Lessons learned from the Fukushima Accident and Safety Improvements at Kashiwazaki Kariwa Nuclear Power Station

January 11, 2016

Shinichi KAWAMURA

TOKYO ELECTRIC POWER COMPANY

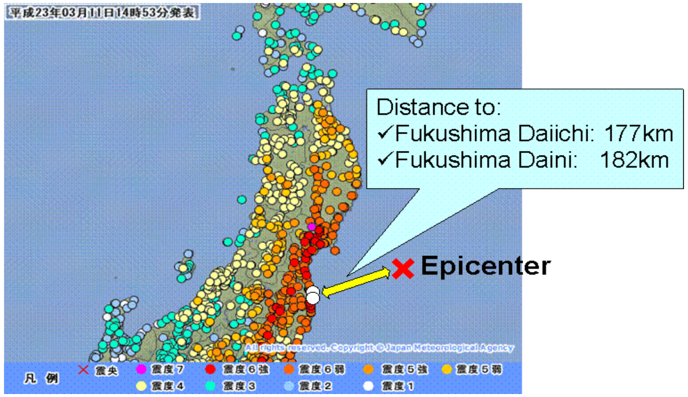
The Great East Japan Earthquake of March 11, 2011

Earthquake

- Mw 9.0: the largest earthquake recorded in Japan
- Max. accelerations were almost equivalent as those of design
- No significant damage or loss of safety systems

Tsunami

- Max. height: 13~15m (design: 6.1m)
- Almost entire site area was flooded
- Loss of all AC and DC power supplies (no instrumentations)
- Loss of ultimate hear sink



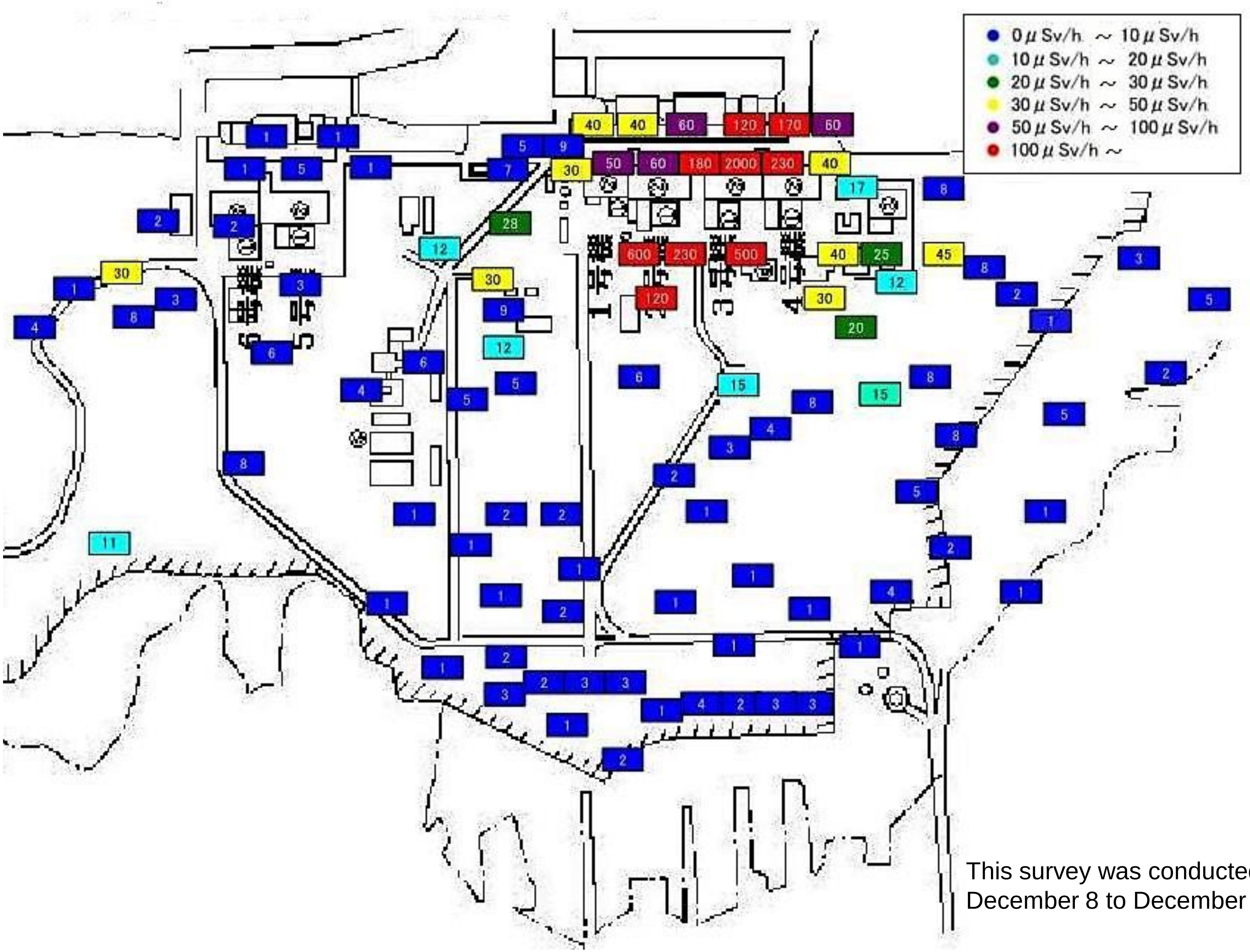
Accident at Fukushima Daiichi NPS

- Serious core damage (melt through) of Unit 1-3
- Damage of the PCV of Unit 1-3

  (Significant amount of radio nuclide release from these Units)
- Explosion of the reactor building of Unit 1, 3 and 4
- Evacuation of about 160,000 local residents

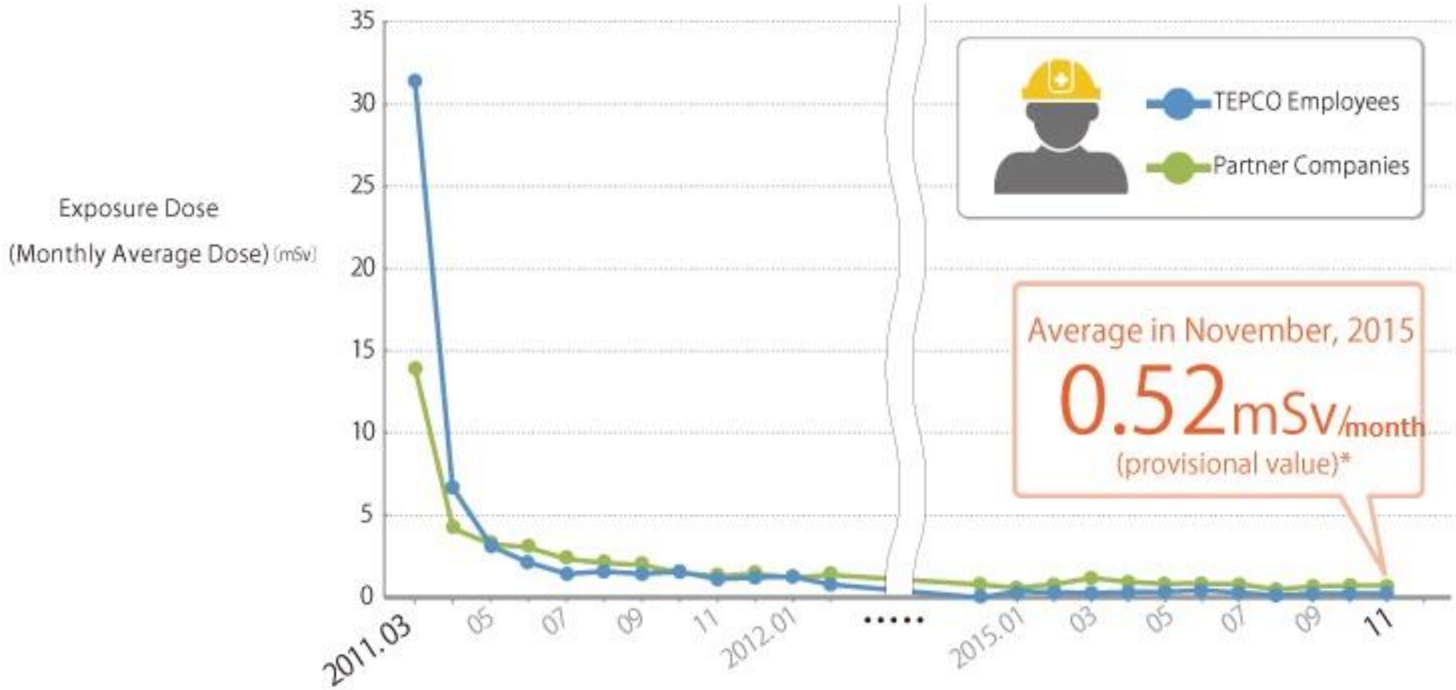
Current Situation at Fukushima Daiichi NPS (Video)

Radiation Levels on the Premises of Fukushima Daiichi NPS



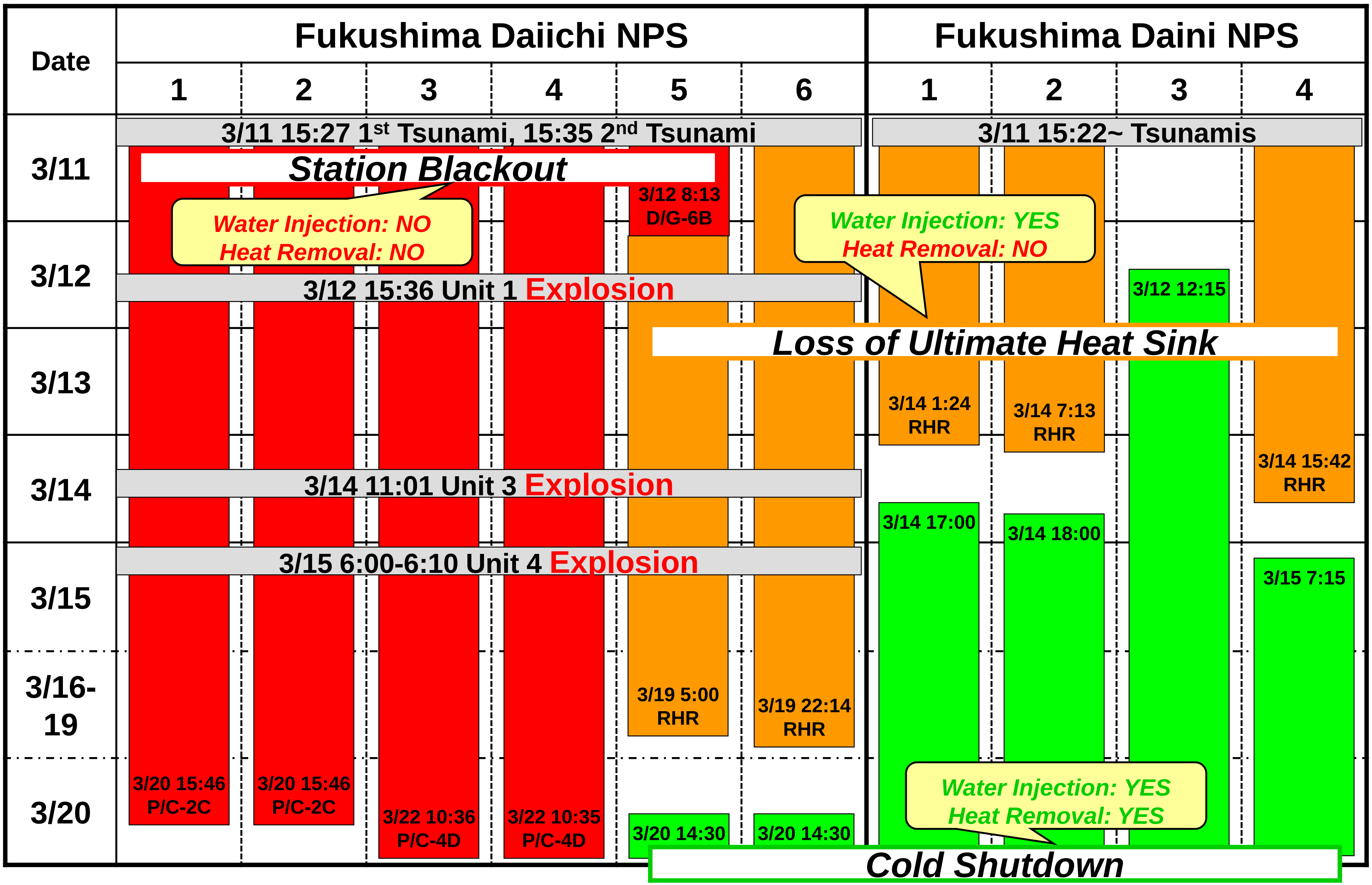
This survey was conducted from December 8 to December 10, 2015.

Measures to reduce Dose and improve Work Environment



- Expansion of the areas without full face-covered mask restrictions by speeding up decontamination work
- Speeding up of the work of handling contaminated water by removing rubble on the ocean side
- Speeding up of contaminated water treatment by improving the multi-nuclide removal equipment
- Use of robots and other remote controlled machine

Overview of the 10-Unit Simultaneous Accidents



Lessons Learned from the Fukushima Daiichi Accident

- Protection against a tsunami exceeding assumption was weak

- Sufficient preparations were not made for
  - preventing station blackout (SBO)
  - mitigating the influence of SBO by ensuring high-pressure core injection, depressurization, low pressure core injection, heat removal

- Measures were not well prepared to mitigate the impact after reactor core damage :
  - prevention of containment failure
  - hydrogen control
  - countermeasures for core melt-through
  - prevention of a large release of radioactive material into the environment, etc.

Basic Policies for Reactor Safety Enhancement

1. Reinforce defense in depth against external events

2. Adopt a concept of Phased Approach to emergency response

3. Ensure integrity of Containment Vessel in severe accidents

Basic Policies for Reactor Safety Enhancement (Continued)

1. Reinforcement of defense in depth against external events

Reinforce defense in depth based on the assumption that multiple function failures could be caused by external events

① Establish safety measures along with defense in depth concept **focusing on diversity and physical separation**

② Consider not only earthquake and tsunami but also **40 natural events** and **20 human induced external events** shown in US NUREG* and the IAEA Safety Guide**

③ Select the external events based on their **cliff edge effect** and their probability, and establish safety measures against them

④ Strengthen measures also against **internal flooding** and **internal fire**

⑤ Use of probabilistic risk assessment (**PRA**) to:

- select accident sequences to be evaluated
- confirm effectiveness of the established safety measures

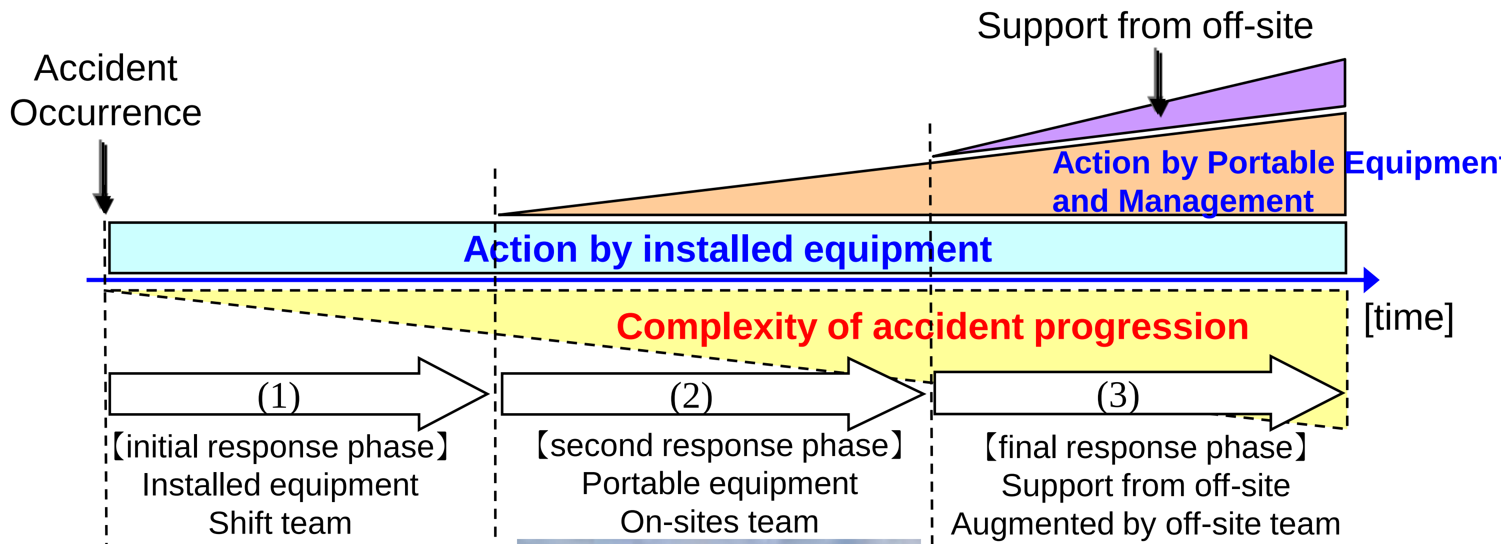
* NUREG/CR-2300 Vol.2, “PRA Procedures Guide”

** IAEA Specific Safety Guide SSG-3, “Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants”

Basic Policies for Reactor Safety Enhancement (Continued)

2. Adoption of phased approach

Select safety measures based on the assumption that possible measures and their required reliabilities are different depending on time to spare



High pressure injection pump (installed equipment)

Fire engines

Power supply cars

Tank trucks from off-site

Basic Policies for Reactor Safety Enhancement (Continued)

3. Ensuring integrity of Containment Vessel in severe accidents

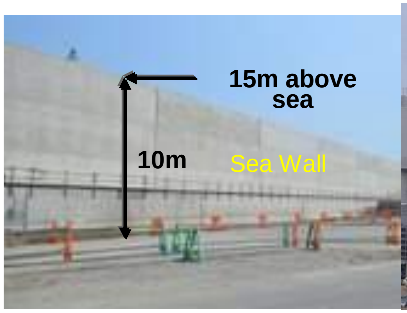
Clarify requirements for Containment Vessel and auxiliary equipment after core damage and then implement safety measures

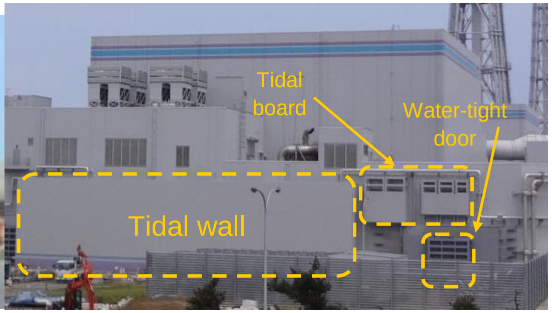
- Define twice design pressure as upper limit pressure of Containment
- Define 200 ºC as upper limit temperature of Containment
- Define function requirements for auxiliary systems in order to contain fission products in Containment as long as possible

Safety Measures to enhance 1st Layer of Defense in Depth

Measures against tsunami (15m)

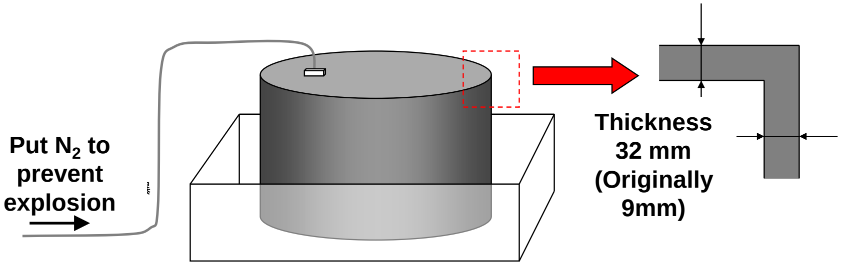
Sea Wall, Tidal Embankment, Tidal Walls, Boards, Water-tight Doors, etc.





Measures against Tornado (Fujita Scale 3)

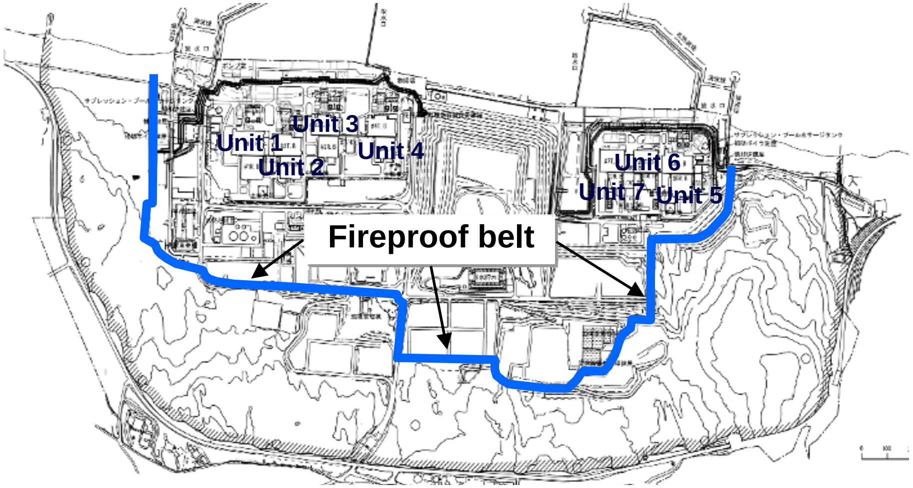
Hardened fuel tanks for emergency diesel generators



Hardened Tank

Measures against External (Forest) Fire

Creation of the fireproof belt

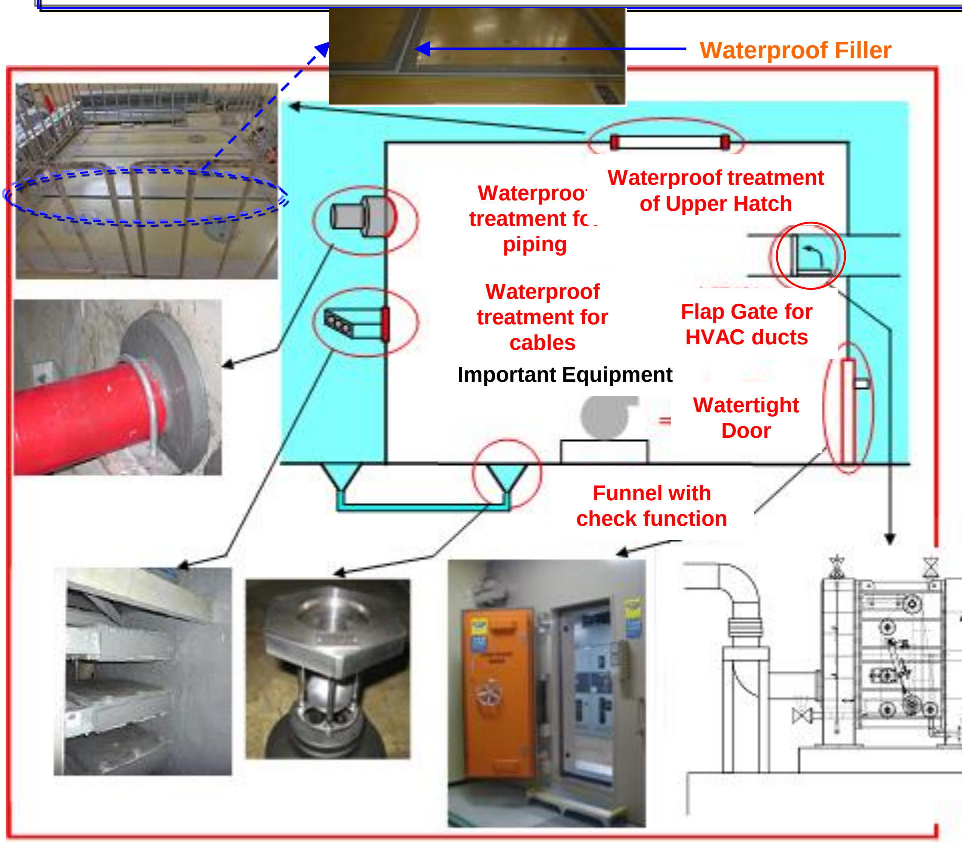


Map of the plant with fireproof belt

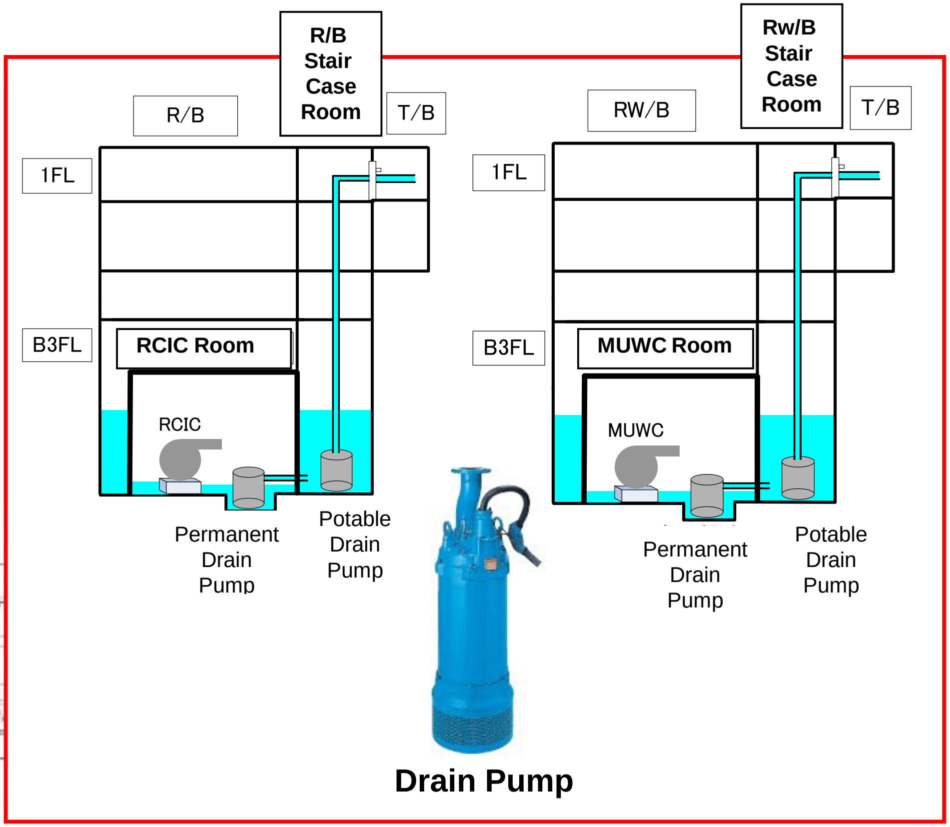
Safety Measures to enhance 2nd Layer of Defense in Depth

Measures against Tsunami Flooding and Internal Flooding

- Reduce flooding sources (seismic reinforcement of low class equipment)
- Waterproof treatments/ flap gates to protect important equipment
- Install drain pumps for inundation beyond postulated damage



Measures against internal flooding



Installation of Drain Pumps

Safety Measures to enhance 2nd Layer of DiD (continued)

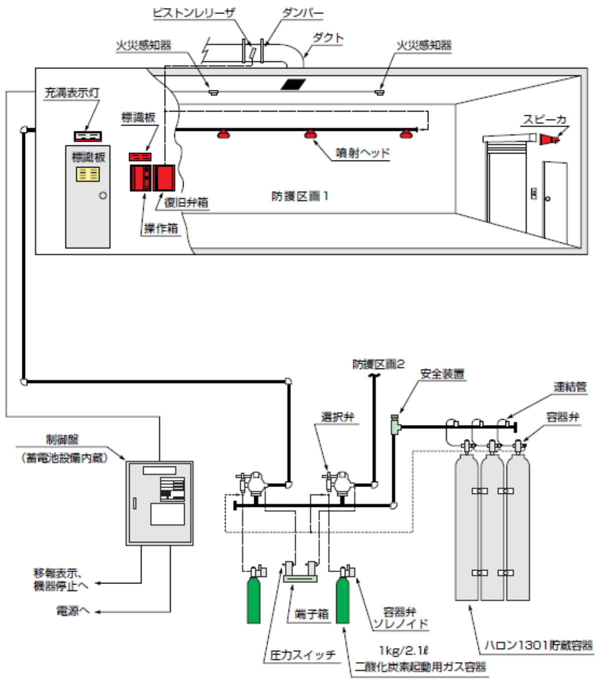
Measures for Fire Protection

➢Prevention

- Fireproof or fire-retardant materials (incombustible cable has been used at KK since construction)
- Rigid management of combustible materials like lubricant oil

➢Early detection and extinction

- Diversified fire detection devices
- Installed fire suppression systems



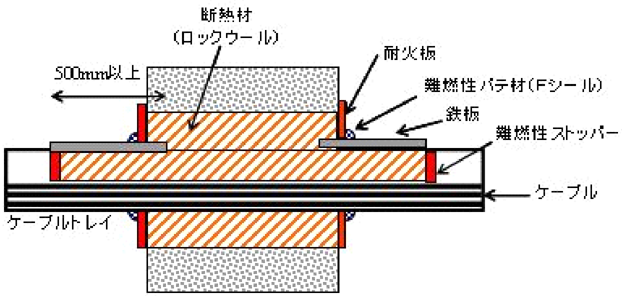
Fire Suppression System

➢Mitigation

Fire Barriers with 3-hour fire resistance capability

- Fire proof dumpers
- Fireproof treatment on piping and cable penetrations
- Cable wrapping

Cable Wrapping (7 layers)

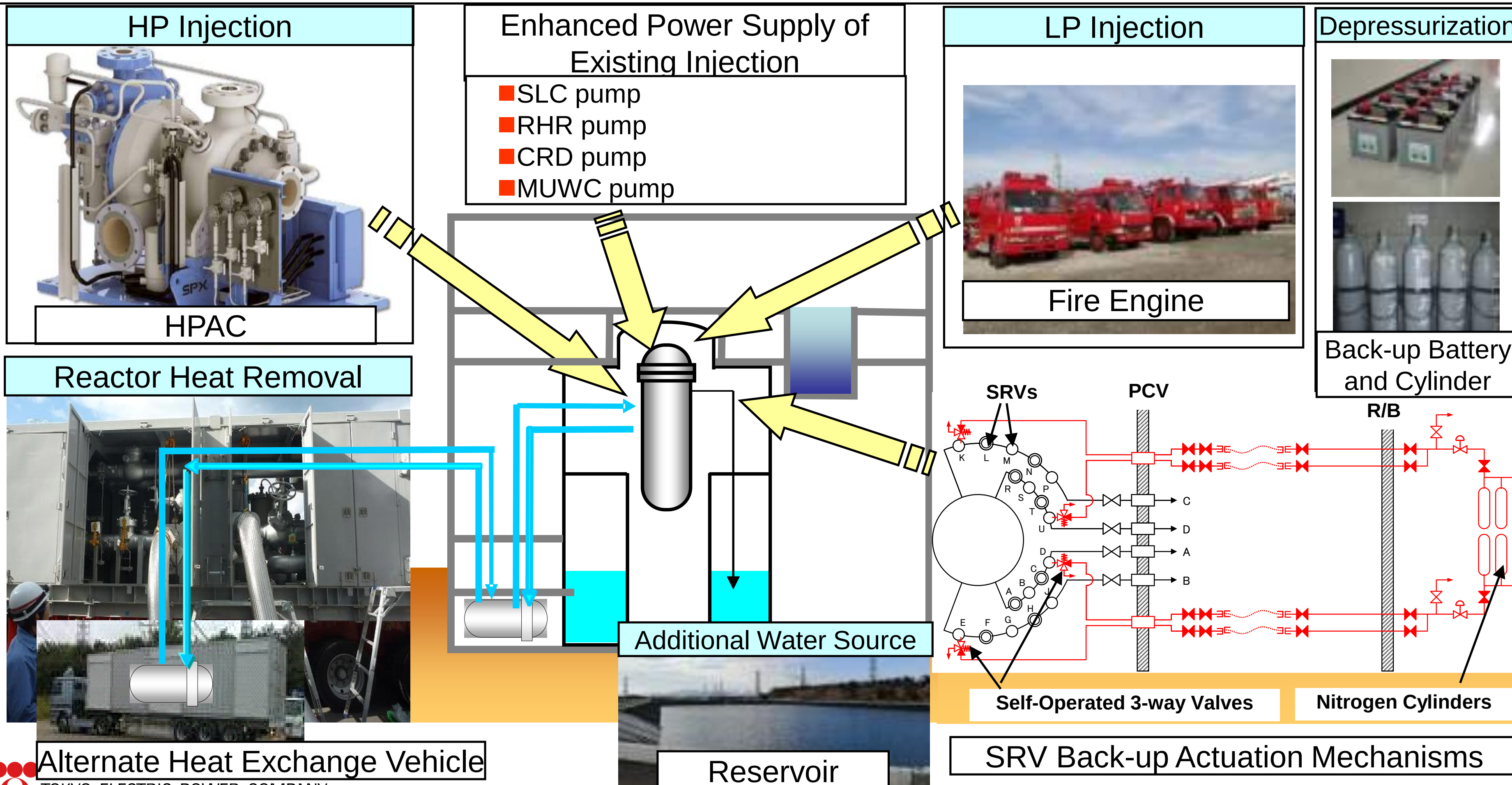


Fireproof Treatment of Cable Penetrations

Measures to enhance 3rd Layer of DiD and Support Systems

Water Injection and Heat Removal Functions

- Enhance High Pressure Injection Function: High Pressure Alternate Cooling System
- Enhance Depressurization: Back-up Actuation Mechanisms for SRVs
- Additional Water Source: Reservoir
- Enhance Heat Removal Function: Alternative Heat Exchanger Vehicles

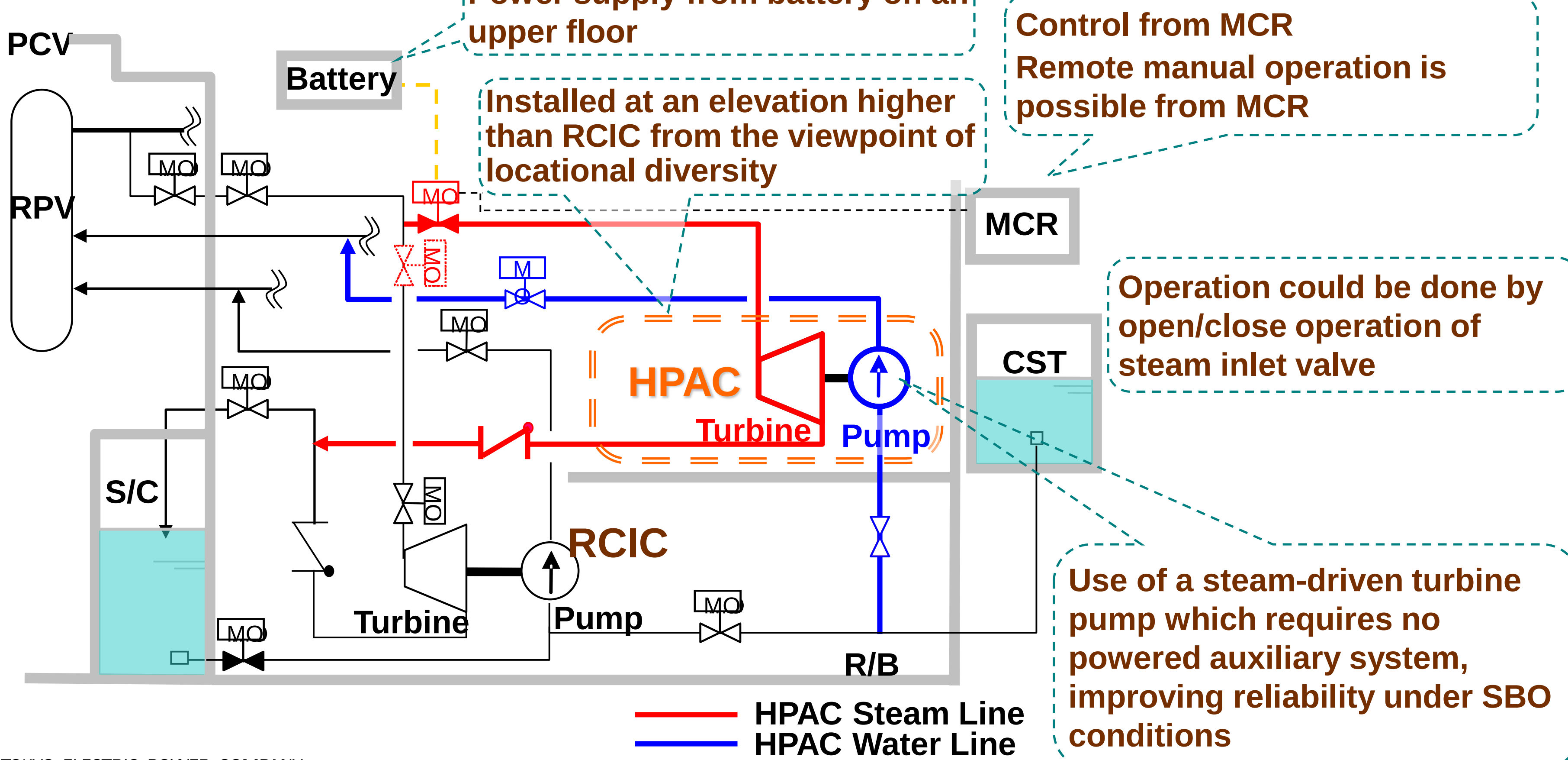


Safety Measures to enhance 3rd Layer of DiD (continued)

High Pressure Alternate Cooling System (HPAC)

Back-up system of RCIC to enhance reliability of high pressure injection, activated in case of malfunction of RCIC under SBO to prevent core damage

○ Illustration of the system



Safety Measures to enhance 3rd Layer of DiD (continued)

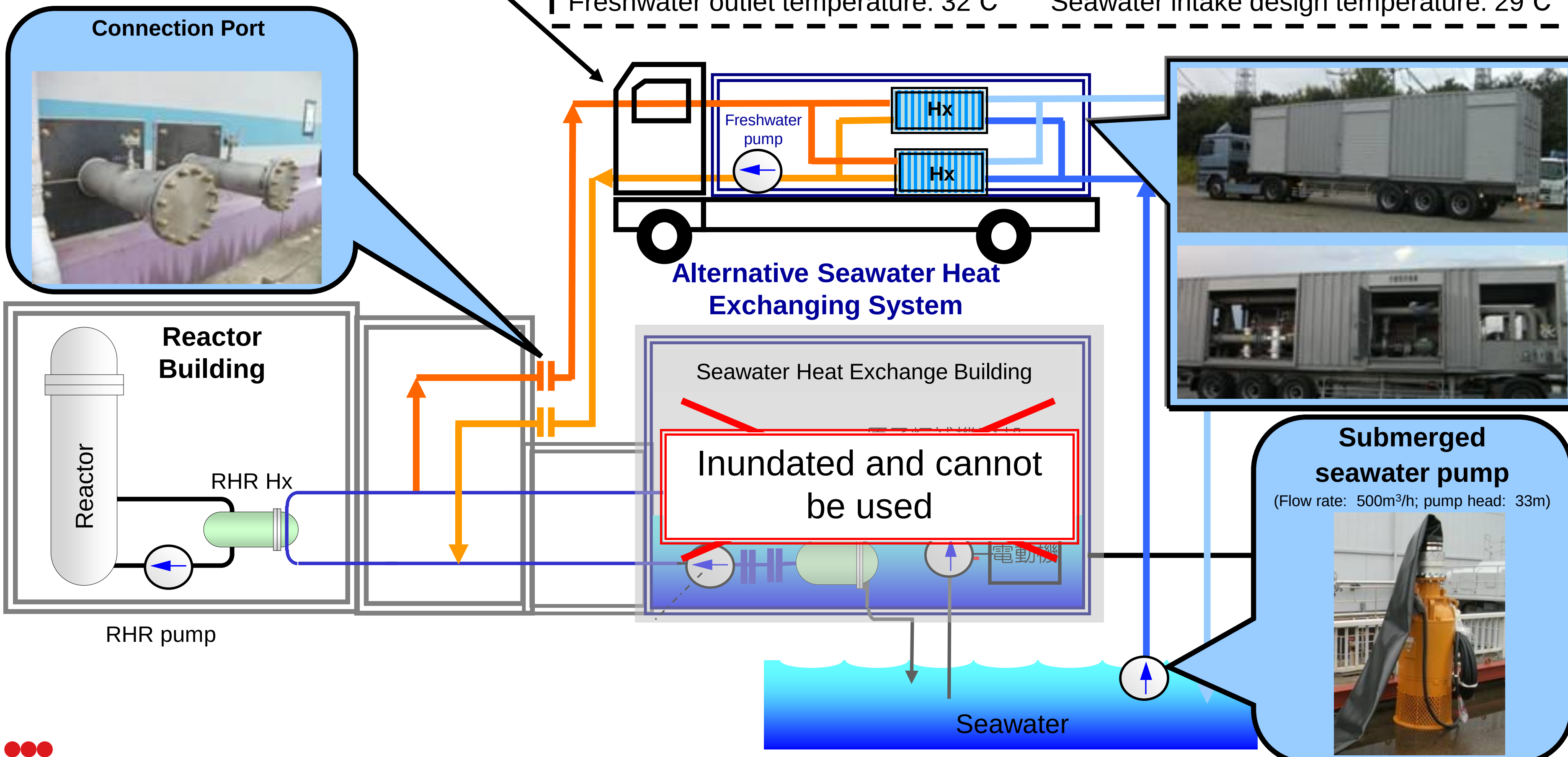
Alternative Heat Exchange Vehicle

Back-up ultimate heat sink for the Reactor in case of LUHS events

[Freshwater Pump Specification]
Quantity: 1; Flow rate: 420m^3/h;
Pump head: 40m

Cold shutdown can be achieved within 48 hours .

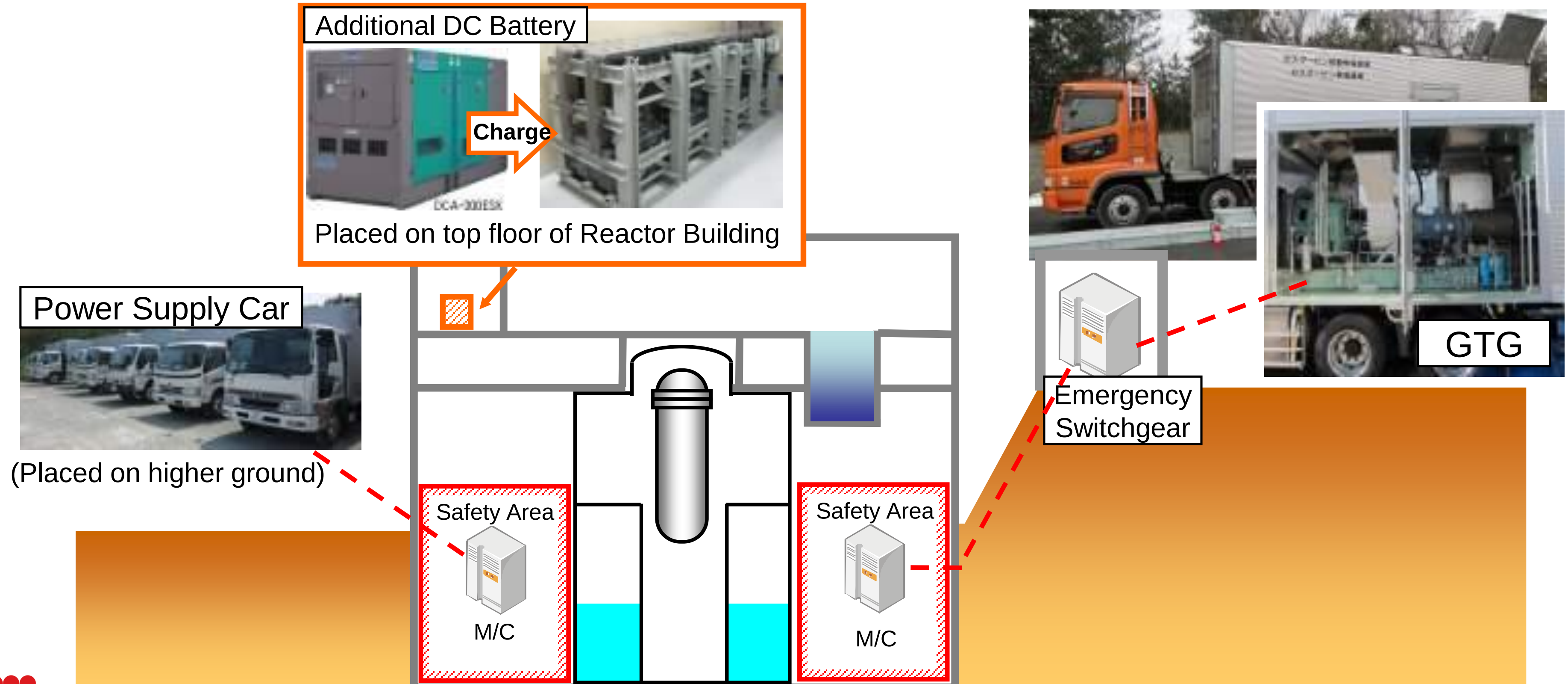
- Heat exchanging capacity: 18.6MW
- Freshwater flow rate: 420m^3/h — Seawater flow rate: 500m^3/h
- Freshwater outlet temperature: 32℃ — Seawater intake design temperature: 29℃



Safety Measures to enhance Support Systems

Power Supply Functions

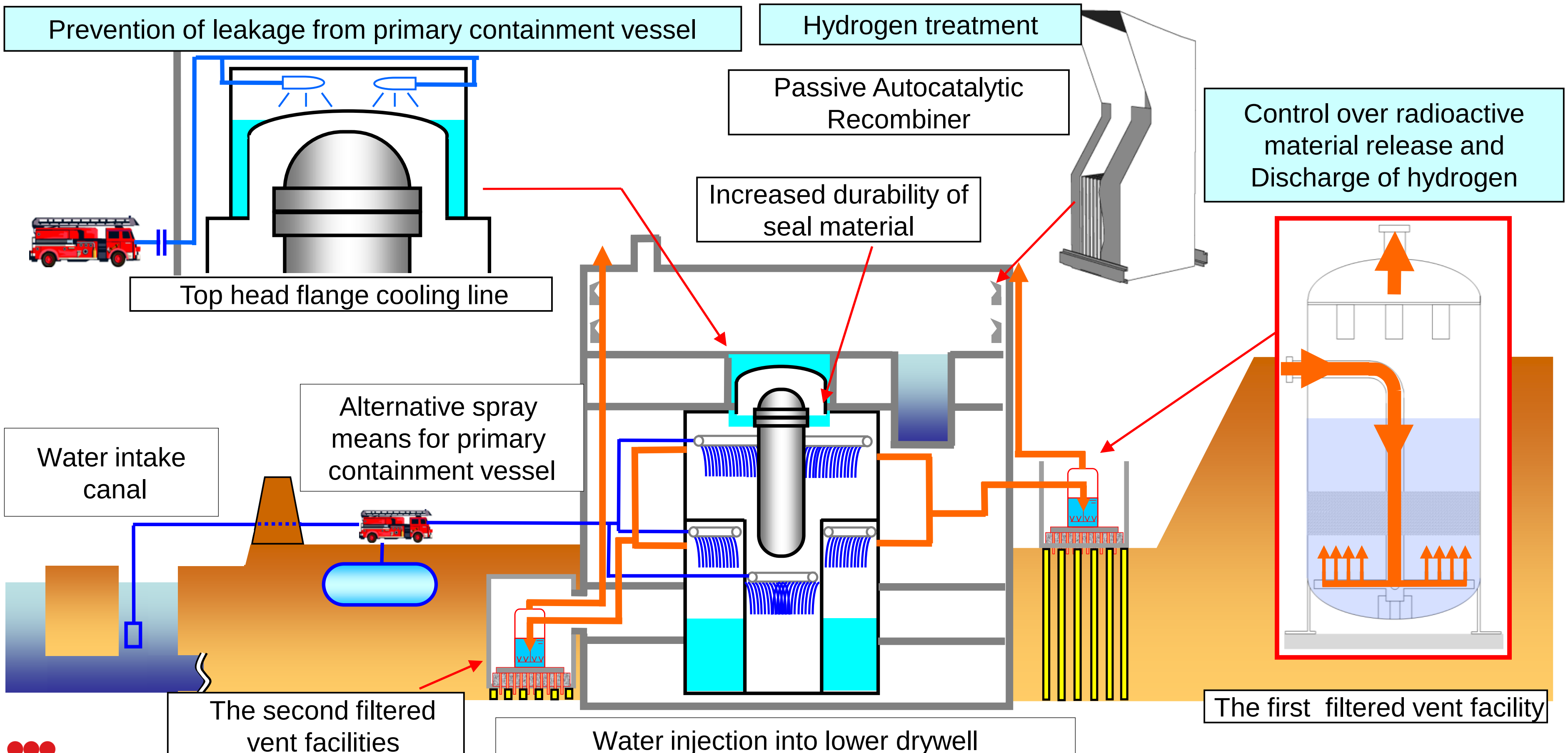
- Measures for quick power supply
  - Gas-turbine generators and power supply cars on higher ground
  - Emergency switchgear and installed electrical power cable
- Enhancement of reliability of DC Power
  - Additional DC power with a small generator on the top floor of the Reactor Building



Safety Measures to enhance 4th Layer of Defense in Depth

Protection of Containment Vessel and prevention of uncontrolled release

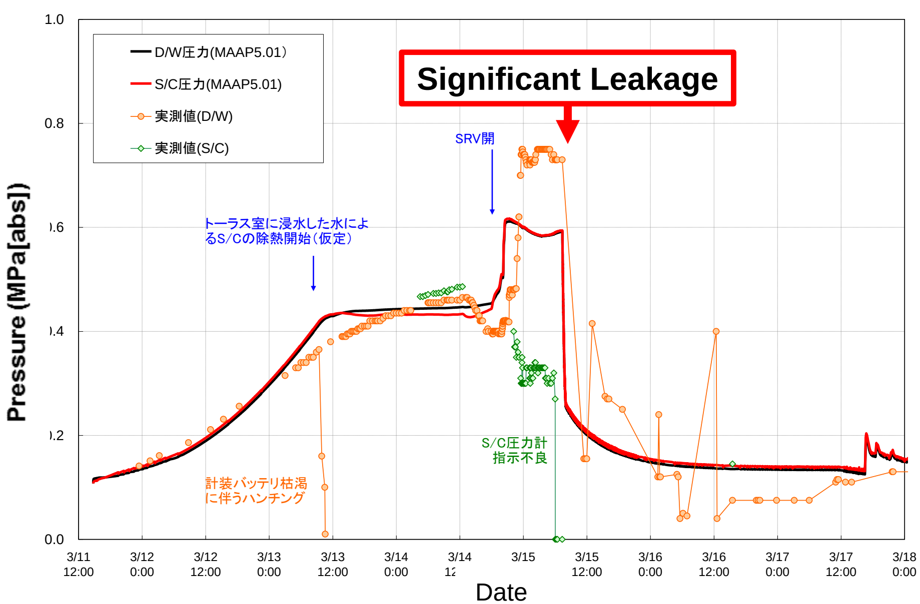
- Protection of Containment by preventing over-pressure/temperature: Top Head Flange Cooling, increased durability of seal in severe accident environment
- Mitigation of Radioactive material release: Filtered Vent
- Prevention of hydrogen explosion: Passive Autocatalytic Recombiner



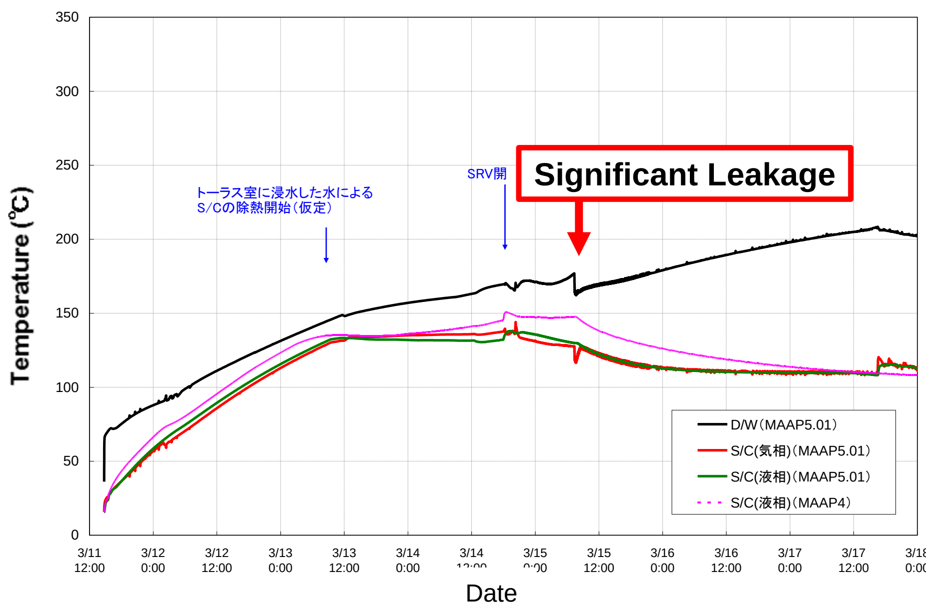
Safety Measures to enhance 4th Layer of DiD (Continued)

Failure of the Containment Vessel at Unit 2 of Fukushima Daiichi NPS

- Significant leakage occurred at 0.75 MPa and 175 ºC
- Near the Containment top flange radiation level after the accident was relatively higher than other area within the reactor building
- Top flange gaskets made of silicon rubber must have been degraded in high temperature steam environment, which continued much longer than design basis LOCA conditions



Containment Pressure

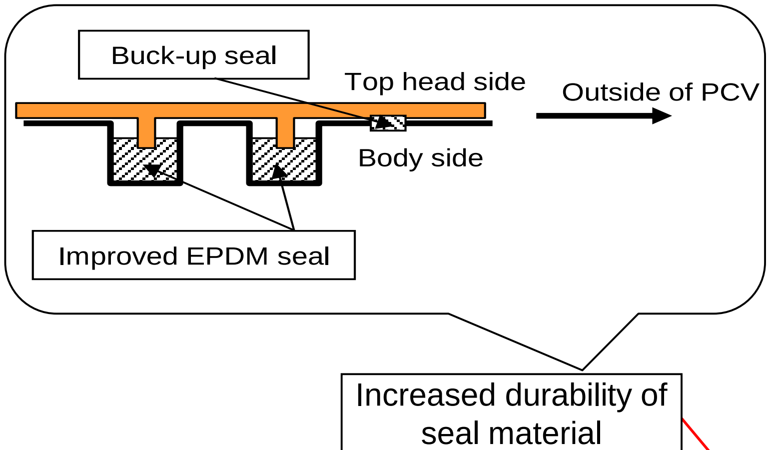


Containment Tremperature

Pressure and temperature trend of Fukushima Daiichi Unit 2 during the accidernt

Safety Measures to enhance 4th Layer of DiD (Continued)

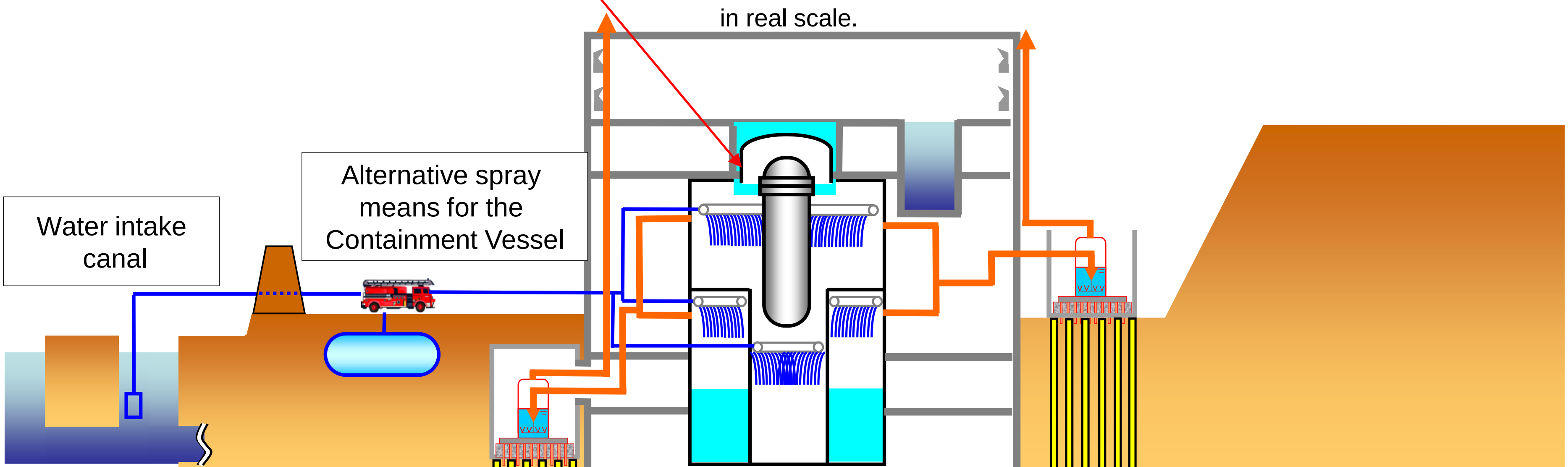
Reinforcement of Containment robustness in SA environment



Results of improved EPDM seal performance tests

No.	Heating condition	Flange opening	0.3MPa	0.65MPa	0.9MPa
1	Dry 200℃, 168h	0.8mm*	No leakage	No leakage	No leakage
2	Steam 1MPa, 250℃, 168h	0.8mm*	No leakage	No leakage	No leakage

* Tests were conducted in ½ scale. A opening of 0.8 mm is equivalent to 1.6 mm in real scale.

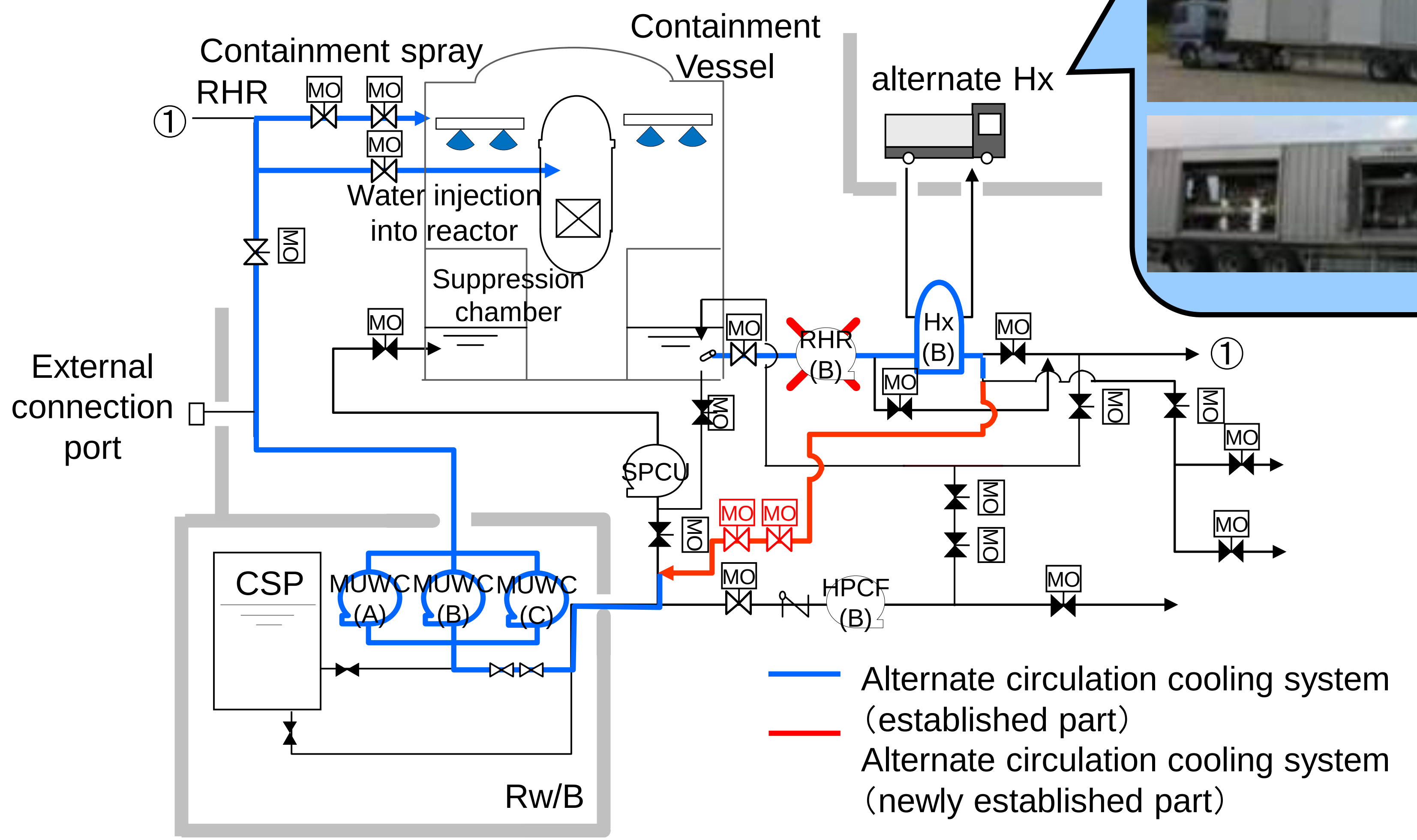


Water injection into lower drywell

Safety Measures to Enhance 4^{th} Layer of DiD (Continued)

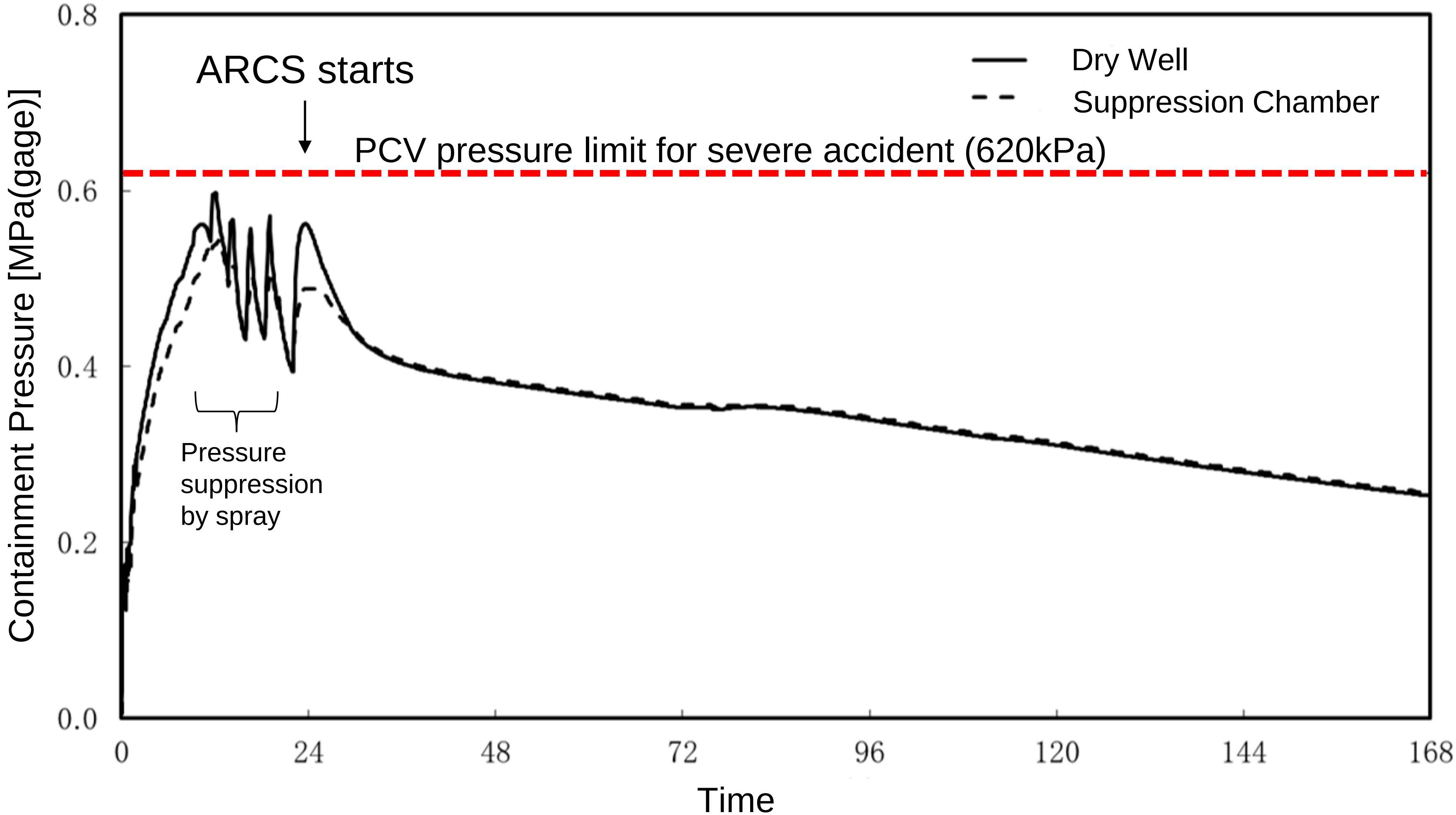
Alternate Recirculation Cooling System(ARCS) developed by TEPCO

- Containment venting can be avoided by continuous heat removal from suppression chamber



Safety Measures to Enhance 4th Layer of DiD (Continued)

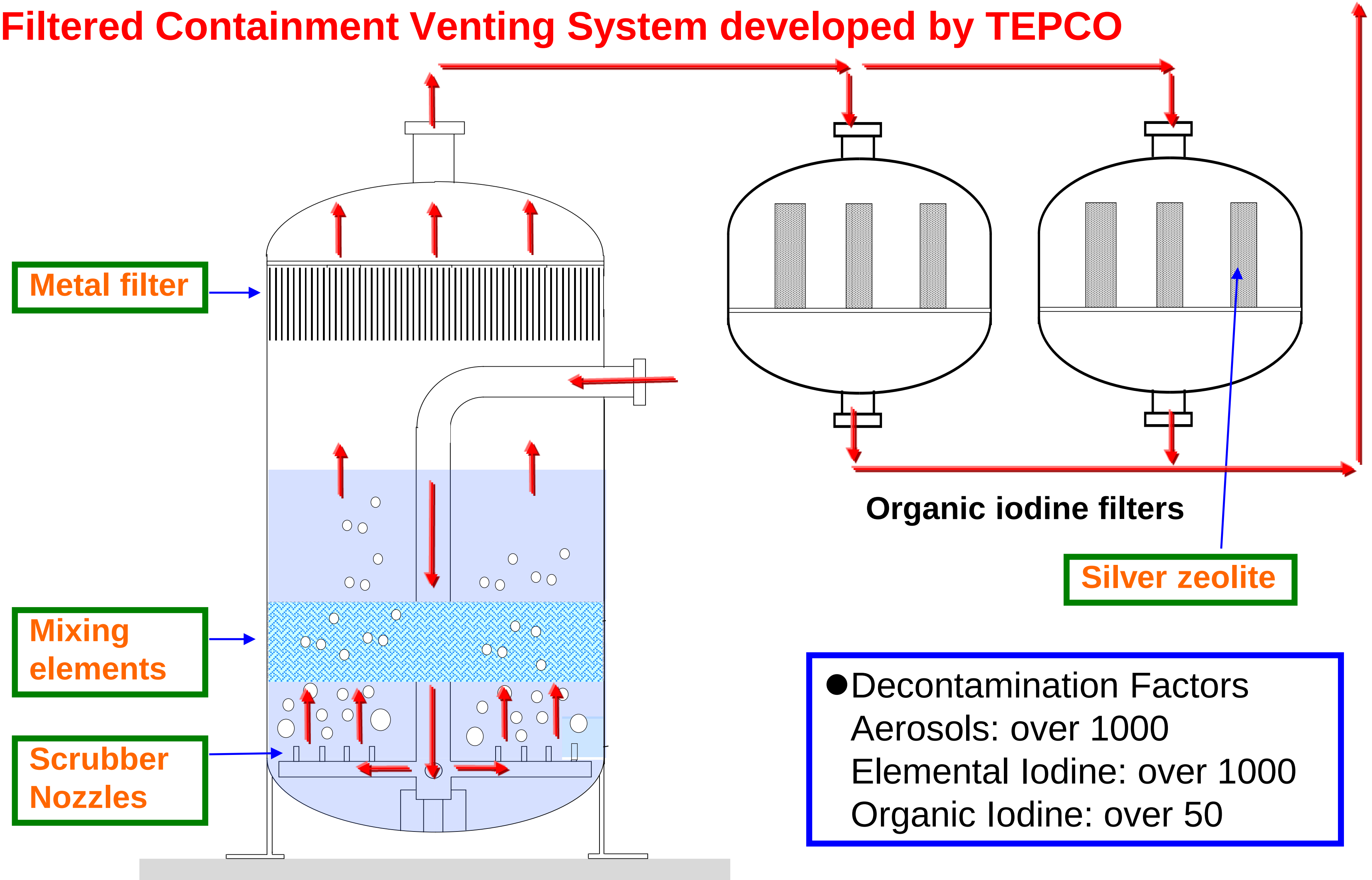
Effectiveness of ARCS



Containment pressure trend of Kashiwazaki Kariwa Unit 7
in a severe accident with large break LOCA, SBO, and loss of all ECCS

Safety Measures to Enhance 4th Layer of DiD (Continued)

Filtered Containment Venting System developed by TEPCO

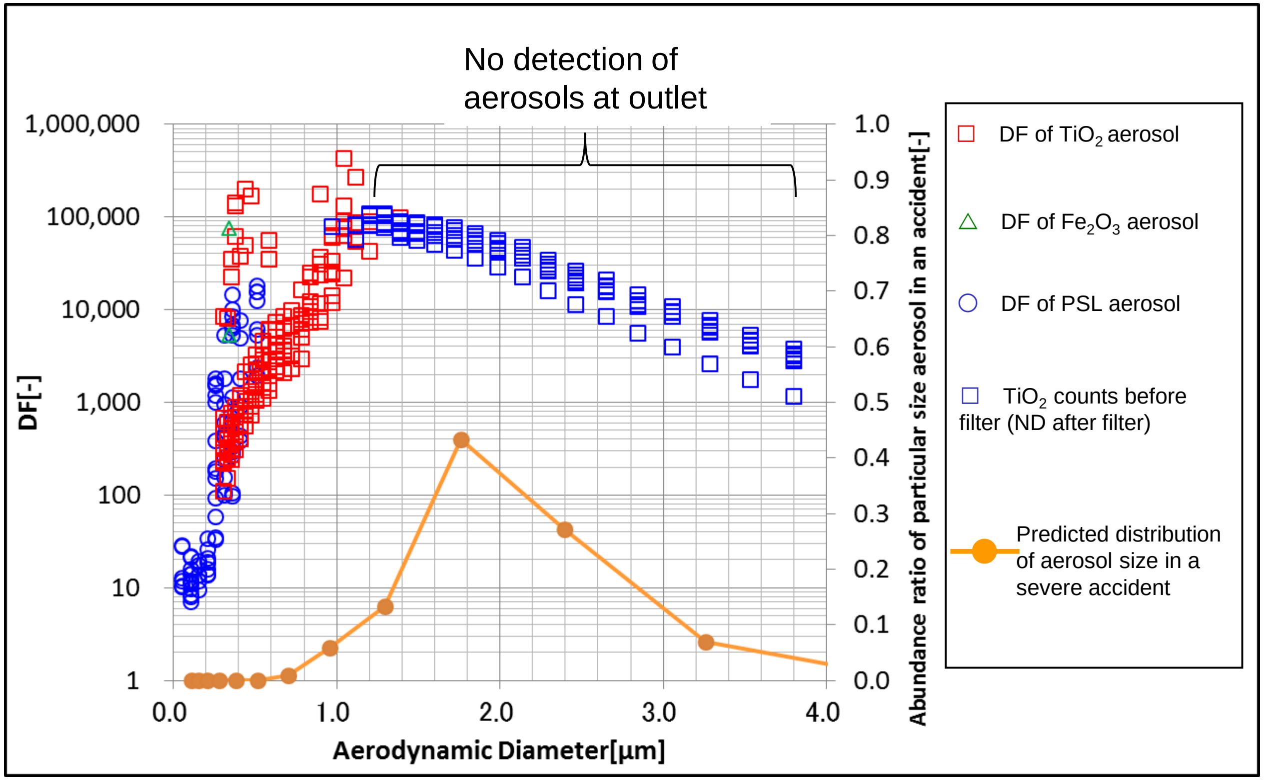


Aerosol and elemental iodine filter

Safety Measures to Enhance 4th Layer of DiD (Continued)

Aerosol filtration performance tests conducted at TEPCO laboratory

- Decontamination Factor (DF) varies depending on the aerodynamic diameter of aerosol
- DF is more than 1000 in the diameter ranges of aerosols generated in various accident conditions

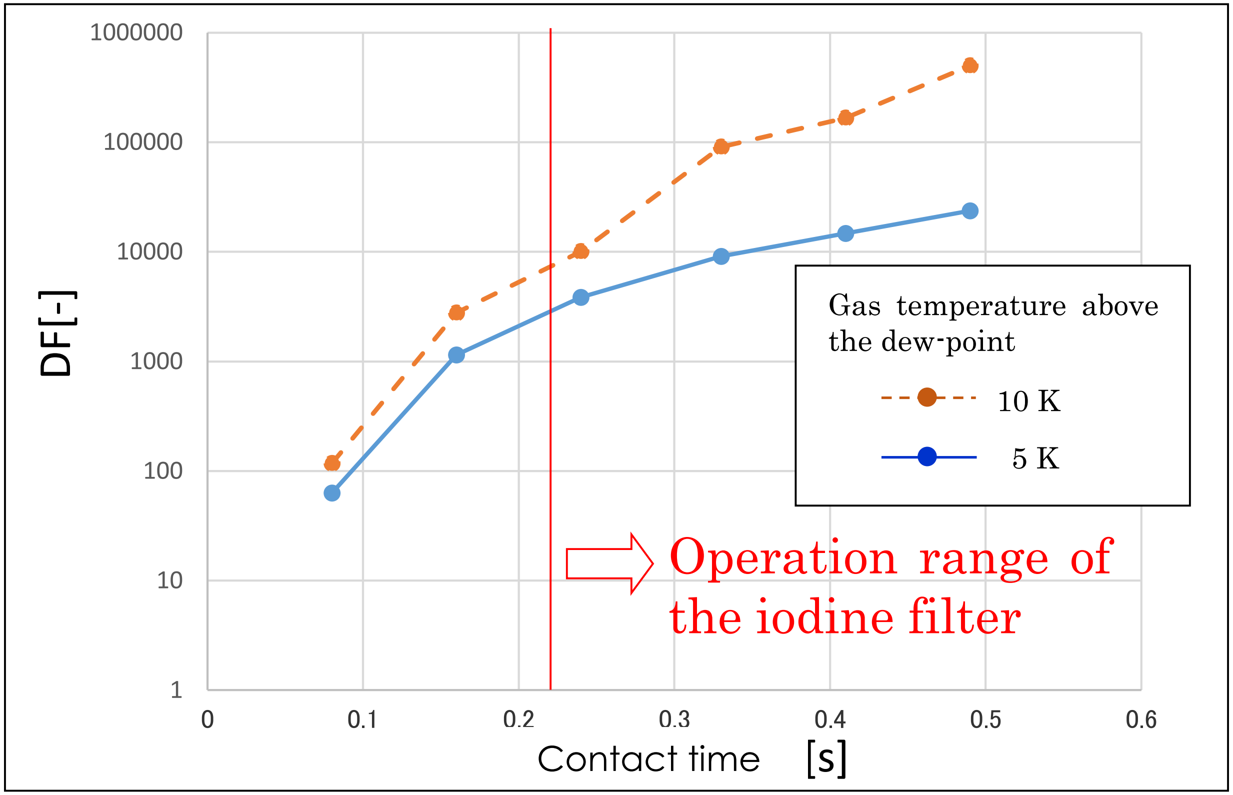


Aerosol decontamination factor (Maximum design flow condition)

Safety Measures to Enhance 4th Layer of DiD (Continued)

Organic iodine (Methyl iodide) filtration performance tests

- DF depends on contact time in the packed zeolite bed
- DF is much higher than 50 under steady state flow conditions with a degree of super heat more than 5 K

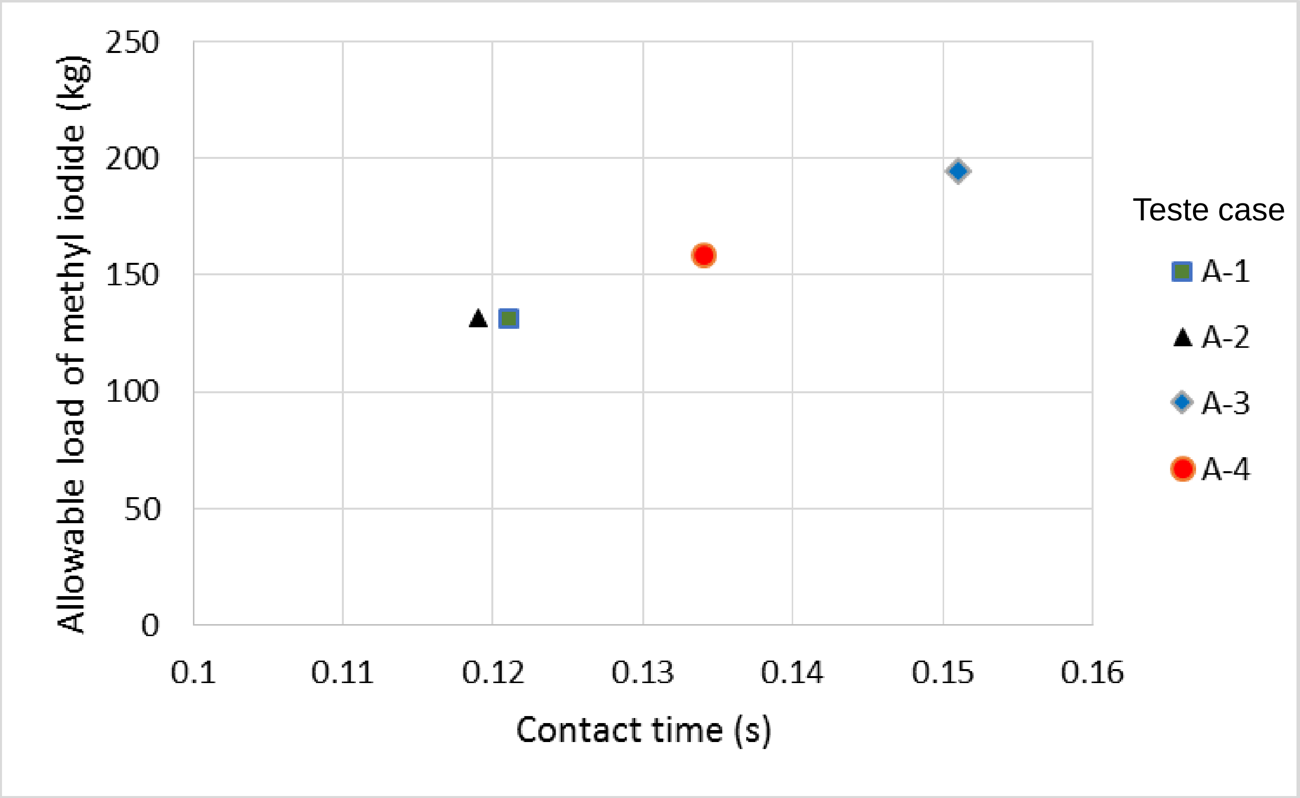


Methyl iodide decontamination factor of the iodine filter under steady state flow conditions

Safety Measures to Enhance 4th Layer of DiD (Continued)

Organic iodine (Methyl iodide) filtration performance tests

- Allowable load of organic iodine depends on the contact time
- Allowable loads in steady state flow conditions are much higher than the amount of organic iodine generated in severe accident conditions



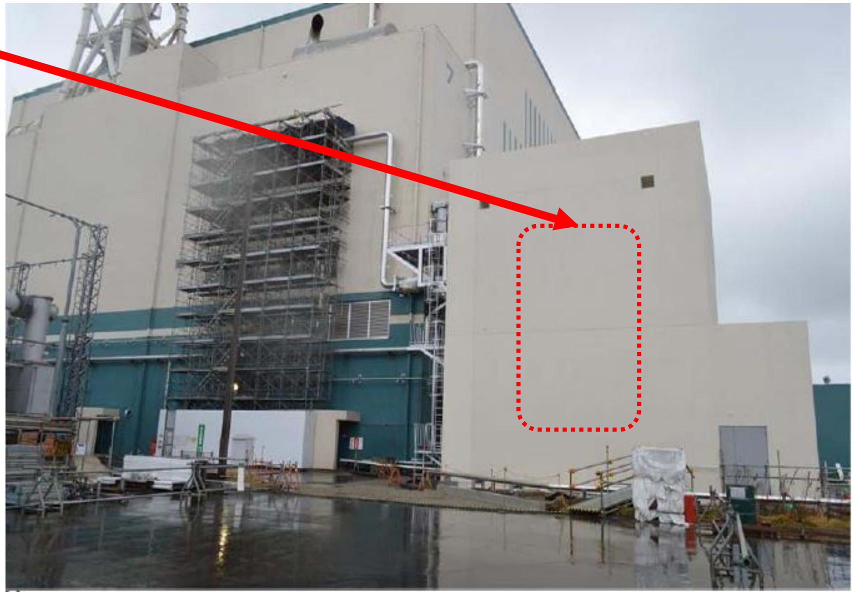
Relationship between contact time and allowable load of methyl iodide on two organic iodine filters for a plant.

Safety Measures to Enhance 4th Layer of DiD (Continued)

Filters for Containment Venting installed at Kashiwazaki Kariwa NPS

An aerosol and elemental iodine filter

An organic iodine filter being manufactured

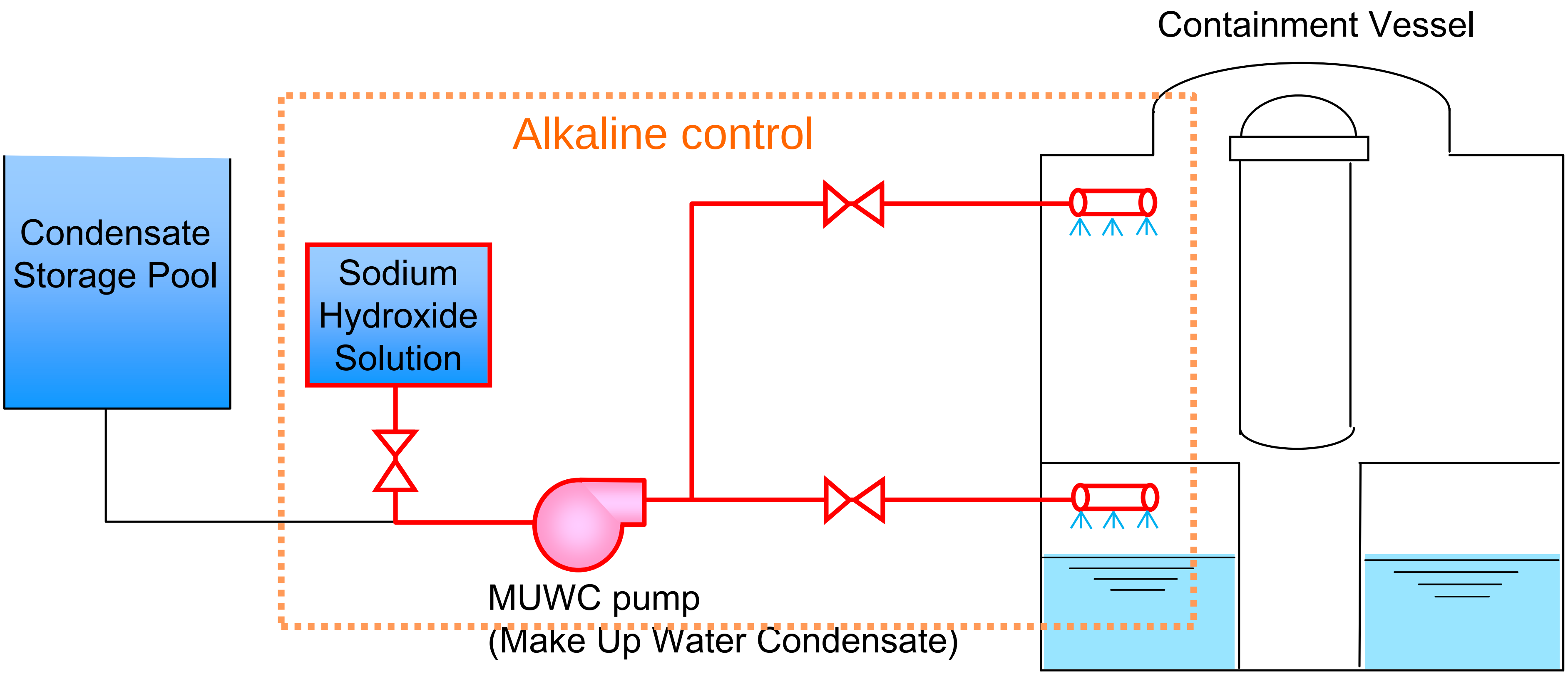


Unit 7 of Kashiwazaki Kariwa NPS, an ABWR plant

Safety Measures to Enhance 4th Layer of DiD (Continued)

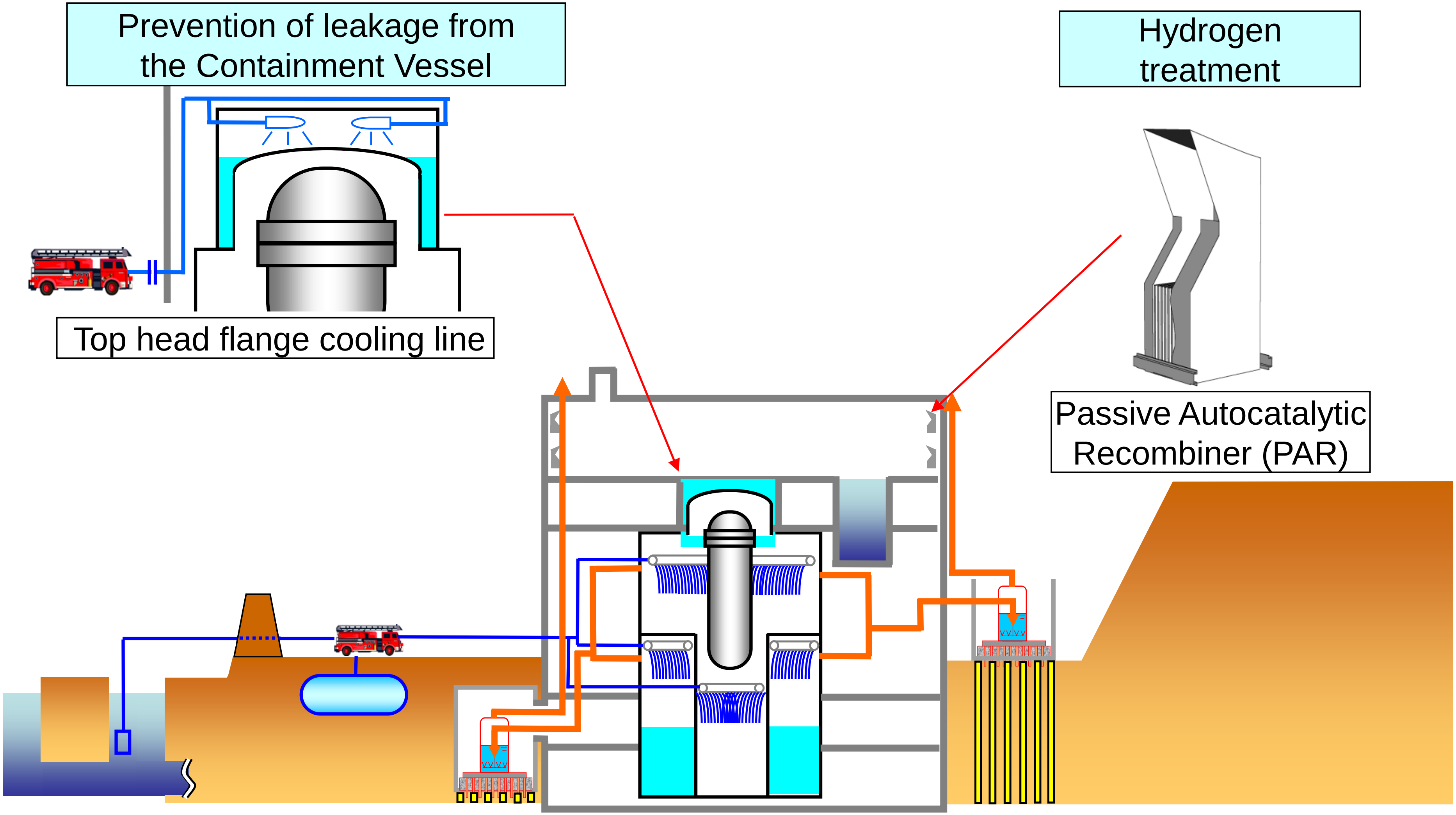
pH Control (alkaline control)

- Inhibit production of iodine gas, and reduce amount of iodine released from the Containment Vessel by keeping water in the Containment alkaline



Safety Measures to enhance 4th Layer of DiD (Continued)

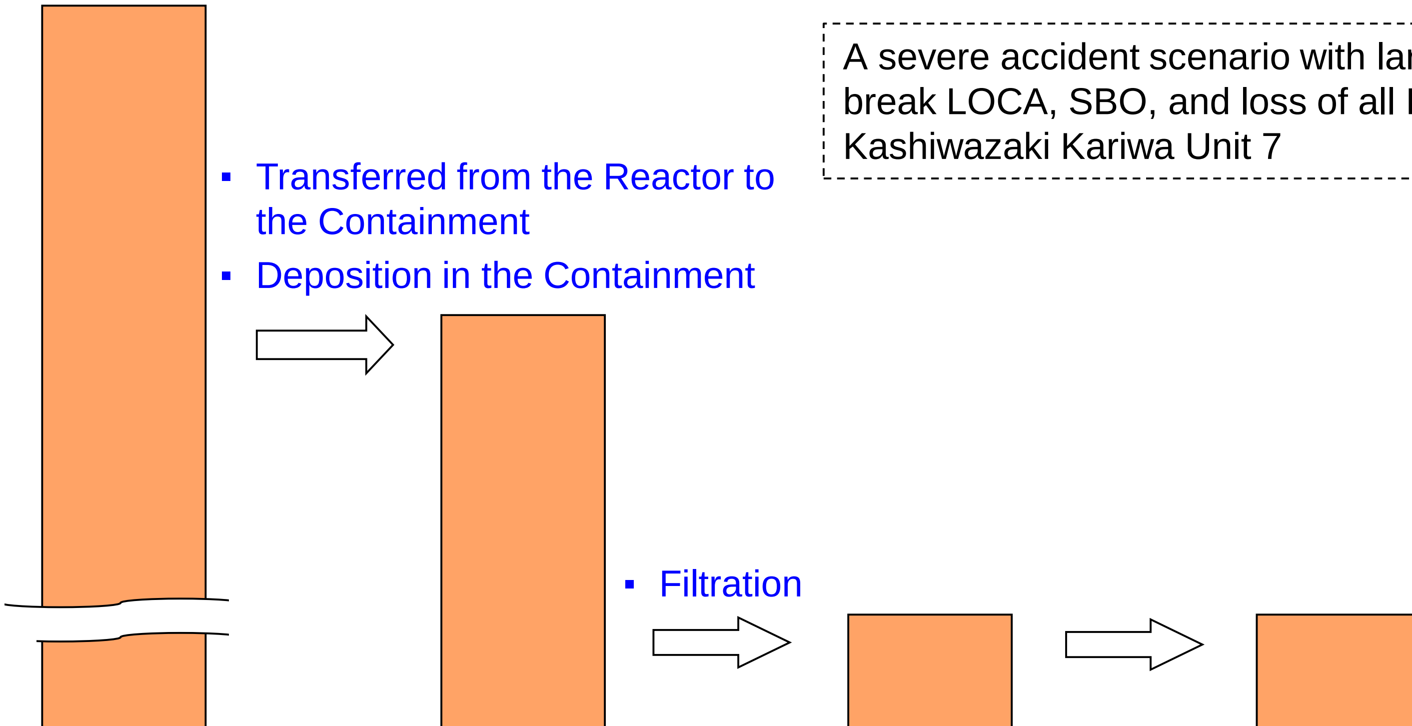
Protection of the Containment and prevention of hydrogen explosion



Safety Measures to Enhance 4th Layer of DiD (Continued)

Effectiveness in the reduction of cesium release

A severe accident scenario with large break LOCA, SBO, and loss of all ECCS at Kashiwazaki Kariwa Unit 7



[Unit: Bq]

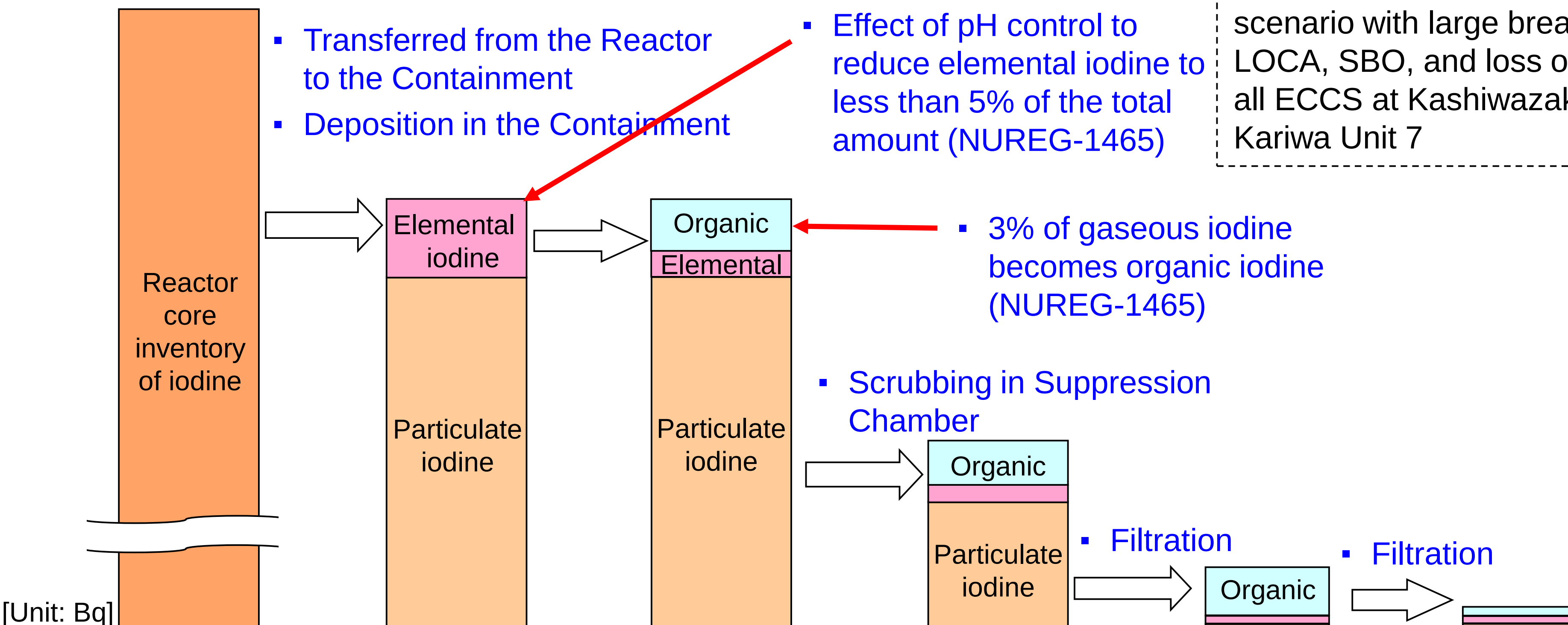
	Reactor core inventory	→	Transferred to aerosol and elemental iodine filter	→	Transferred to organic iodine filter	→	Release to the atmosphere
Cs-137	**5.2×10^{17}**	→	**1.1×10^{12}**	→	**1.1×10^{9}**	→	**1.1×10^{9}**

* Aggregated amount for 7 days

Safety Measures to Enhance 4th Layer of DiD (Continued)

Effectiveness in the reduction of iodine release

A severe accident scenario with large break LOCA, SBO, and loss of all ECCS at Kashiwazaki Kariwa Unit 7



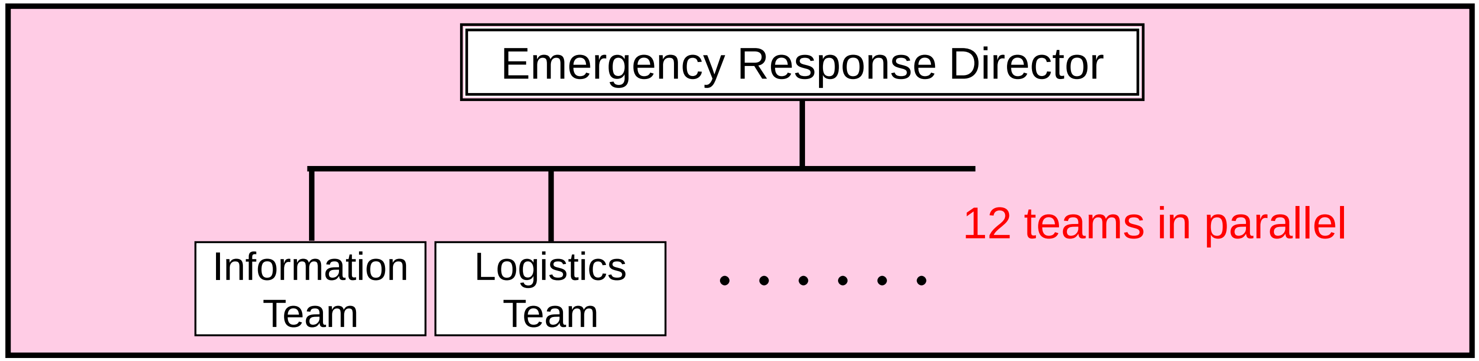
	Reactor core inventory	→	After deposition in the Containment	→	Generation of organic iodine	→	Transferred to aerosol and elemental iodine filter	→	Transferred to organic iodine filter	→	Release to the atmosphere
CsI			4.5×10^{14}		4.5×10^{14}		4.5×10^{12}		4.5×10^{9}		4.5×10^{9}
I_2	6.3×10^{18}	→	2.2×10^{13}	→	2.2×10^{13}	→	2.2×10^{11}	→	2.2×10^{8}	→	2.2×10^{8}
CH_3I			-		6.7×10^{11}		6.7×10^{11}		6.7×10^{11}		1.3×10^{10}
Total	6.3×10^{18}	→	4.7×10^{14}	→	4.7×10^{14}	→	5.4×10^{12}	→	6.7×10^{11}	→	1.8×10^{10}

* I-131 equivalent values

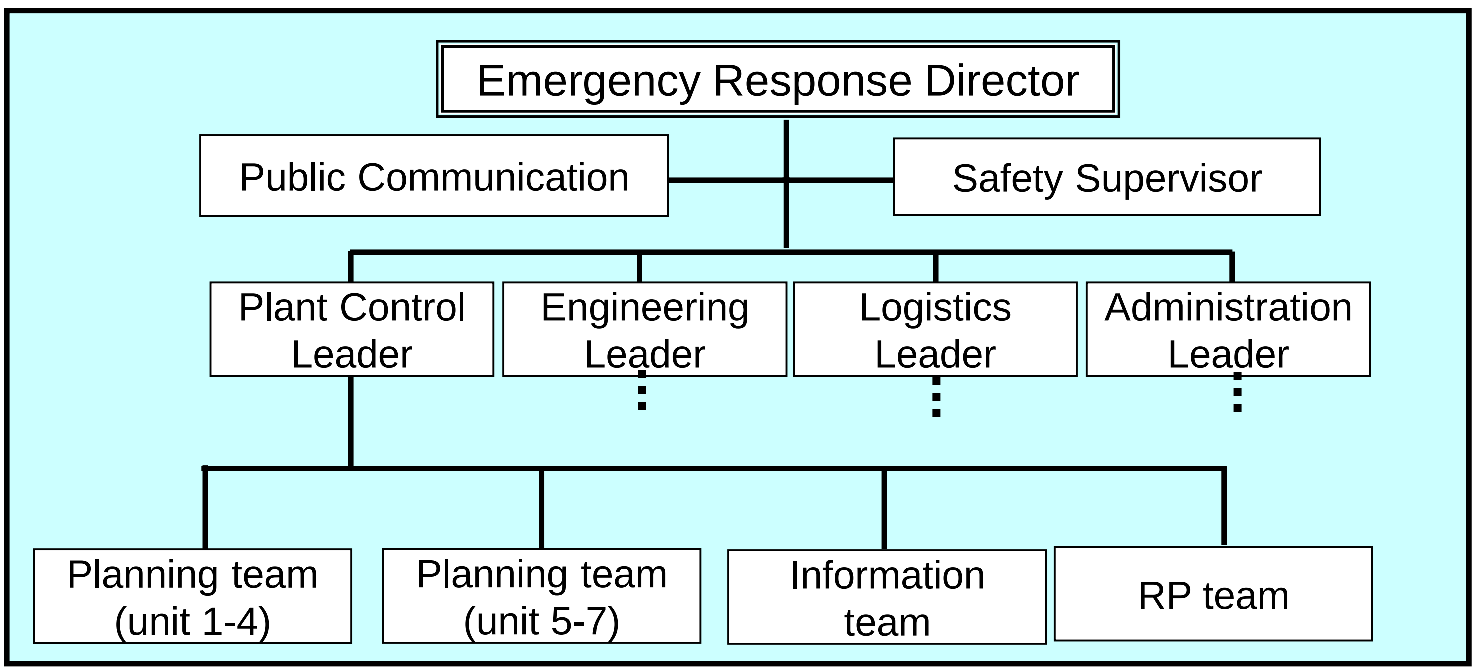
Emergency Response Capability

Restructure of Emergency Response Organization

Before



After (ICS)



Emergency Response Capability (Continued)

Training for Emergency Response

- Comprehensive emergency drills and specific skill trainings have been conducted for 45 times and 7600 times respectively since the accident
- Night trainings were carried out with temporary lighting (Car headlight, flashlight, balloon light)

ERC

Rubble removal by wheel loader

Gas turbine generator

Power supply car

Offsite center

Firefighting training

Alternative heat exchanger

Hose Laying

Logistics support base

Transport of injured person

Satellite communications vehicle

Transport of N_2 compressed gas cylinder

Emergency Response Capability (Continued)

Offsite Emergency Support Center

- Sufficient food and fuel are stored on-site to support emergency response (food for 8 days and fuel for 150 days)
- Making emergency transportation contract with transportation company and giving drivers lectures on radiation.
- Offsite emergency support centers has been prepared to control entry into affected zone and support materials

On-site Emergency Food

Image of Offsite Emergency Support Center

(Picture of J-Village)

Emergency Response Capability (Continued)

Enhancement in Logistics

Kashiwazaki Kariwa NPS

Kashiwazaki Energy Hall (8km)

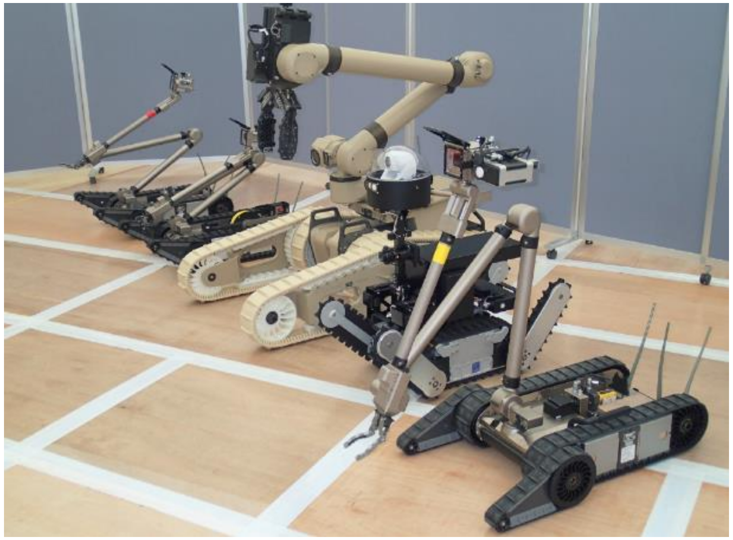
TEPCO Shinanogawa Power Station (23km)

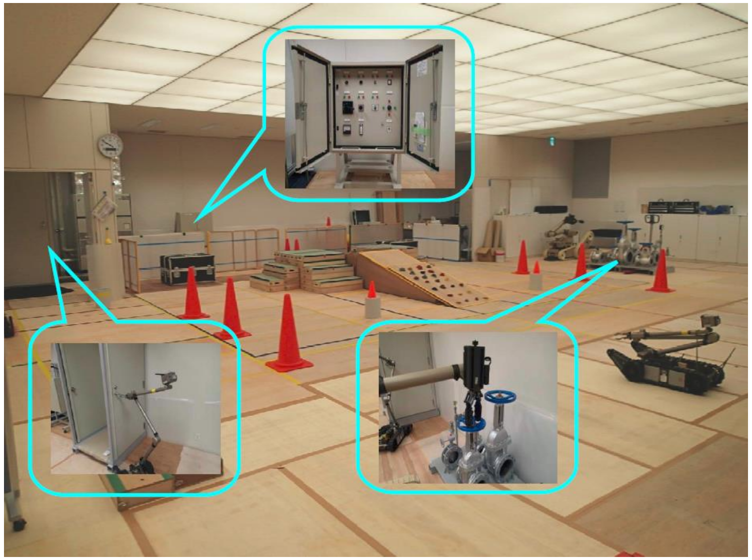
Atema Highland Resort (44km)

Emergency Response Capability (Continued)

Nuclear Emergency Assistance Center (J-NEACE)

- Located in Fukui Prefecture (350km from Kashiwazaki Kariwa NPP)
- Operated by JAPC (Japan Atomic Power Co.)
- 20 staff, on-call around the clock, 5 remote-control robots
- Main missions are:
  - Emergency transportation of robots
  - Support of robot operation
  - Training of emergency response staff of nuclear operators





Conclusion

- TEPCO is enhancing safety measures at Kashiwazaki Kariwa Nuclear Power Station based on lessons learned from the Fukushima Daiichi accident.

- Probability of the release of radioactive material in severe accidents and potential consequences of the release can significantly be reduced by additional safety measures including ARCS, Containment pH control and FCVS with organic iodine filters.

- You are always welcome to have technical information exchange with us.

- For further information please contact at shinichi.kawamura@tepco.co.jp or find it at http://www.tepco.co.jp/en/index-e.html.


Thank you for your attention