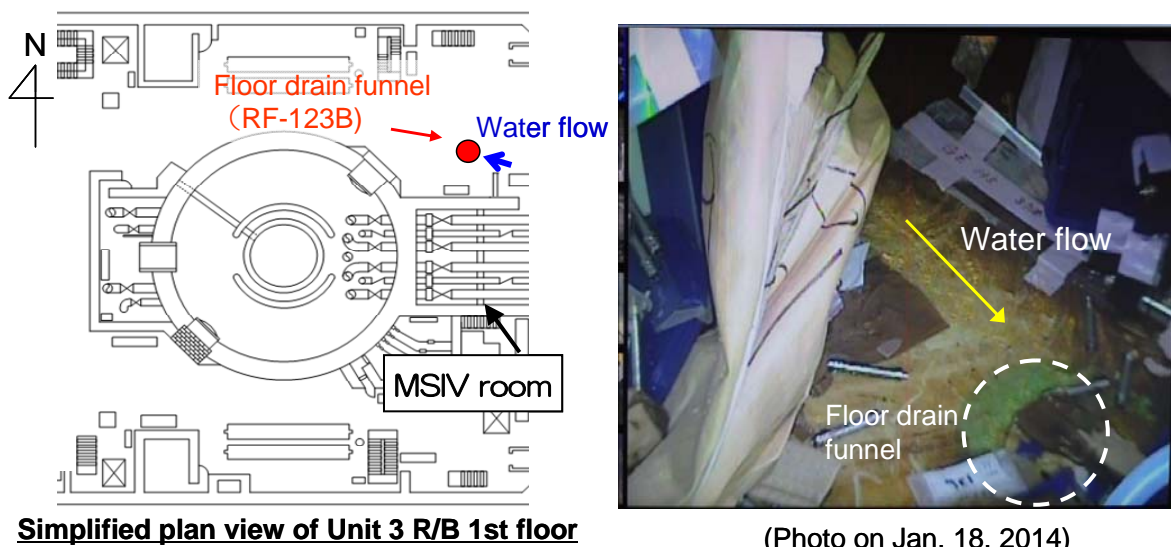


Figure 4-2 Water leak near the MSIV room door of Unit-3

The water level in the PCV is estimated as about OP.12m (about 2 m above the reactor building first floor) by converting the S/C pressure obtained by the existing pressure indicators to water head. This elevation is on the level of PCV penetrations for main steam lines, thus indicating the possibility of water leaks from the PCV penetration in the MSIV room as the source of the water flow. In consideration of this possibility, instrumentation was inserted into the MSIV room from the HVAC system room on the floor above, in April and May 2014, and photos were taken and dose rates were measured in the room, in order to locate the water flows in the room. Water leaks were from near the expansion joint of main steam line D. It was concluded [19] that the leakage had occurred only from the main steam line D, based on: (1) confirmation of no leaks from the main steam lines A, B and C, and their main steam drain pipes; and (2) the flow directions of leaked water on the floor.

[18] Handout document, Action progress towards decommissioning of Units 1 to 4 of Fukushima Daiichi Nuclear Power Station, 2nd Decommissioning and Contaminated Water Response Team Joint Meeting, January 30, 2014.

[19] Handout document, Action progress towards decommissioning of Units 1 to 4 of Fukushima Daiichi Nuclear Power Station, 6th Decommissioning and Contaminated Water Response Team Joint Meeting, May 29, 2014.

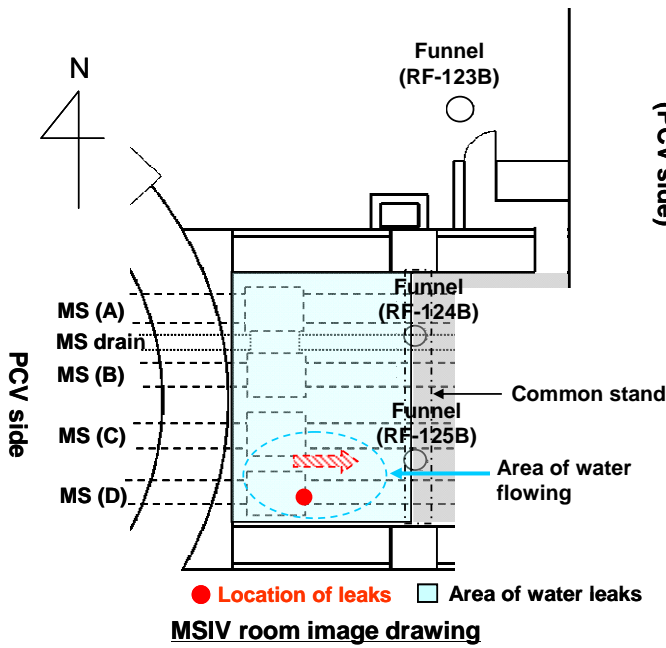
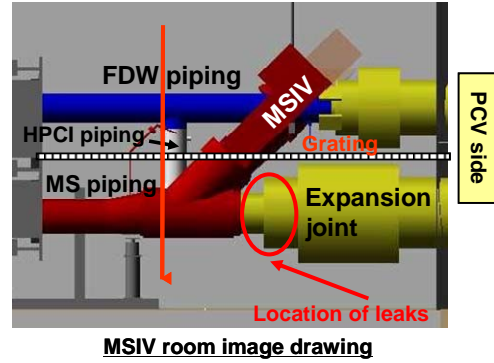
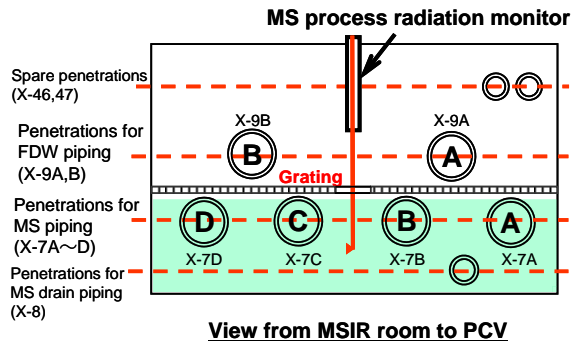
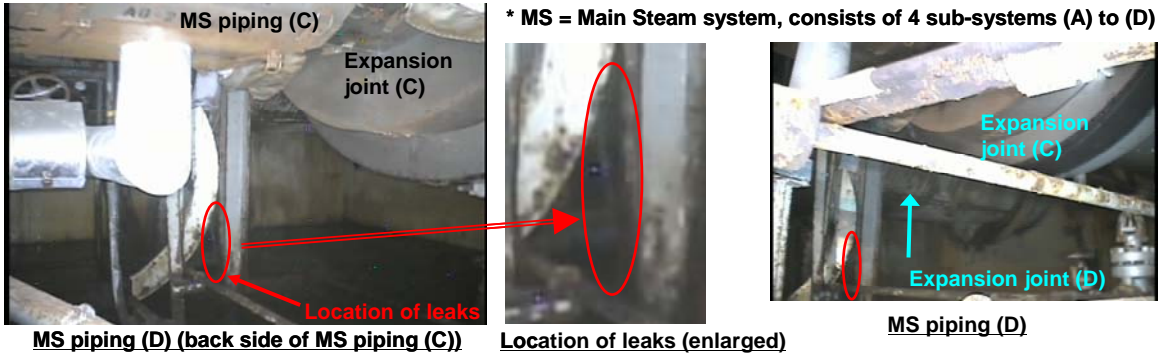


Figure 4-3 Water leaks from main steam line D in MSIV room

(End)