Investigation of the cause of hydrogen explosion at the Unit 4 Reactor Building

24th July 2012
Tokyo Electric Power Company, Inc.

TOKYO ELECTRIC POWER COMPANY

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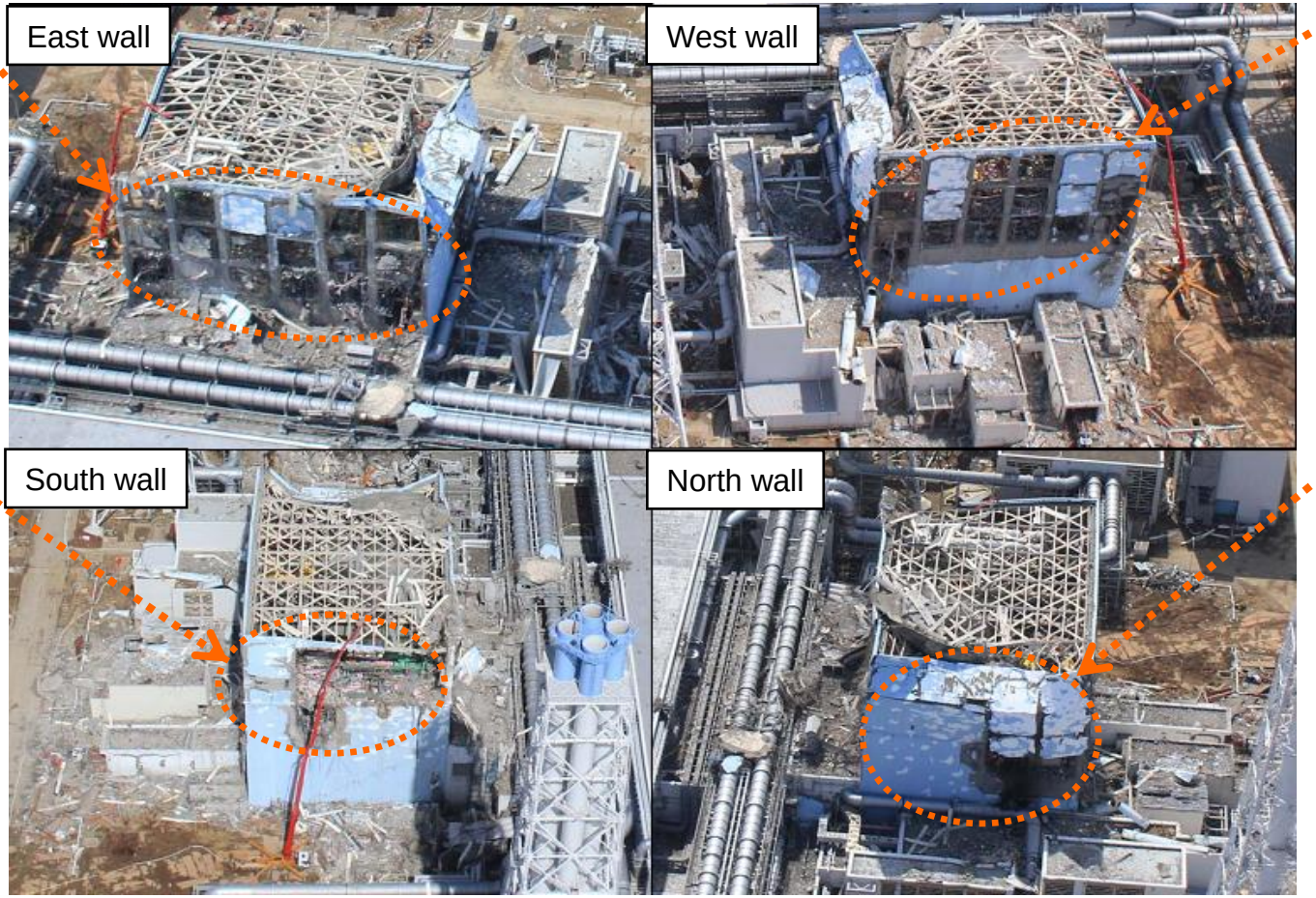
1. Summary

- It is estimated that there is no possibility that the combustible gas which caused Unit 4 R/B explosion was emitted.
- It is presumed that the PCV ventilation gas from Unit 3 flowed into the Unit 4 R/B through the SGTS piping.
- It is presumed that the main pressure was generated near the air-conditioning duct of the 4th floor of R/B.

2. The situation of the damaged R/B

○All walls of 5th floor were damaged, and walls of 4th and 3rd floor were partially damaged.
○While walls of reinforced concrete were damaged broadly, some of the roof truss and pillars maintained their form and remain.

Almost all walls of 5th floor were damaged.
All walls of 4th floor were damaged.



Almost all walls of 5th floor were damaged.
All walls of 4th floor were damaged.
North side wall of 3rd floor was partially damaged.

Walls and pillars of 5th floor were damaged except for the west side.
Only one wall of 4th floor was damaged.

Walls of 5th floor were partially damaged.
West side walls of 4th floor were severely damaged.
West side walls of 3rd floor was damaged.

3. Possibilities of the generation of combustible gas

It is estimated that there is no possibility that the combustible gas which caused Unit 4 R/B explosion was emitted.

- Hydrogen from the reactor

  →The Unit 4 was under refueling outage and all fuels were in the SFP.

  →There is no possibility of the hydrogen generation by water-zirconium reaction.

- Hydrogen from the SFP

  →Fuel damage was not confirmed in observation of the fuel in the SFP with camera.

  →Possibility of hydrogen generation in the SFP due to water-zirconium reaction and radiolysis of water must be very low.

- Turbine oil of PLR MG set

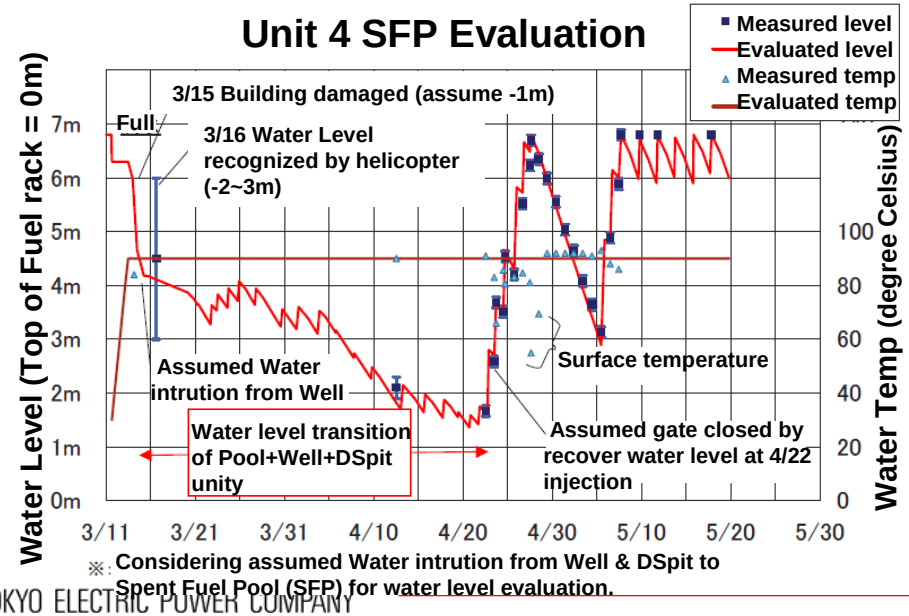
  →No high temperate area in R/B except for the inside of D/W.

PLR MG set (on 8th Nov. 2011)

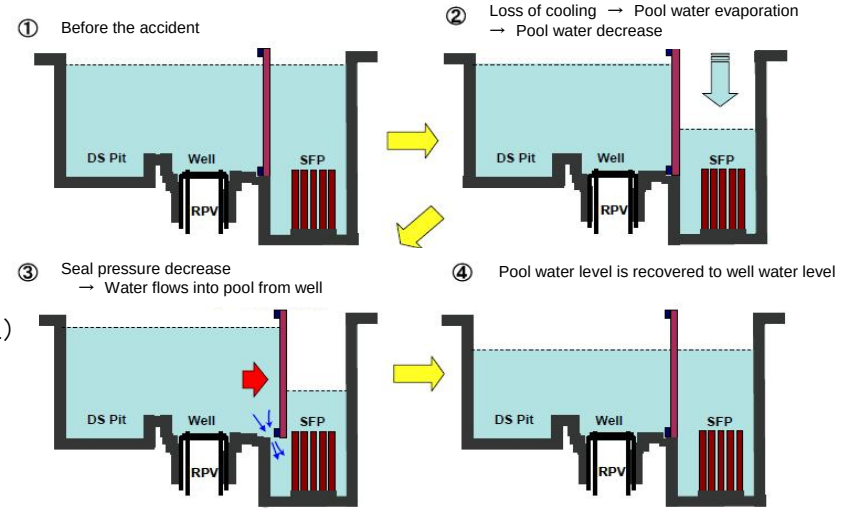
3. Possibilities of the generation of combustible gas (Condition of the SFP)

・All fuels were in the SFP, and Unit 4 SFP had the largest heat load in Fukushima-daiichi 7SFPs.
・It was confirmed that the water level in the SFP was adequate enough. By subsequent analysis, it turned out that the water of the reactor well flowed into the SFP through the pool gate.
・The picture in the SFP and the results of nuclide analysis of the pool water confirmed that there was no damage in the fuel.

The surface of the water that was confirmed from a helicopter（Photo from the east, 16th May, 2011）



※: Considering assumed Water intrution from Well & DSpit to Spent Fuel Pool (SFP) for water level evaluation.



The mechanism of water flow from the pool gate

The situation in the SFP

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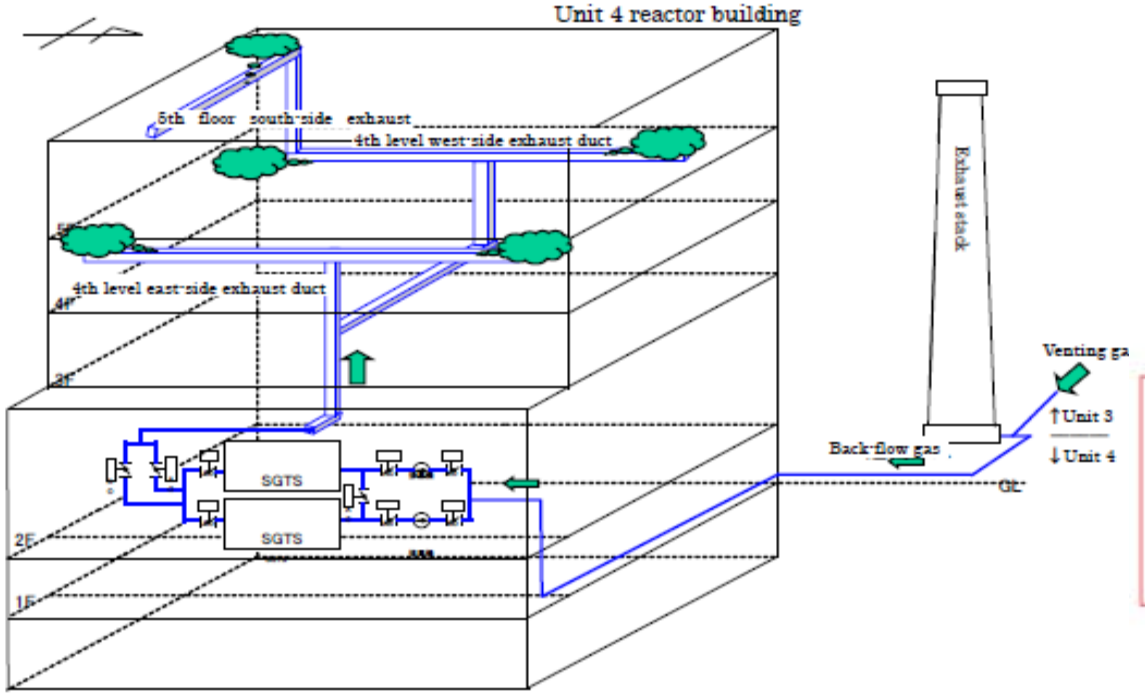
4. Hydrogen flow pass into the R/B (Flow pass through SGTS line to the R/B)

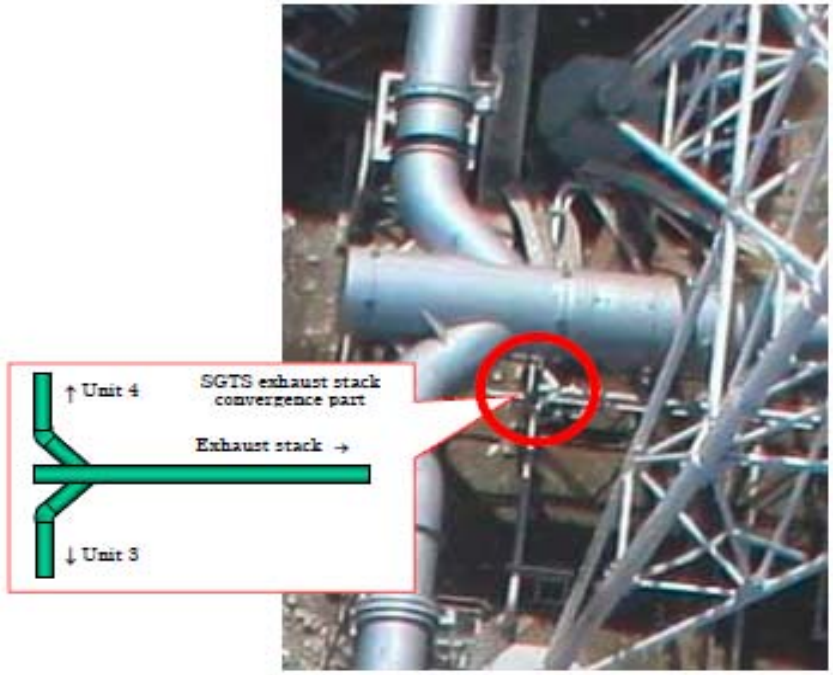
- No hydrogen from the reactor core.
- Possibility of hydrogen generation in the SFP due to water-zirconium reaction and radiolysis of water must be very low.

The SGTS exhaust pipe of Unit 4 joins the Unit 3 exhaust pipe at the main exhaust stack convergence part.

→ It is presumed that the PCV ventilation gas from Unit 3 flowed into the Unit 4 R/B through the SGTS piping.

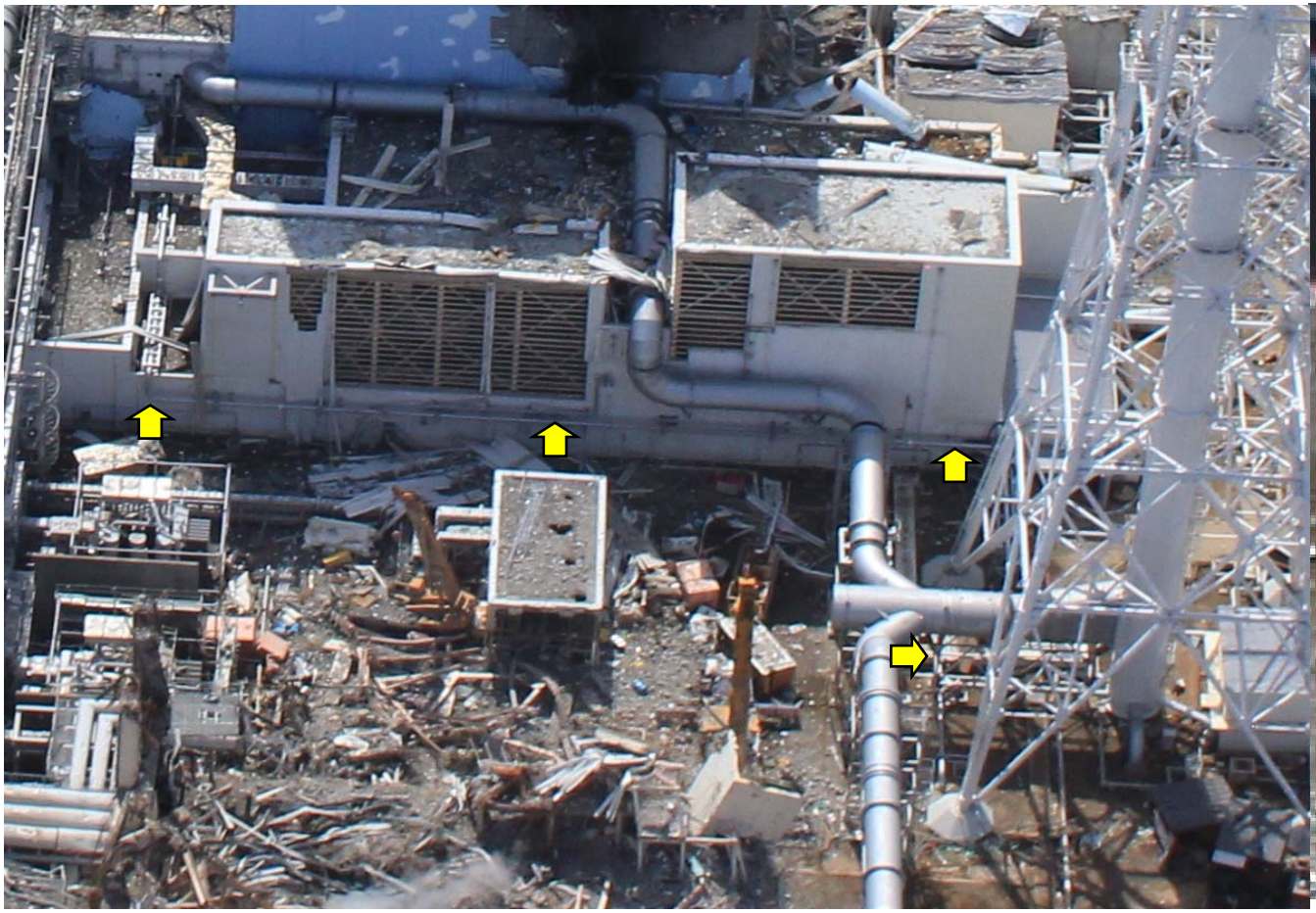


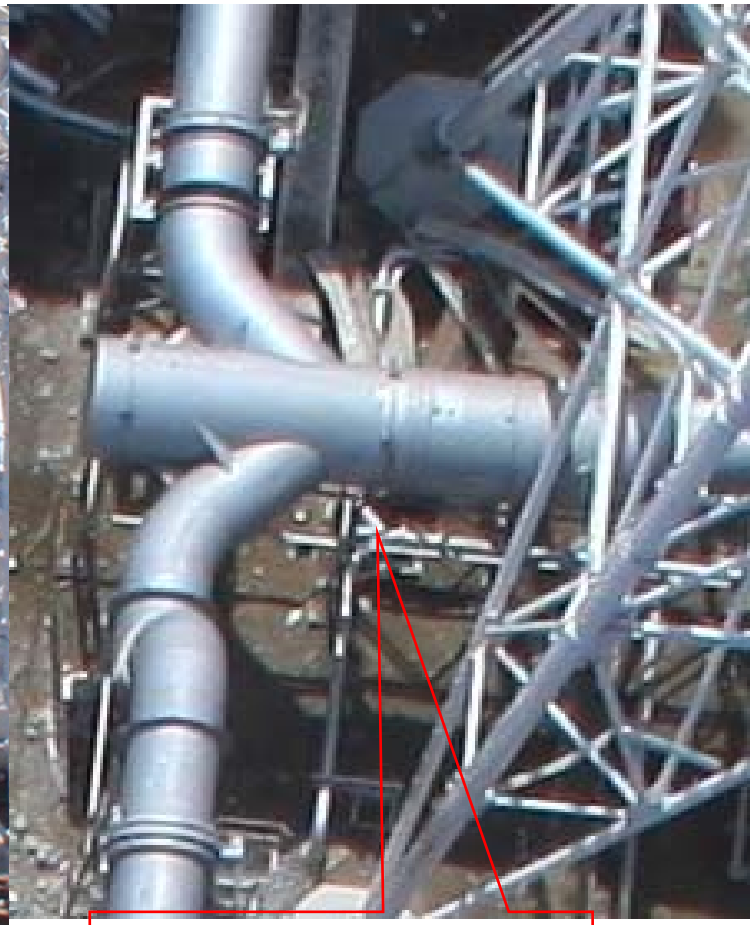
Flow path of the PCV venting gas flow from Unit 3 to Unit 4

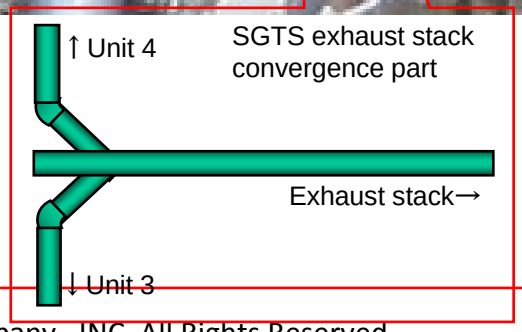


SGTS pipe

4. Hydrogen flow pass into the R/B (SGTS exhaust piping of Unit 3 and 4)







4. Hydrogen flow pass into the R/B（The inflow rate to Unit 4 of Unit 3 PCV ventilation gas（Pressure loss evaluation of the piping ））

- About the inflow rate to Unit 4 of the Unit 3 PCV ventilation gas, rough estimation of the amount of hydrogen inflow to Unit 4 was carried out based on pressure loss calculation etc.

$$\frac{\Delta P_1}{\Delta P_2} = \frac{\frac{1}{2}\lambda\frac{L_1}{D_1}v_1^2}{\frac{1}{2}\lambda\frac{L_2}{D_2}v_2^2} \cong \frac{\frac{L_1}{D_1}\left(\frac{Q_1}{A_1}\right)^2}{\frac{L_2}{D_2}\left(\frac{Q_2}{A_2}\right)^2} = 1$$

v1：Flow velocity in the main exhaust stack (m/s)
v2：Flow velocity in SGTS piping (m/s)
Q1：Main exhaust stack side inflow rate (m^3)
Q2：Unit 4 side inflow rate (m^3)
ΔP1：Pressure loss of the main exhaust stack (Pa)
ΔP2：Pressure loss of air-conditioning system and SGTS of Unit 4 (Pa)
L1：Main exhaust stack side equivalent piping length (m)
L2：Unit 4 side equivalent piping length (m)
D1：The diameter of the main exhaust piping (mm)
D2： The diameter of Unit 4 side piping (mm)
A1：Cross-sectional area of piping in the main exhaust stack (mm^2)
A2：Cross-sectional area of SGTS piping (mm^2)
λ：Pipe friction coefficient

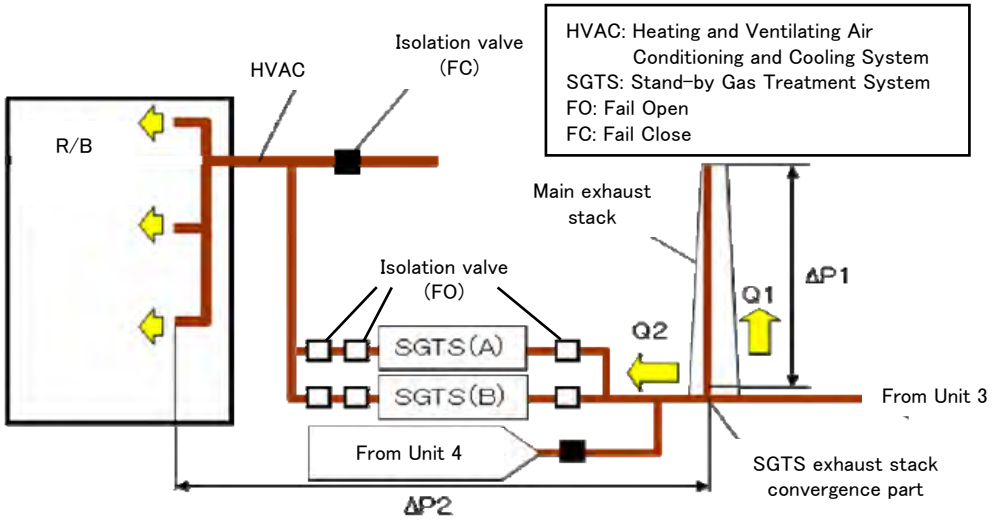


Figure. Evaluation model

The quantity which flows into Unit 4 R/B is estimated as about 40 percent of the quantity emitted from the main exhaust stack.

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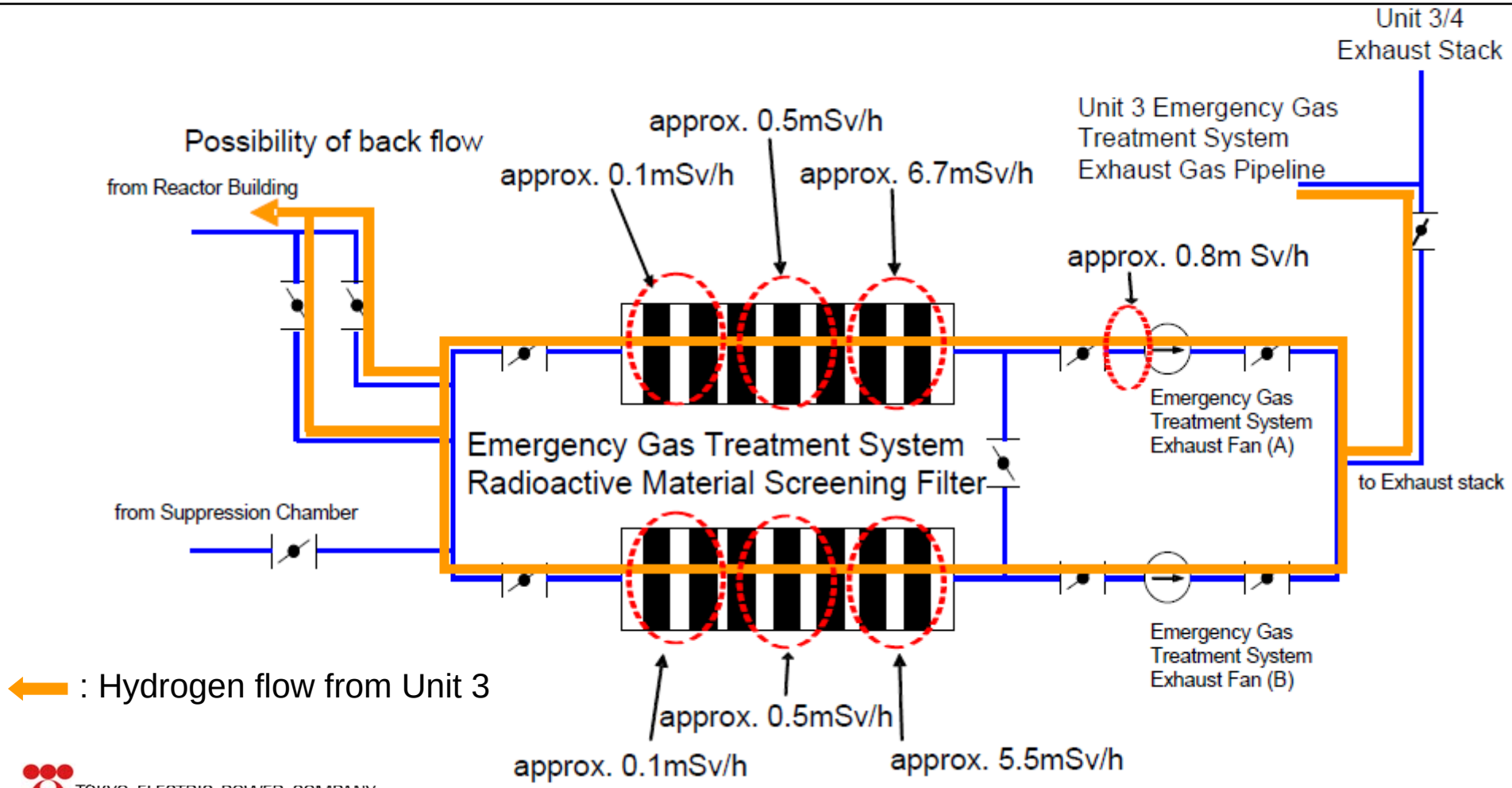
4. Hydrogen flow pass into the R/B (Radioactive dose measurement at Unit 4 SGTS filters (conducted on 25th August, 2011))

- After measuring the radiation dose of the Unit 4 SGTS filters, it was found that the radiation dose level of the downstream filter was higher than those of the upstream filters.
- This fact is well corresponding to the presumed mechanism of the explosion.



4. Hydrogen flow pass into the R/B
（The on-site situation before R/B explosion ）

✓In order that the restoration team of the ERC at the power station might check the Unit 4 SFP on March 14, they went to the operating floor in the R/B. But, since the dose rate in R/B was high※, they were not able to go to the operating floor.

※The restoration team went into the Unit 4 R/B around 10:30 on March 14. (It was determined that the S/C had been vented at approximately 9:20 on March 13 in Unit 3) After going into the R/B, in 10 to 15 seconds, the alarm of 4mSv APD sounded and they returned.
Then, since the maximum range of the mobile dosimeter (1000mSv) was exceeded when they tried to enter the R/B again and opened the door of R/B, they gave up going into the R/B.

- The water level of the SFP has been checked
- Fuels are not contained in the RPV
- PCV ventilation of Unit 3 has been carried out on March 13

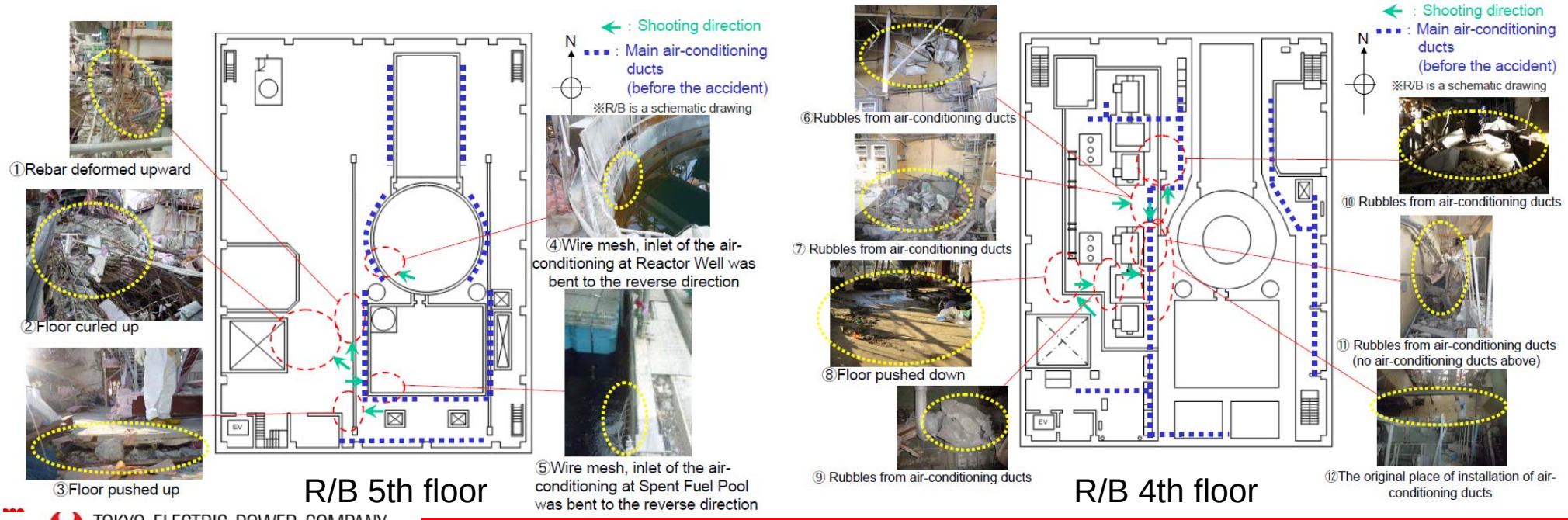
⇒ The radioactive material (noble gas) have turned to Unit 4 as the PCV ventilation of Unit 3.
(It is presumed that iodine was caught by the SGTS charcoal filter.)

5. The center of explosion in the R/B (Survey result of damages to exhaust ducts etc. in the Unit 4 R/B (conducted on 8th November, 2011))

Survey results of the R/B

- ○The floor surface of the 5th floor was pushed up.(②、③)
- ○The floor surface of the 4th floor was pushed down.(⑧)
- ○Wire meshes of ventilation inlet were bent to the reverse direction.(④、⑤)
- ○On the 4th floor, exhaust ducts are missing and there exist many rubbles which seems to be the wrecks of the ducts.(⑥、⑦、⑨～⑫)

It is presumed that the main pressure was generated near the exhaust duct of the 4th floor of R/B.



Thank you for your attention.

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Appendix

Survey result of damages to air-conditioning ducts etc. in the Unit 4 R/B (conducted on 8th November, 2011)

Survey result of damages to air-conditioning ducts etc. in the Reactor Building, Unit 4, Fukushima Daiichi Nuclear Power Station

<The sequence of events>

- At 6:12 am on March 15, an explosion occurred at Unit 4. It was possible that hydrogen generated in Unit 3 went through air-conditioning ducts of the emergency gas treatment system and flowed into the Reactor Building, Unit 4.
- On November 8, in order to investigate the status of explosion of the Reactor Building, Unit 4, we conducted a site survey, such as damage to the air-conditioning ducts in the Reactor Building.

<Date and time of the site survey>

From 2:30 pm to 4:30 pm on November 8, 2011 (Tue)

<Survey results>

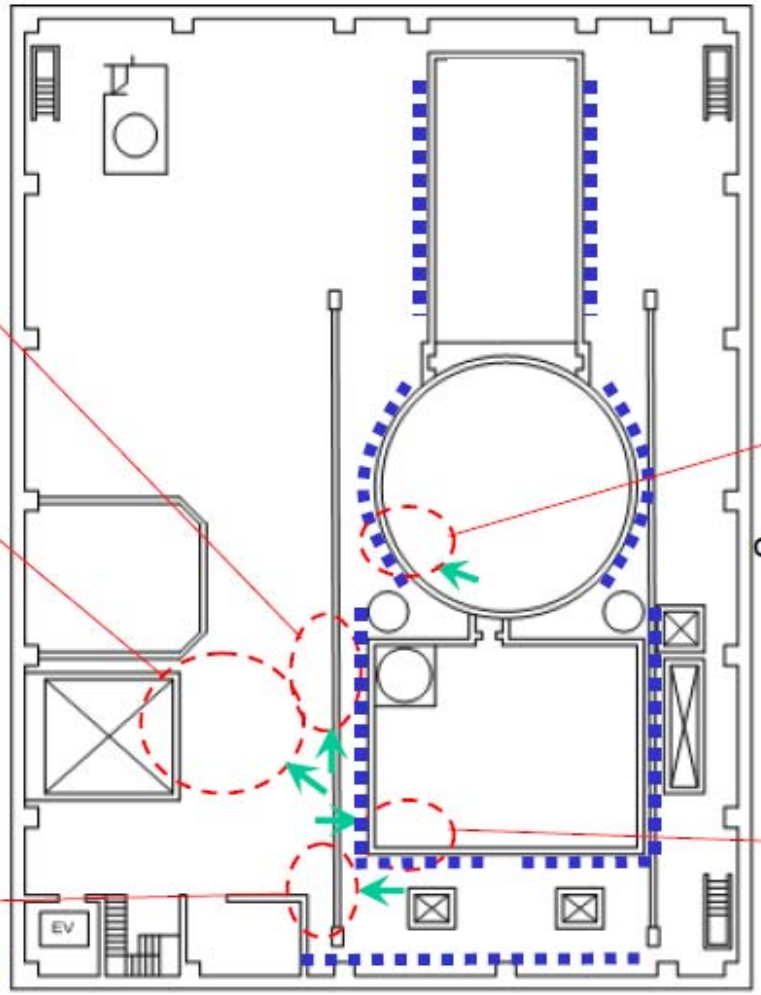
- It was likely that the explosion at Unit 4 occurred mainly on the fourth floor of the Reactor Building because (i) the floor on the fifth floor was pushed up and the floor on the fourth floor was pushed down and (ii) wire meshes attached to inlets of the air-conditioning on the fifth floor were bent to the reverse direction of the normal air flow.
- On the fourth floor of the Reactor Building, as there were no air-conditioning ducts at the original place of installation and instead, numerous rubbles presumably from air-conditioning ducts were scattered, it was possible that the explosion occurred around the air-conditioning ducts.

Observation results of the Unit 4 R/B (5F)

①Rebar deformed upward

②Floor curled up

③Floor pushed up



← : Shooting direction

N

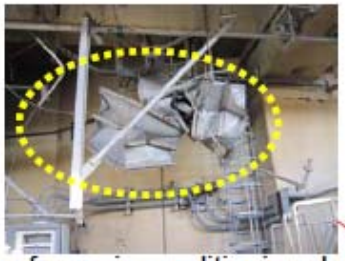
▪▪▪ : Main air-conditioning ducts (before the accident)

※R/B is a schematic drawing

④Wire mesh, inlet of the air-conditioning at Reactor Well was bent to the reverse direction

⑤Wire mesh, inlet of the air-conditioning at Spent Fuel Pool was bent to the reverse direction

Observation results of the Unit 4 R/B (4F)

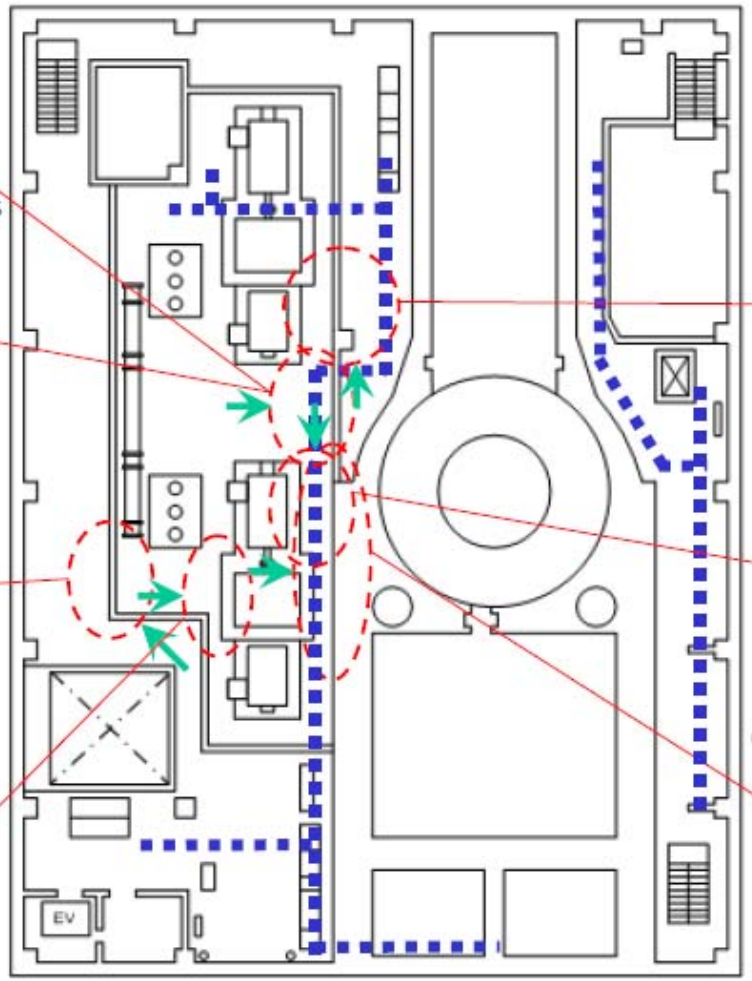


⑥Rubbles from air-conditioning ducts

⑦ Rubbles from air-conditioning ducts

⑧Floor pushed down

⑨ Rubbles from air-conditioning ducts



: Shooting direction

: Main air-conditioning ducts (before the accident)

※R/B is a schematic drawing

N

⑩ Rubbles from air-conditioning ducts

⑪ Rubbles from air-conditioning ducts (no air-conditioning ducts above)

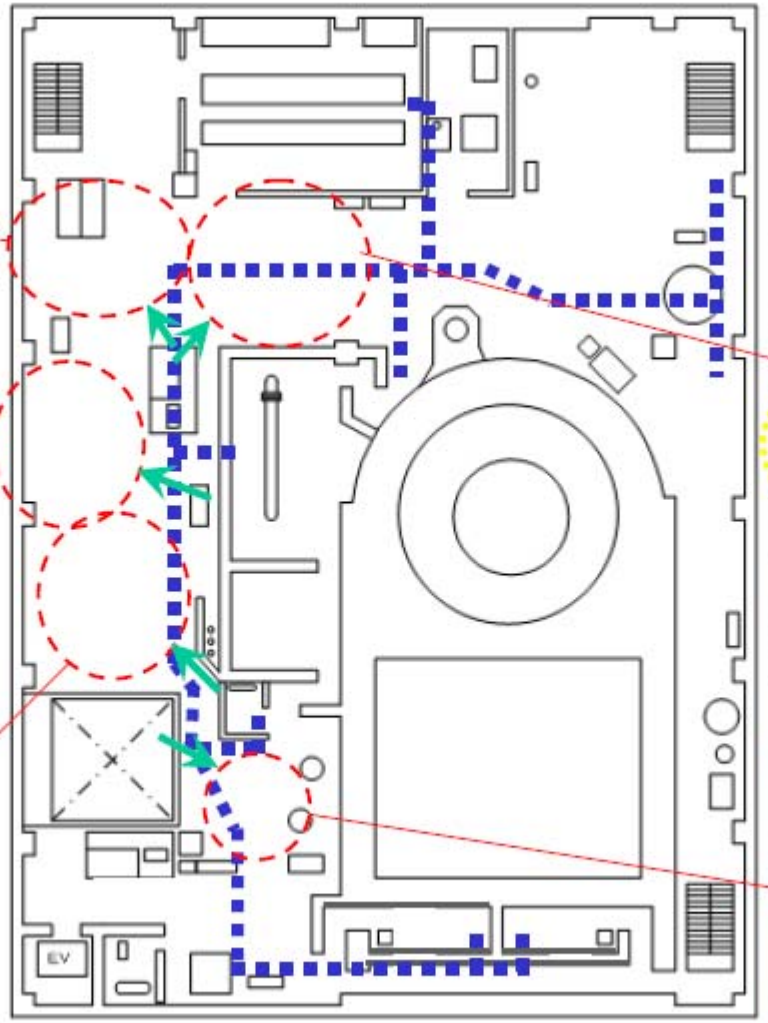
⑫The original place of installation of air-conditioning ducts

Observation results of the Unit 4 R/B (3F)

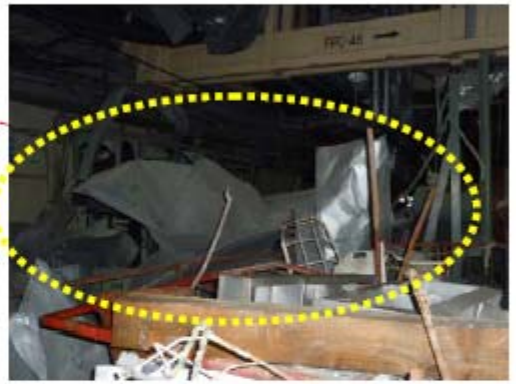
⑬Damages to the floor

⑭Floor pushed down
(in front is rubbles from air-conditioning ducts)

⑮ Rubbles from air-conditioning ducts



: Shooting direction
: Main air-conditioning ducts (before the accident)
N
※R/B is a schematic drawing



⑯ Rubbles from air-conditioning ducts

⑰ Rubbles from air-conditioning ducts