The Accident at TEPCO’s Fukushima Nuclear Power Stations

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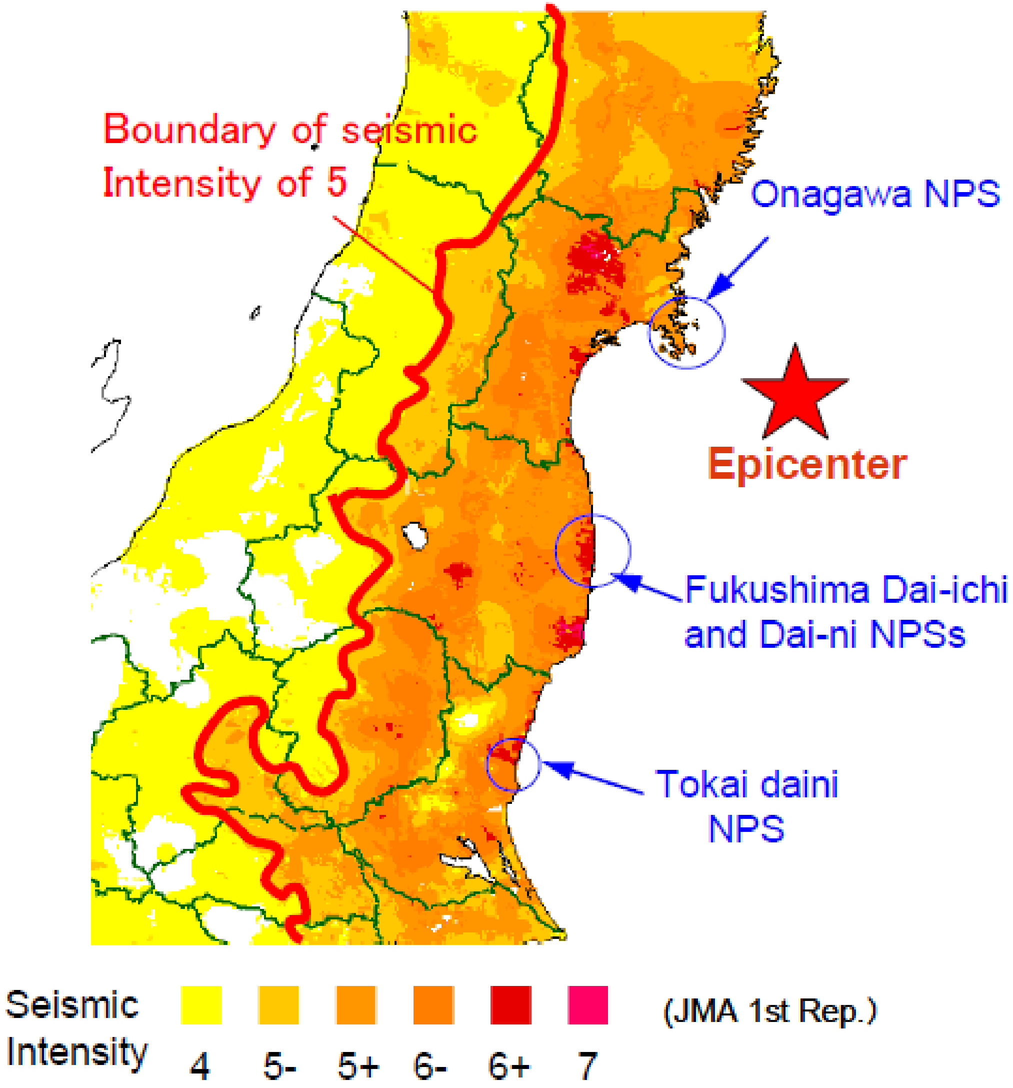
1. Earthquake and tsunami

Tohoku District - off the Pacific Ocean Earthquake



Reference: JMA Release [Online]. http://www.jma.go.jp/jma/index.html
Partially modified by JNES.

Map of JMA seismic intensities observed during the main shock.

- Occurrence: 14:46 March11, 2011
- Mw(moment magnitude): 9.0
- Epicenter: approximately 130km off the coast of Sanriku (at 38.10 degrees north latitude, 142.86 degrees east longitude and 23.7km deep)

Tohoku District-Off the Pacific Ocean Earthquake and resulting tsunamis

- A **large slip of 55m to not quite 70m** was estimated for the Tohoku earthquake in the shallow part of the plate boundary along the Japan Trench.

- There is a high probability that

  ✓ the Tohoku earthquake was a giant earthquake of **M9** in viewpoint of **long period** ground motions;

  ✓ however, it had the same characteristics as an **M8 earthquake** in viewpoint of **short period** ground motions.

- It is likely that

  ✓ the large slip in the shallow area along the Japan Trench,

  ✓ and the overlap effects of tsunami waves due to rupture delays associated with the interlocked rupturing of multiple source areas

  had large effects on tsunami water levels.

2. Occurrence and development of the accident

(1) **Main sequence of the accident**

[attack of the earthquake and the tsunami

→loss of all AC power

→core melt

→injection of the coolant water into the reactor］

Status of the Fukushima Dai-ichi Nuclear Power Station(before the attack of the earthquake)

- Unit1：under operation
- Unit2：under operation
- Unit3：under operation
- Unit4：under periodic inspection(all the fuel were removed from the reactor to the spent fuel pool)

- Unit5：under periodic inspection
- Unit6：under periodic inspection

Collapsed Tower

- Damage of external power supply systems of the Fukushima Dai-ichi and Dai-ni NPSs

Source TEPCO

Tsunami getting over seawall
at the Fukushima Dai-ichi NPS

Source TEPCO

Fukushima Dai-ichi NPS

(AC Power supply)

[External power supply] ➡ [Emergency diesel generators]

X	Yonomori -line No.1
X	Yonomori- line No.2
X	Okuma- line No.1
X	Okuma-line No.2
X	Okuma-line No.4
X	TEPCO nuclear line

↑

Earthquake and Tsunami

X	▭	(Unit 1)
X	▭	(Unit 1)
X	▭	(Unit 2)
X	▭	(Unit 2)
X	▭	(Unit 3)
X	▭	(Unit 3)
X	▭	(Unit 4)
X	▭	(Unit 5)
X	▭	(Unit 5)
X	▭	(Unit 6)
X	▭	(Unit 6)
O	▭	(Unit 6)

↑

Tsunami

Main Sequence of the accident of Unit1, Unit2 and Unint3 of Fukushima Dai-ichi NPS

Loss of external power supply due to earthquake

Start-up of emergency power generation

All emergency diesel power generators stopped except for one generator in Unit6 due to tsunami

(11 emergency diesel power generator stopped, and one generator(with air cooling)survived.)

Loss of all AC power supply except for Unit6

(Unit 5 took power supply from Unit6 on 13 March).

Core cooling system not using AC power

(Unit1:IC(isolation condenser), Unit2 (RCIC(reactor core isolation cooling system), Unit3: RCIC and HPCI (high pressure core injection system)

Stop of core cooling system not using AC power

Water injection from a fire extinguishing line

(Unit1:pure water->sea water, Unit2: sea water Unit3: pure water-> sea water)

During this time without cooling, the fuel was exposed and core melt started, generating hydrogen

Accident Management

●Aim

①To prevent severe accident

②To mitigate effect of severe accident

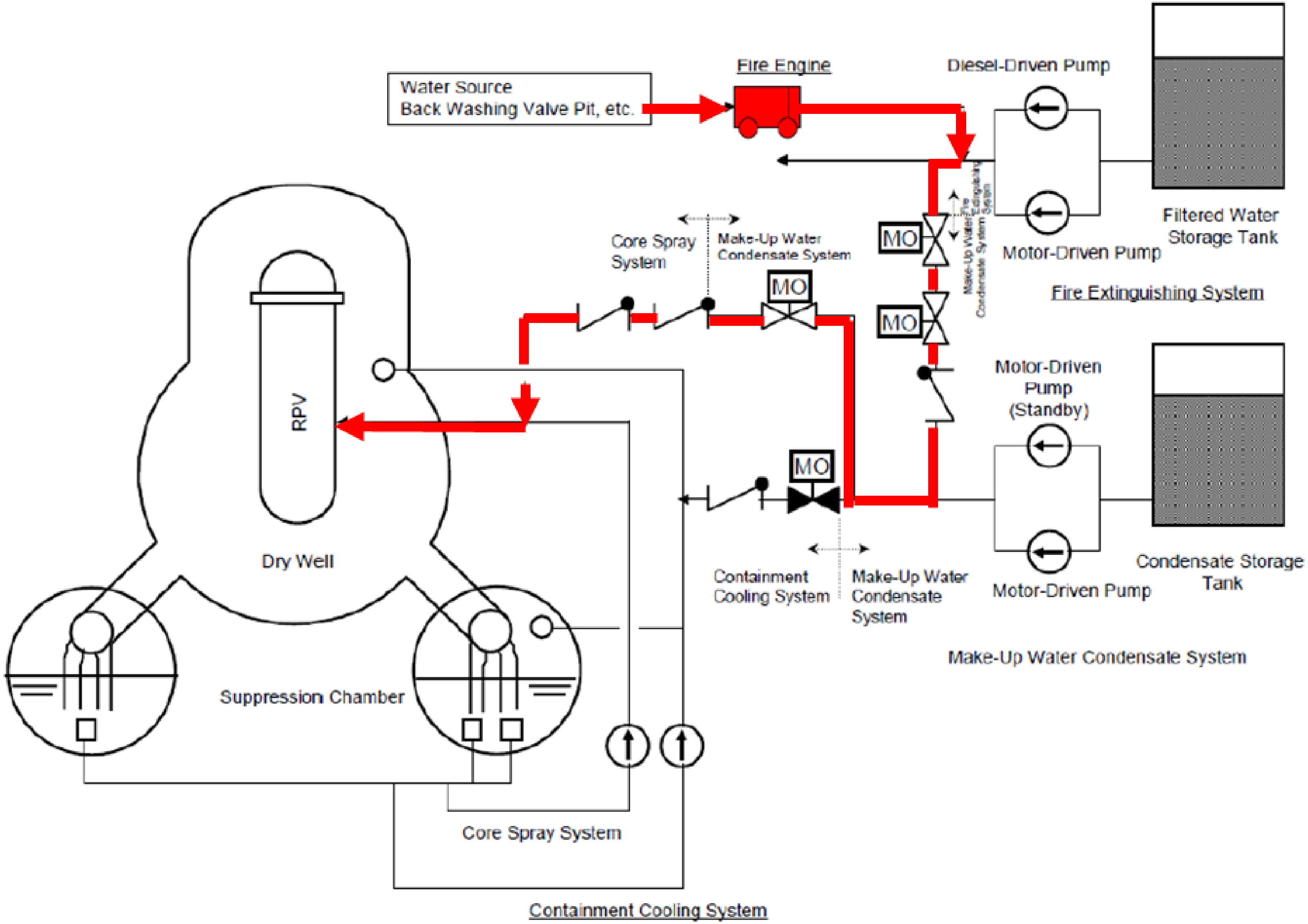
●Implementation

・Operators’ voluntary implementation
（1992～）

Accident Management Measures at Fukushima Dai-ichi related to this Accident

Items	Contents
Alternative coolant injection	• Lines via condensate water makeup systems from the condensate storage tanks as the water sources • Lines via fire extinguishing systems and condensate water makeup systems from the filtrate tanks as the water sources
PCV vent facilities	• PCV vent facilities were installed to bypass the standby gas treatment system so that they can vent the PCV when the pressure is high.
Power interchange facilities	• Power interchange facilities have been installed such that the power supply of the alternating current source for power machinery (6.9kV) and the low voltage alternating current source (480V) can be interchanged between adjacent reactor facilities (between Units 1 and 2, between units 3 and 4, and between Unit 5 and 6).

Unit 1 (alternative coolant injection via a fire extinguishing line)



Main events of the accident at the Fukushima Dai-ichi Nuclear Power Staition

（１）Core melt in the reactor

（２）Decrease of cooling water at the spent fuel pool

（３）Hydrogen explosion

(2) core melt in the reactor

［Occurrence of the core melt due to the exposure of the fuels during the time between the loss the AC power and injection of the coolant water at Unit 1 ,Unit 2 and Unit 3］

Unit 1 RPV pressure and water level

Code

Methods for Estimation of Leakages and Consequences of Releases (**MELCOR**)

Analysis conditions

- IC worked intermittently until tsunami attacked. Further operation of IC was not considered.
- Based on the records, HPCI operation was not considered.
- PCV leakage areas (assumption) at 18 hours and at 50 hours are ca. 7 cm^2 and ca. 35 cm^2, respectively.
- Amount of water injected through the fire extinguishing line is based on the records, but varies with RPV pressure.

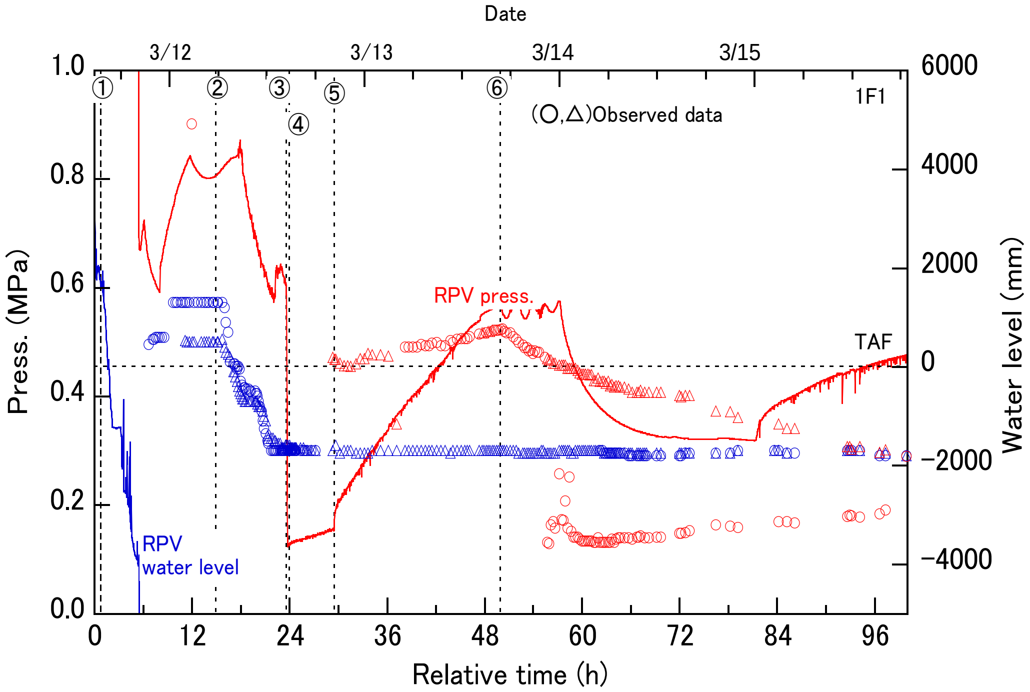


Fig. RPV pressure and water level (unit 1) [case 2]
①IC stop, ②PCV failure (assumption), ③W/W ventilation (open), ④W/W ventilation (close), ⑤sea water inject., ⑥expansion of PCV failure (assumption)

Fukushima Dai-ichi NPS Unit 1

(Status of the reactor core)

- 14:46 March 11: Loss of external power supply, Start-up of emergency diesel generators
- 14:52 March 11: Start-up of isolation condenser
- 15:37 March 11: Loss of all AC power
- 05:46 March 12: Start of fresh water injection from a fire extinguishing line

→Water injection seemed to have stopped for 14 hours and 9 minutes.

- **around 17:00 March 11**: **The fuel was exposed, and the core melt started afterwards**.

Unit 2 RPV pressure and water level

Code

Methods for Estimation of Leakages and Consequences of Releases (**MELCOR**)

Analysis conditions

- RCIC had worked until 13:25 on Mar 14.
- Water source of RCIC is changed from CST to S/P at 4:20 on Mar 12.
- Leakage (ca. 50 cm^2) from gas phase of D/W at 21 hours is assumed.
- Leakage (ca. 300 cm^2) from gas phase of S/C is assumed.
- Amount of water injected through the fire extinguishing line is based on the records, but varies with RPV pressure.

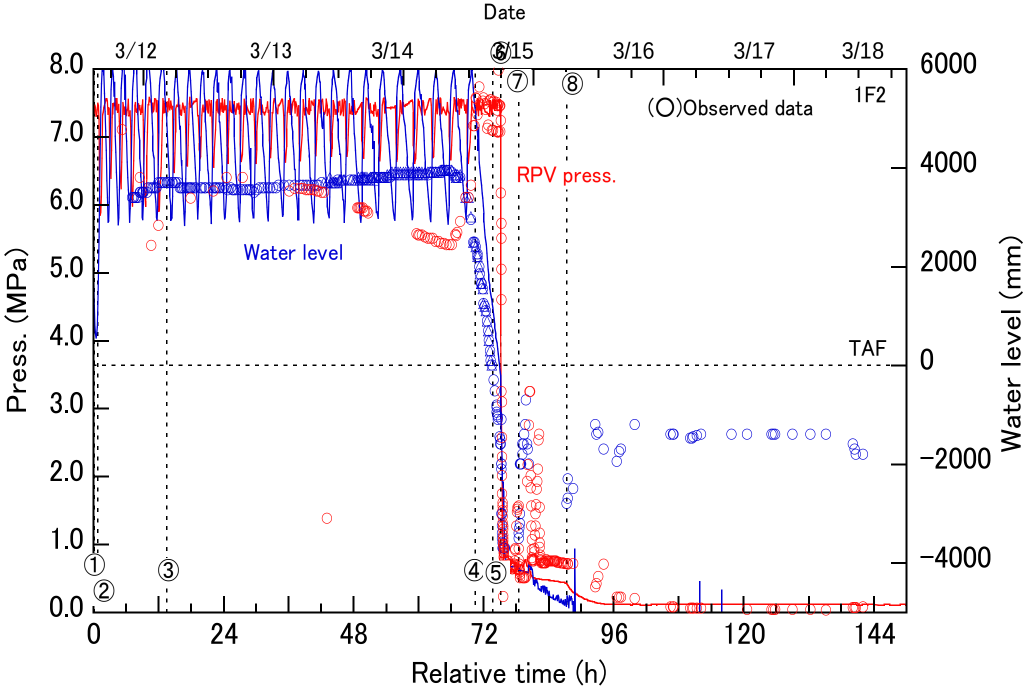


Fig. RPV pressure and water level (unit 2) [TEPCO-2] ①RCIC start manually, ②SBO, ③Water source change from CST to S/P, ④RCIC stop, ⑤Sea water inject., ⑥ RPV depressurized, ⑦S/R valve-2 open, ⑧Impact sound

Fukushima Dai-ichi NPS Unit 2

(Status of the reactor core)

- 14:47 March 11: Loss of external power supply, Start-up of emergency diesel generators
- 14:50 March 11: Start-up of RCIC (reactor core isolation cooling system)
- 15:41 March 11:Loss of all AC power
- 13:25 March 14: Stop of RCIC
- 19:54 March 14: Start of seawater injection from a fire extinguishing line

Water injection seemed to have stopped for 6 hours and 29 minutes.

- **around 18:00 March 14 : The fuel was exposed, and the core melt started afterwards**.

Unit 3 RPV pressure and water level

Code

Methods for Estimation of Leakages and Consequences of Releases (**MELCOR**)

Analysis conditions

- RCIC had worked until 11:36 on Mar 12.
- HPCI worked from 12:35 on Mar 12 to 2:42 on Mar 13.
- Water source of RCIC and HPCI is CST.
- Depressurization of RPV was confirmed at 9:20 on Mar 13.
- PCV ventilation line was opened and closed repeatedly.
- It is presumed that water injection rate can maintain slightly below the level of the fuel range, and not the flow rate of the discharge side of the fire pump.

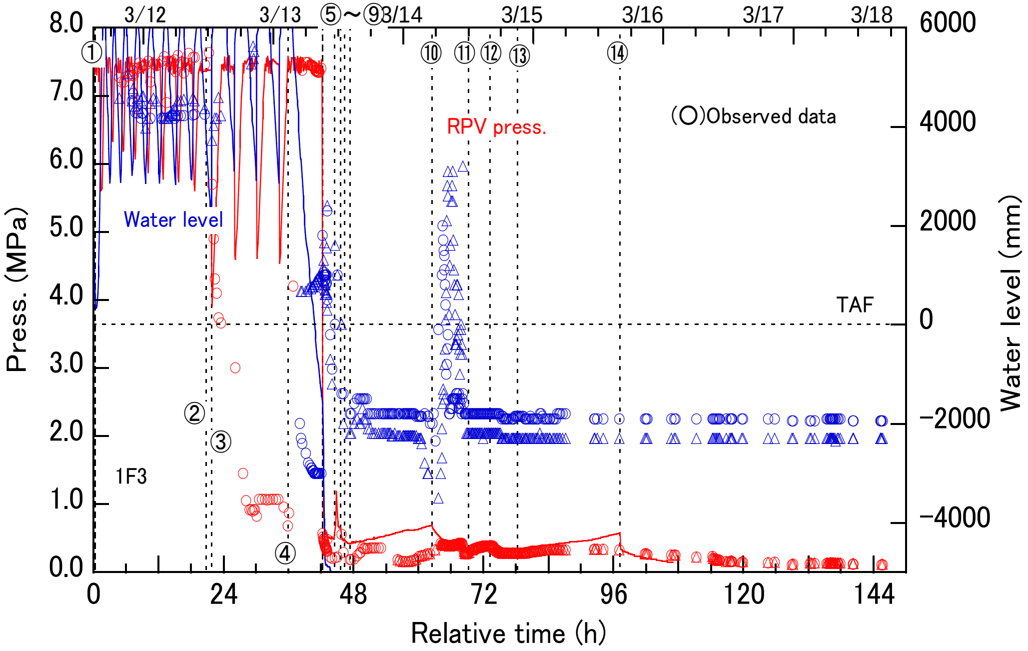


Fig. RPV pressure and water level (unit 3) [TEPCO-2] ①RCIC start manually, ②RCIC stop, ③HPCI start, ④HPCI stop, ⑤S/RV(open), ⑥PCV vent (open), ⑦Water inject., ⑧PCV vent (close), ⑨Sea water inject., ⑩~⑭PCV vent (open⇔close)

Fukushima Dai-ichi NPS Unit 3

(Status of the reactor core)

- 14:47 March 11: Loss of external power supply, Start-up of emergency diesel generators
- 15:05 March 11: Start-up of RCIC
- 15:41 March 11: Loss of all AC power
- 11:36 March 12: Stop of RCIC
- 12:35 March 12: Start-up of HPCI (high pressure core injection system)
- 02:42 March 13: Stop of HPCI
- 09:25 March 13: Start of fresh water injection from a fire extinguishing line

→Water injection seemed to have stopped for 6 hours and 43 minutes.

- **around 08:00 march 13**: **The fuel was exposed, and the core melt started afterwards.**

Core melt at Unit 1,Unit2 and Unit3

●Core melt

A considerable amount of melted fuel seems to have moved to and accumulated at the bottom of the RPV.

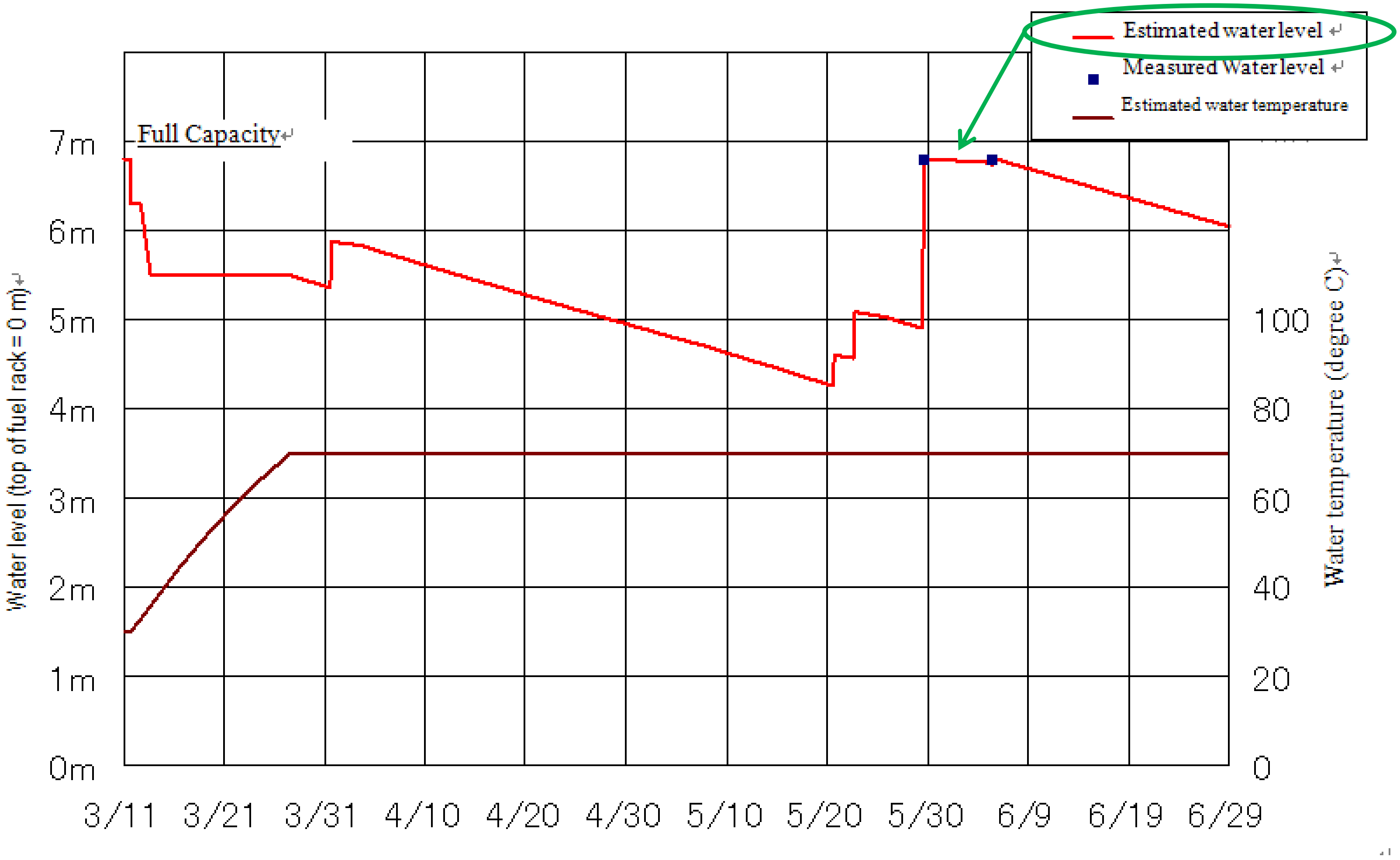
●Damage at the bottom of the RPV

There is a possibility that the bottom of the RPV was damaged and some of the fuel might have dropped and accumulated on the D/W floor (lower pedestal).

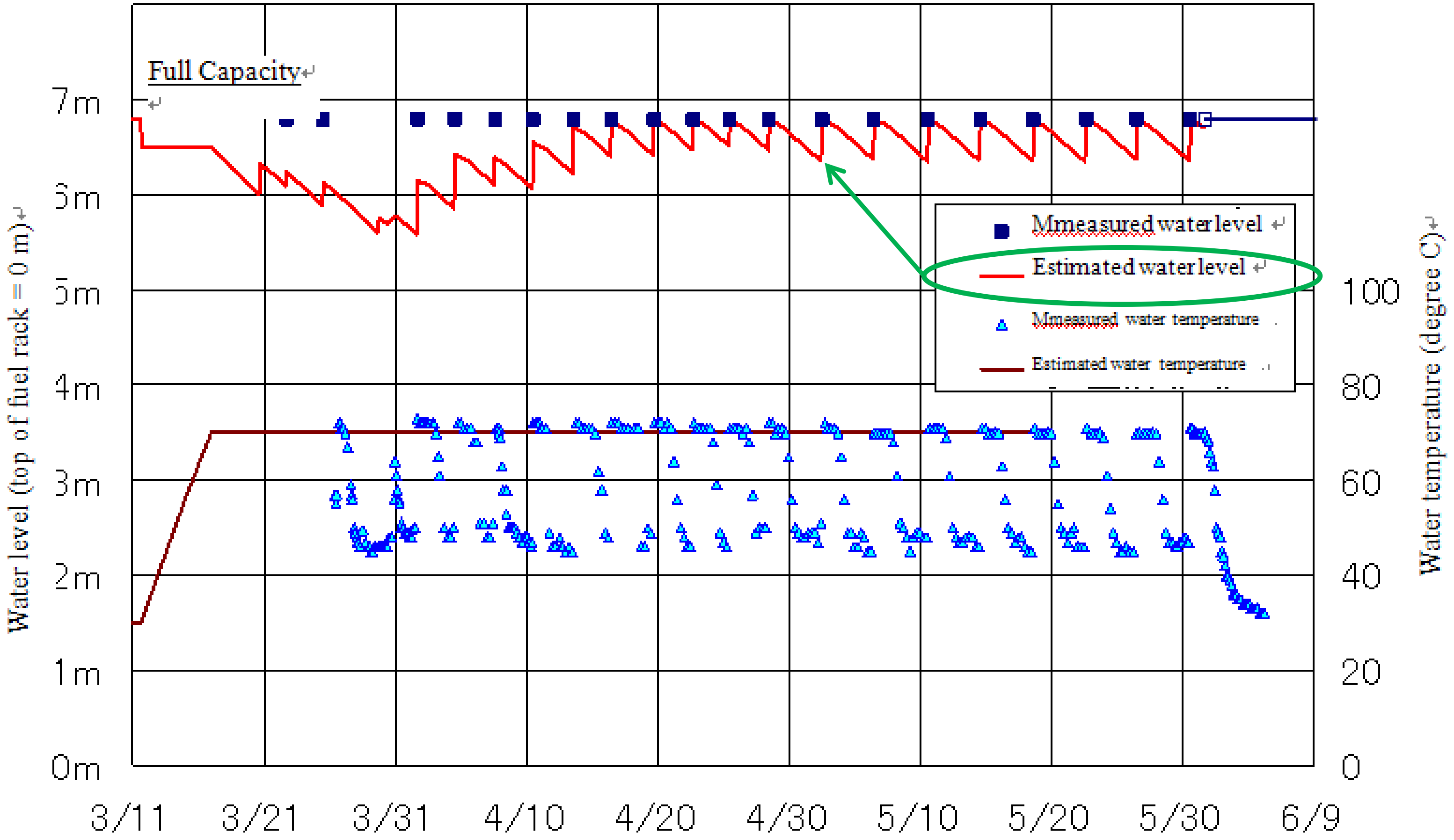
(3) Decrease of the coolant water in the spent fuel pool

［Although level of the coolant water in the spent fuel pool decreased , the spent fuels were not exposed.］

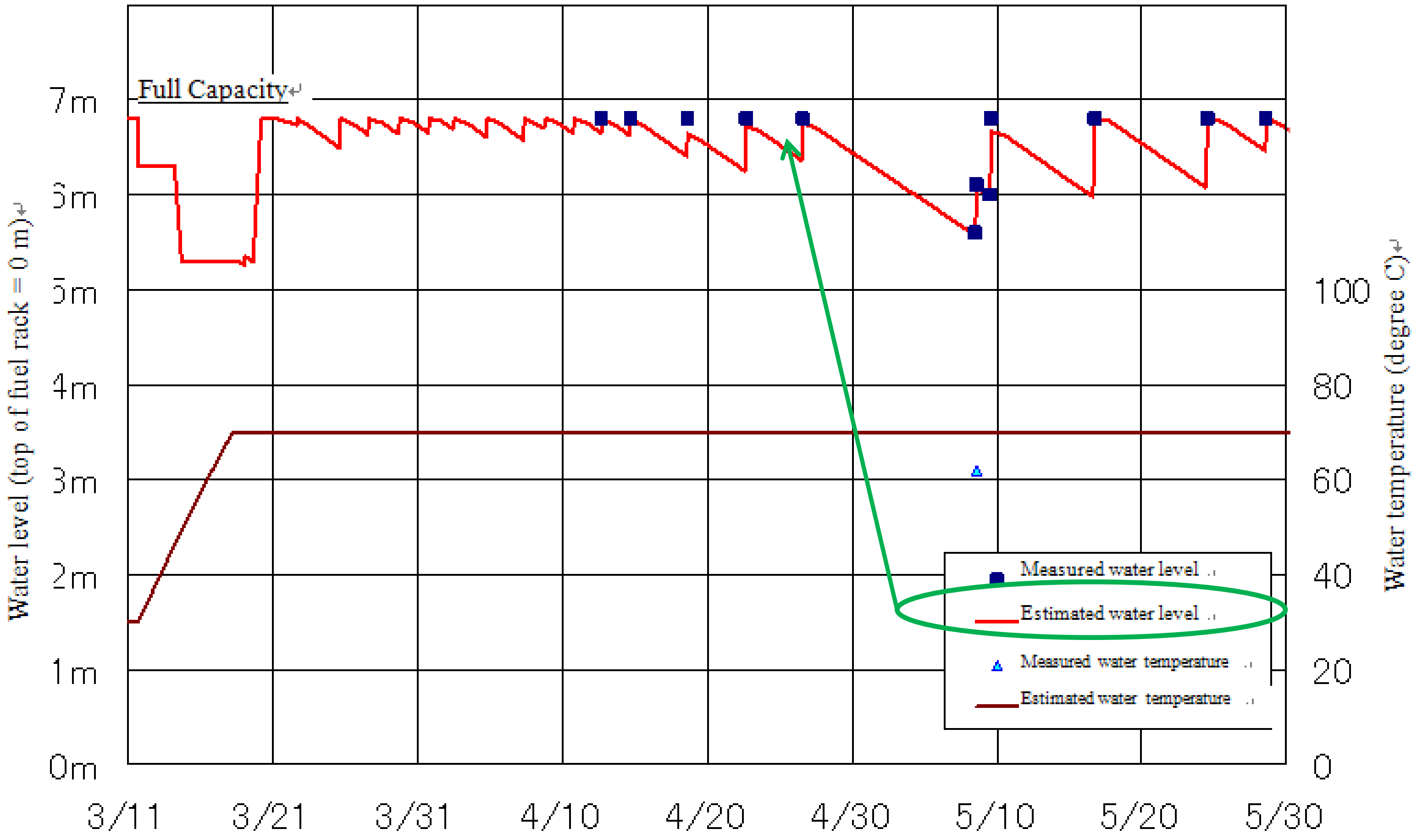
Unit 1: Spent Fuel Pool Evaluation Results



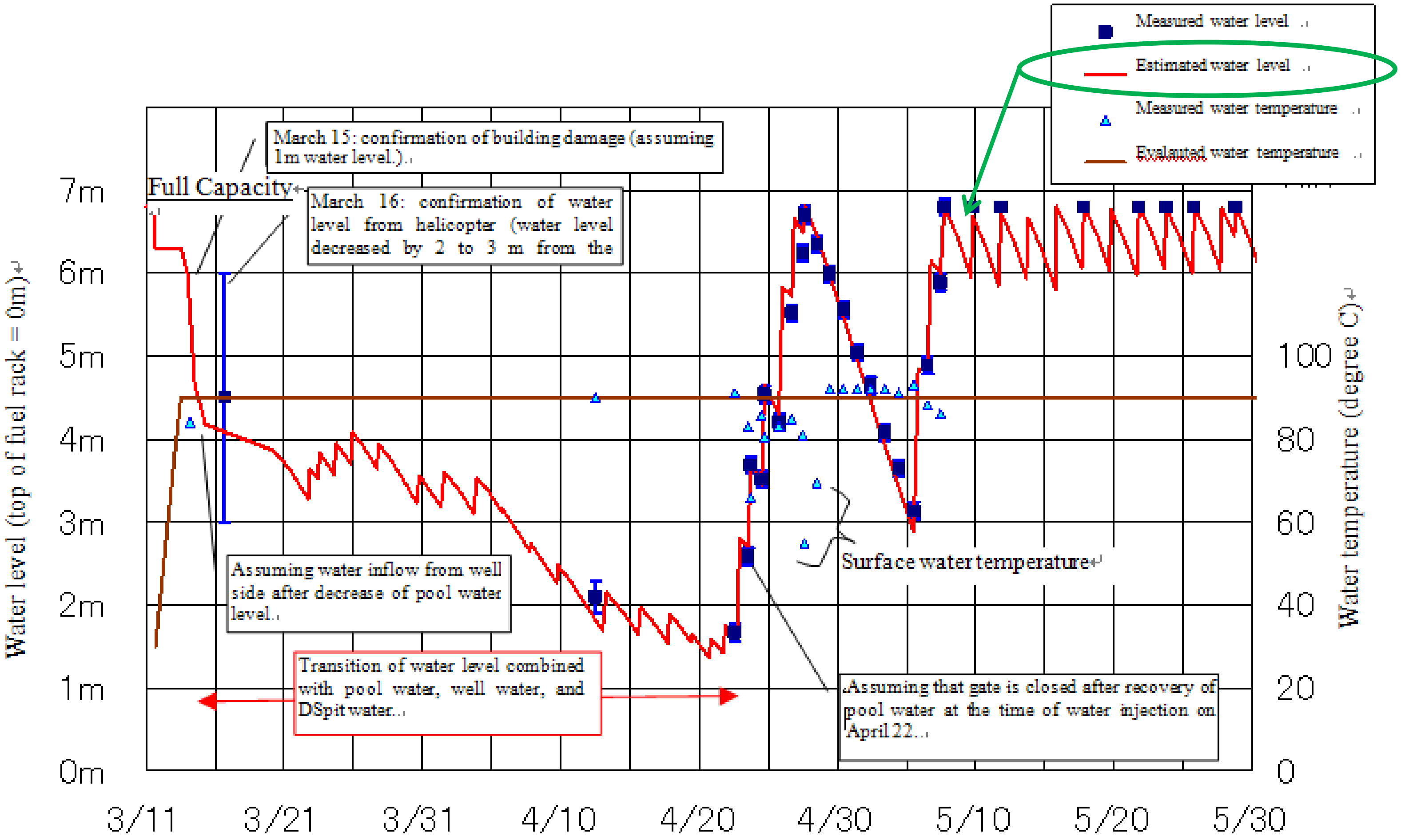
Unit 2: Spent Fuel Pool Evaluation Results



Unit 3: Spent Fuel Pool Evaluation Results



Unit 4: Spent Fuel Pool Evaluation Results



March 15: confirmation of building damage (assuming 1m water level.).

March 16: confirmation of water level from helicopter (water level decreased by 2 to 3 m from the

Assuming water inflow from well side after decrease of pool water level.

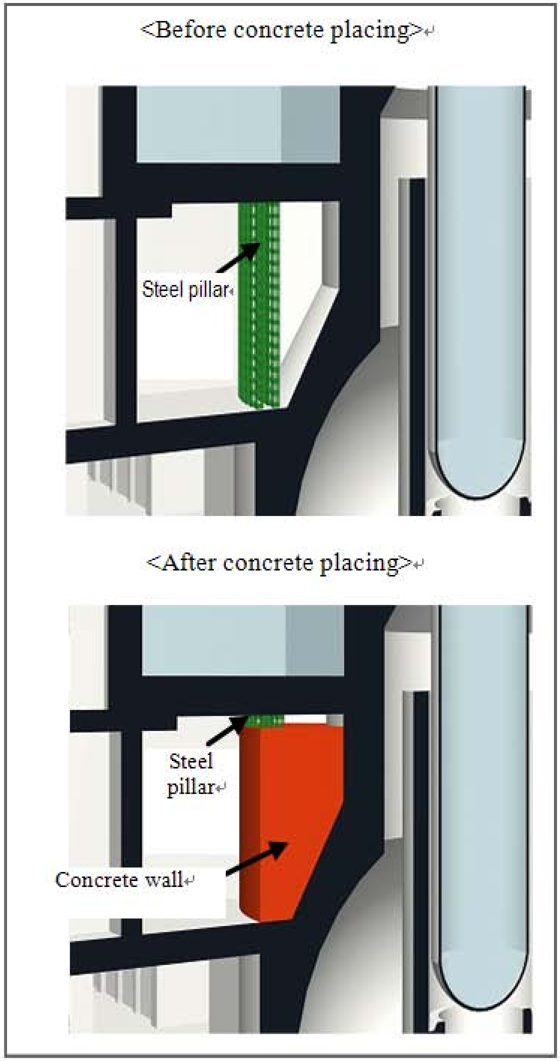
Transition of water level combined with pool water, well water, and DSpit water.

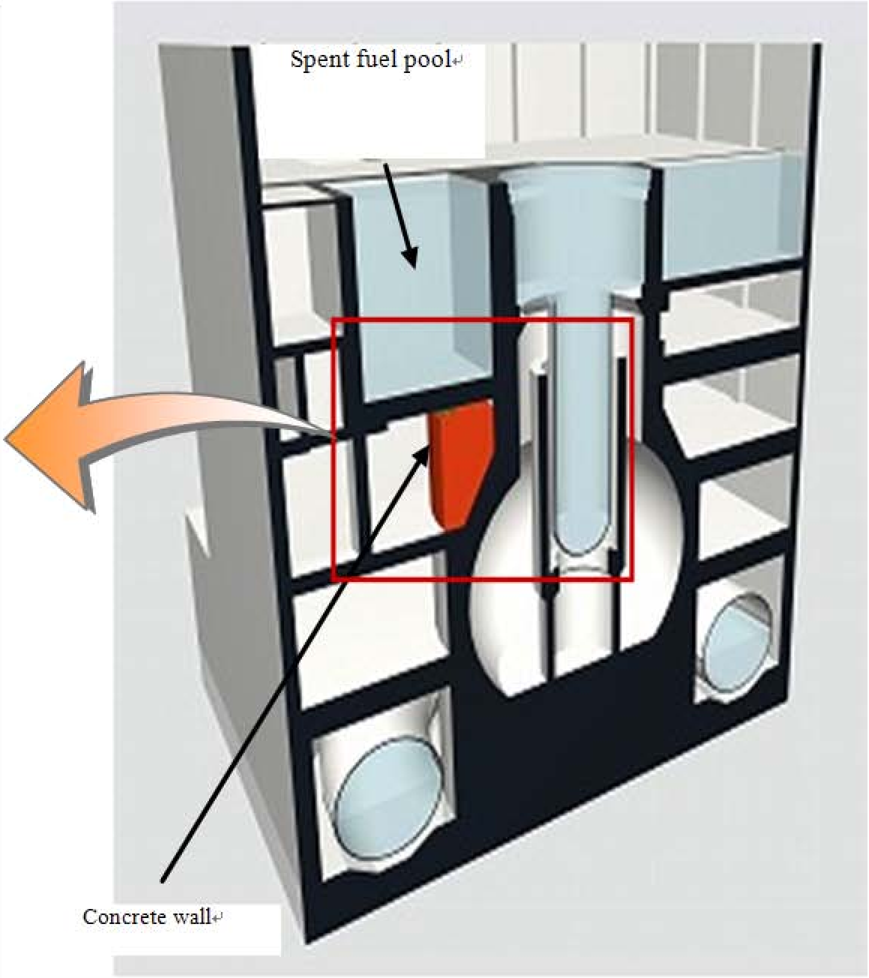
Assuming that gate is closed after recovery of pool water at the time of water injection on April 22.

Condition of the spent fuel pool (Unit 4)

Due to the analysis result of nuclides in the water extracted from the spent fuel pool using a concrete pump truck, it is assumed that no extensive damage in the fuel rods occurred.

Unit4（reinforcement of the bottom of the spent fuel pool）





Image

(4)Hydrogen explosion at the reactor buildings

［Hydrogen explosion occurred at the reactor buildings of the Unit 1 and the Unit 3.Hydrogen explosion occurred at the Unit 3 where there was no fuel in the reactor.］

Generation of hydrogen and its explosion (Unit 1 and Unit 3)

☐ Generation of hydrogen by the zirconium-water reaction due to rising of the temperature in the reactor

↓

☐ Leakage of hydrogen from the reactor to the PCV

↓

☐ Leakage of hydrogen from the PCV to the reactor building

↓

☐ Explosion of hydrogen accumulated at the upper part of the reactor building

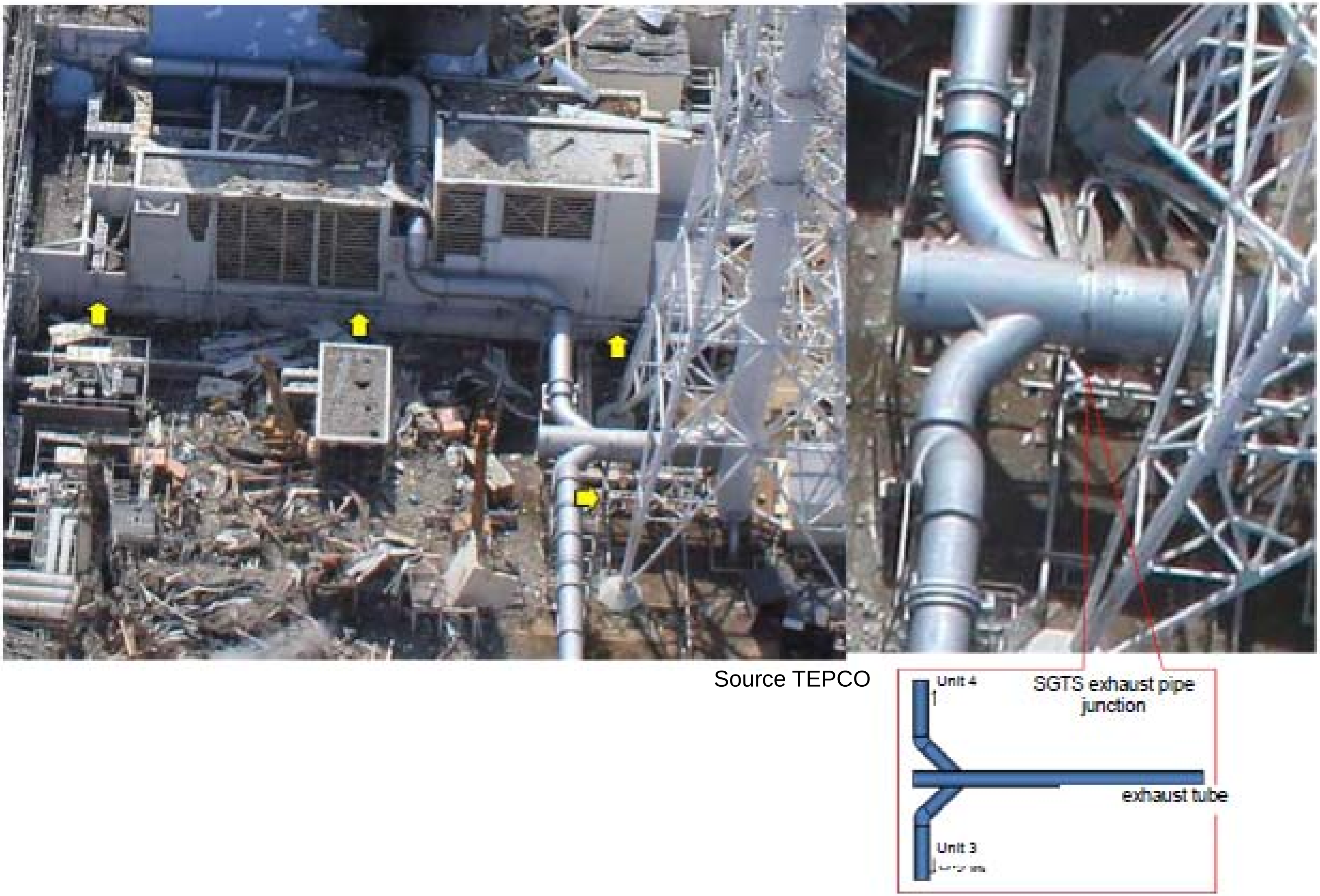
Occurrence of hydrogen explosion

- Unit 1 15:36 March 12: Hydrogen explosion in the reactor building

- Unit 3 11:01 March 14: Hydrogen explosion in the reactor building

- Unit 4 around 06:00 March 15: Explosion in the reactor building (**An inflow of hydrogen from Unit 3 may be possible**, as the exhaust pipe for venting the PCV joins the exhaust pipe from unit 4 before the exhaust.)

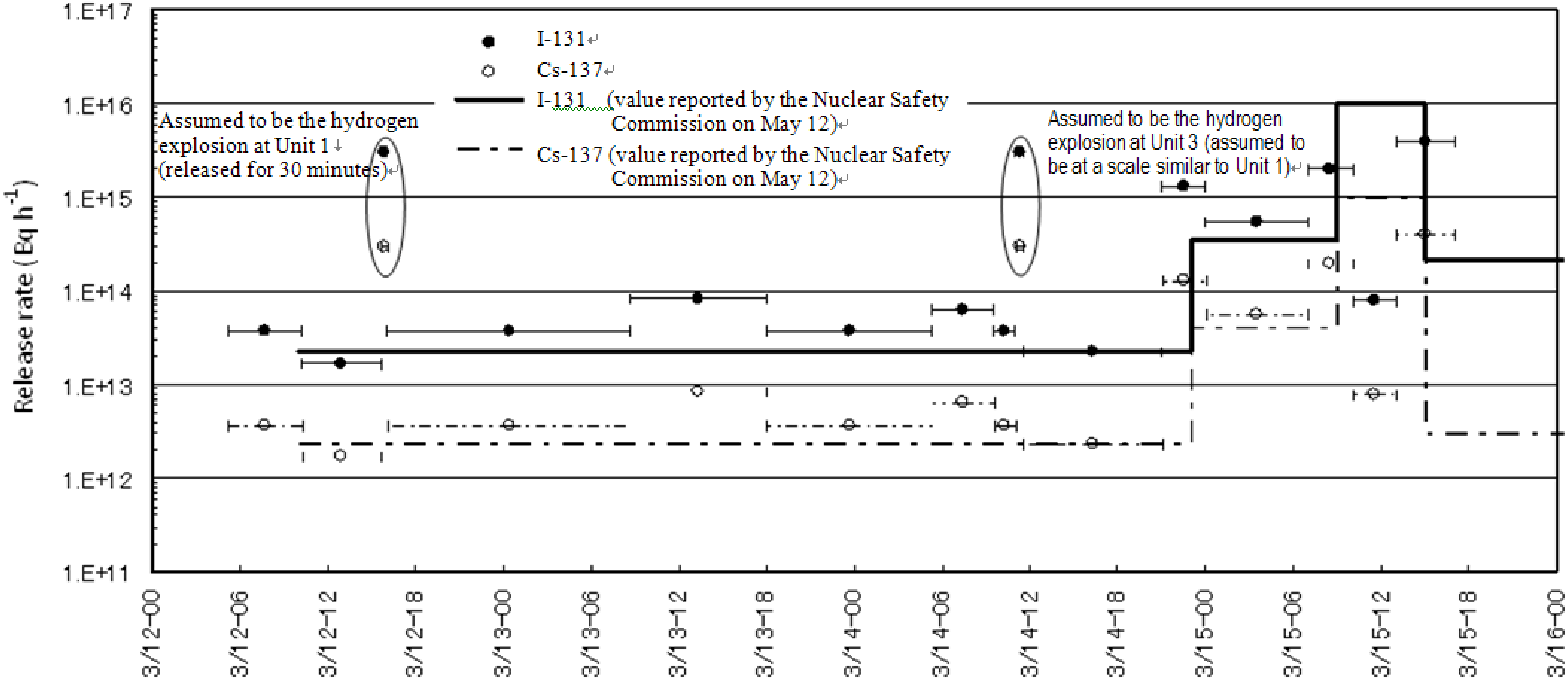
Standby Gas Treatment System exhaust pipe



Source TEPCO

3. Discharge of Radioactive Materials to the Environment

Release of Radioactive Materials: Initial Release Trends (Bq/h)



Release rate of radioactive materials

Fukushima Dai-ichi	Noble gases	Iodine	Other nuclides
Unit 1	Almost all	1%	Other nuclides: Less than 1%
Unit 2	Almost all	0.4%~7%	Tellurium: 0.4%~3% Cesium : 0.3%~6%
Unit 3	Almost all	0.4%~0.8%	Other nuclides: 0.3%~0.6%

Amounts of radioactive materials discharged to the atmosphere

Organization	I-131	Cs-137
NISA (JNES) (April)*	$1.3X10^{17}$	$6.1X10^{15}$
NISA (JNES) (May)*	$1.6X10^{17}$	$1.5X10^{16}$
NSC (JAEA)**	$1.5X10^{17}$	$1.2X10^{16}$

(Unit: Bq)

*NISA with assistance from JNES made this estimation based on the analysis of reactor status.

**NSC with assistance from JAEA made this estimation based on the data of environmental monitoring and air diffusion calculation.

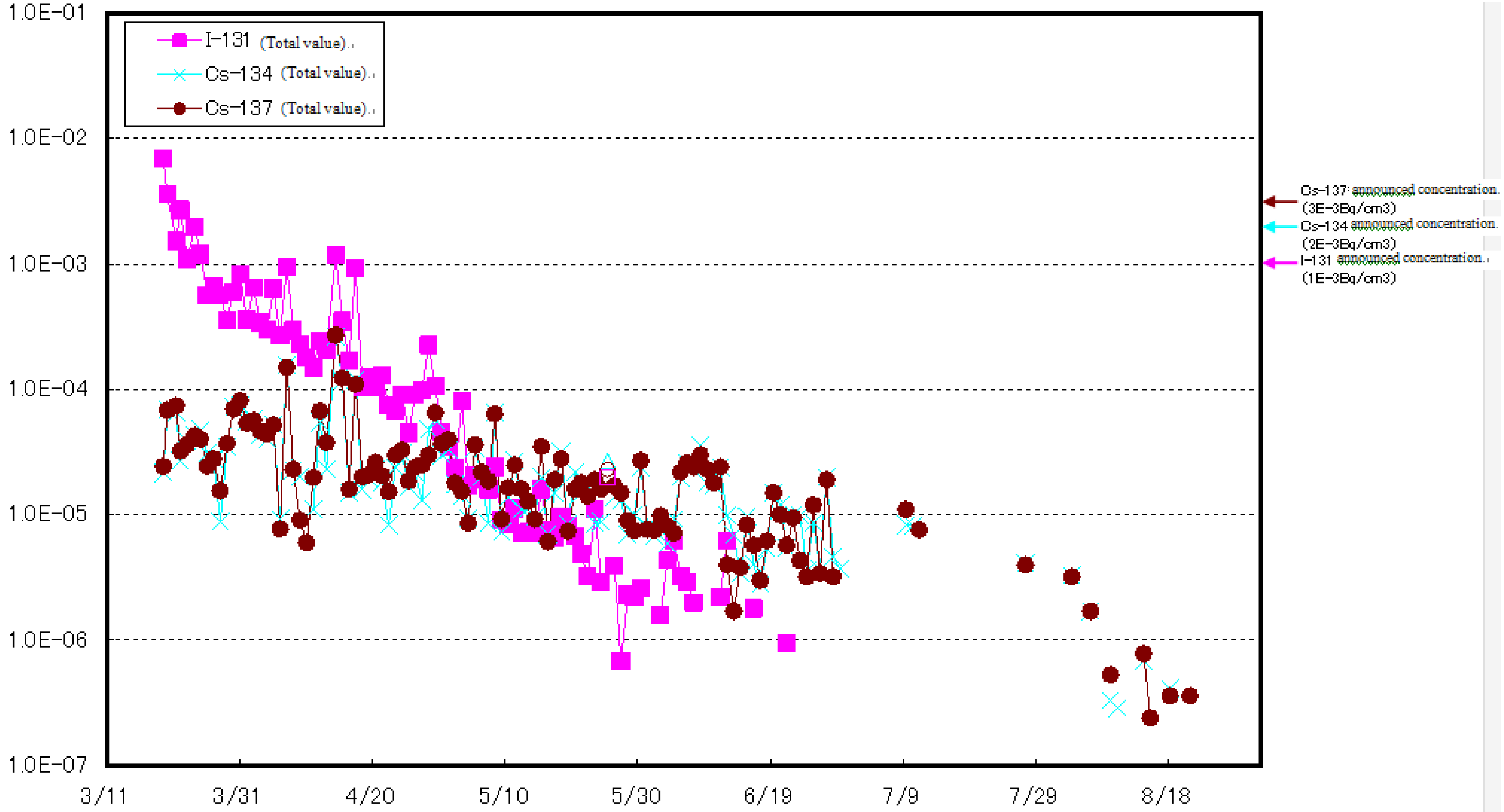
International Nuclear and Radiological Event Scale (INES)

- ☐ Evaluated amount of the release of radioactive materials to the atmosphere which exceeded 10^{16} Bq of iodine-131

↓

- ☐ Announcement of a provisional evaluation of Level 7 in the IENS scale

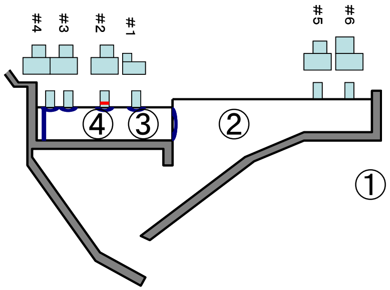
Fukushima Dai-ichi NPS: Trends in the Airborne Concentration of Radioactive Materials



Release of radioactive materials to the seawater

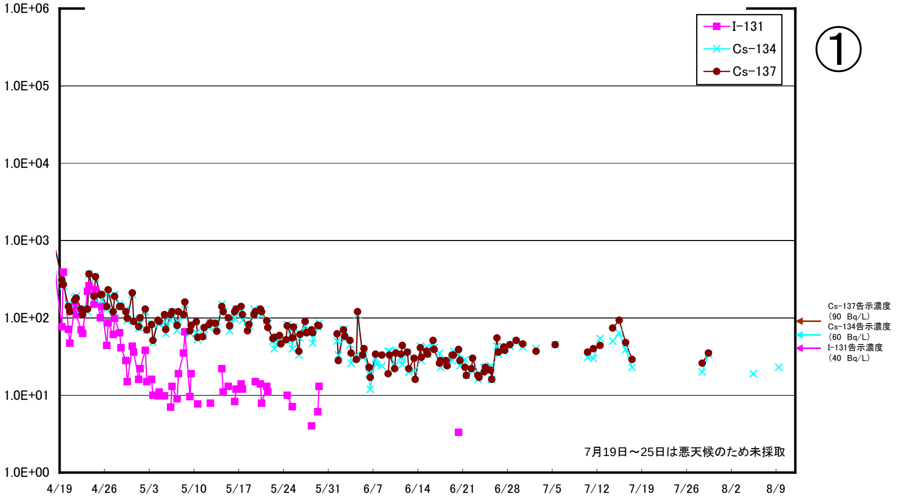
Events	Results	Remarks
Leakage from Unit2 (2 April -6April)	On April 2, it was discovered that highly contaminated water was flowing into the seawater from the crack on the lateral surface of the pit. Total discharged amount of the radioactive was assumed to be approximately 4.7 $X10^{15}$ Bq.	**[Countermeasures]** Drilled a hole into the pit and injected water glass (sodium silicate) into the pit.
Discharge to the sea (4 April-10 April)	In order to secure capacity for highly contaminated water, TEPCO discharged low-level radioactive water into the sea water. Total discharged amount was presumed to be approximately $1.5X10^{11}$ Bq.	The radioactive density monitored at the measurement points including near the power station did not indicate significant fluctuation in comparison with the trend one week before the discharge.
Leakage from Unit3 (11 May)	On May 11, TEPCO confirmed the outflow from a pit near the Intake Channel of Unit3 into the sea. Total amount can be estimated at $2.0X10^{13}$Bq.	**[Countermeasures]** • Inserting fabrics and filling concrete inside pit • Reconfirmation of other leakage possibilities • Strengthening the monitoring

Monitoring around the Fukushima Dai-ichi NPS



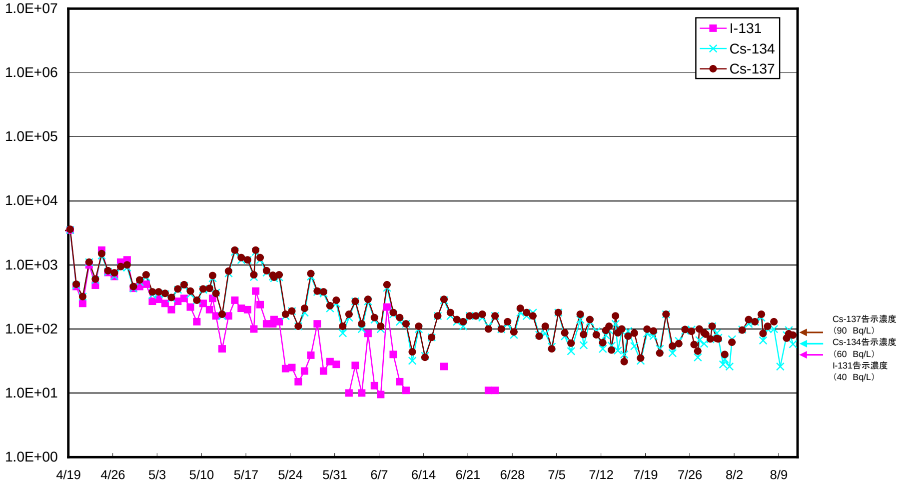
Northern Side of the Water Discharge Canal of 5 and 6

①



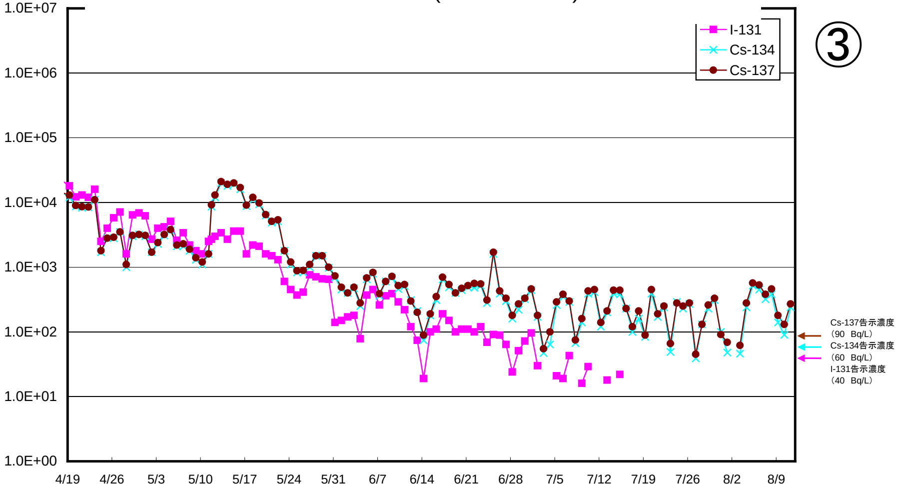
Near the Shallow Draft Quay

②



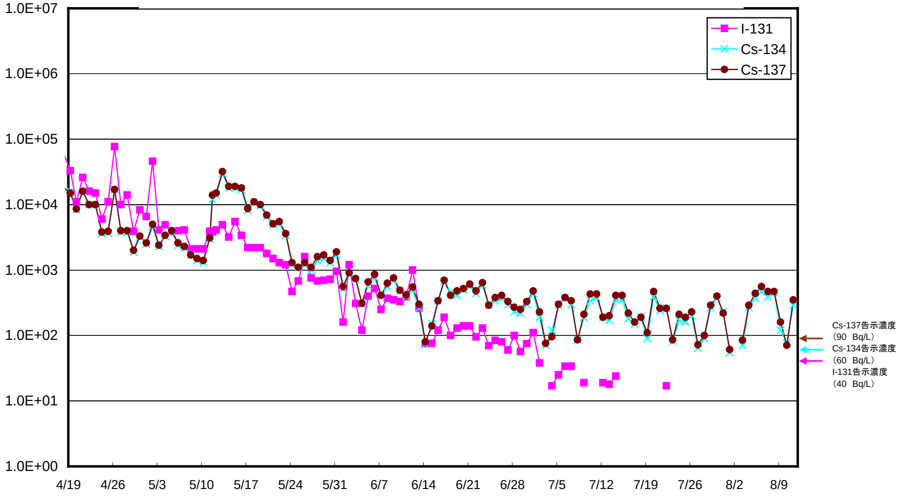
Inside the Water Intake Channel (Northern Side) for Units 1 to 4

③



At Unit 2 (Outside the Silt Fence)

④



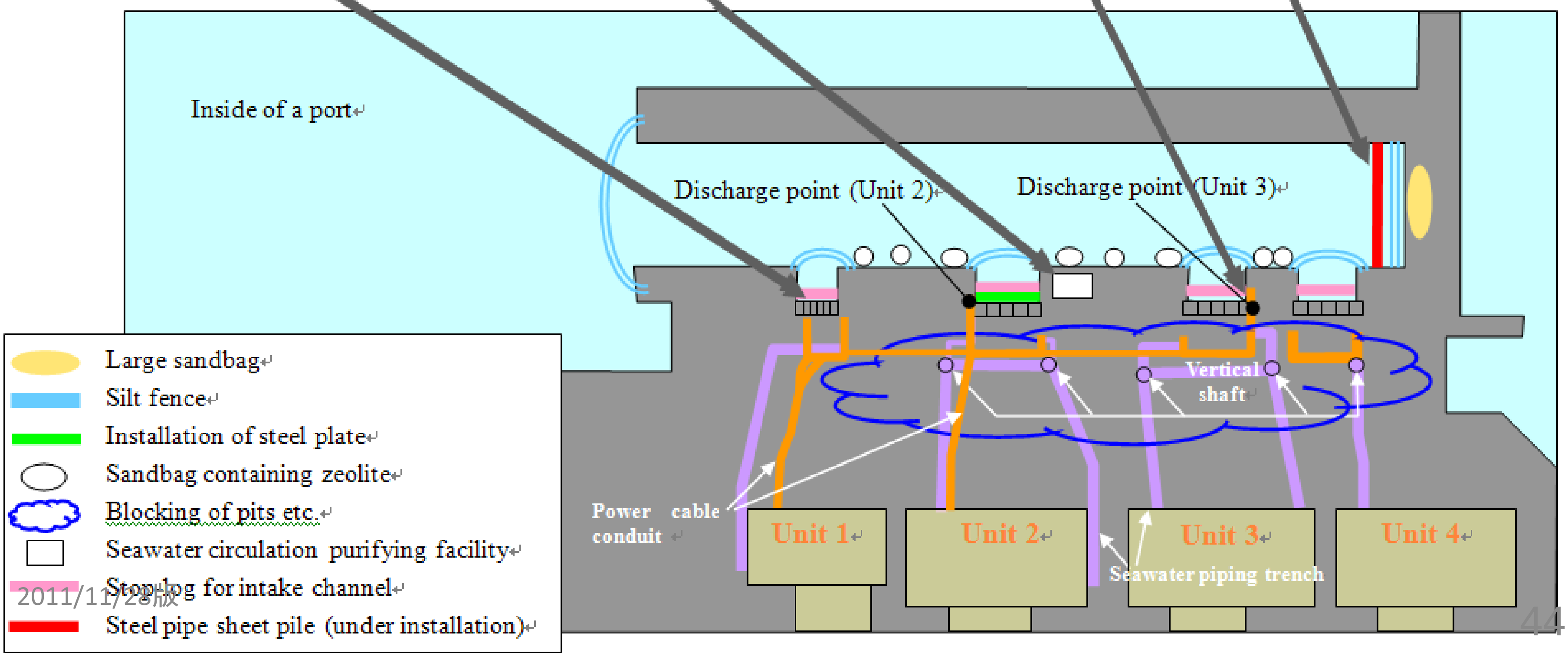
The state of enhancement measures to prevent contaminated water from flowing out and mixing with the sea


Photograph 1
Installation of Stop-Log


Photograph 2
Seawater Circulation Purifying Facility


Photograph 3
Blocking of Pits etc.


Photograph 4
Steel Pipe Sheet Pile (Example)



4. Radiation exposure of the workers

Workers

- Revision of dose limit in emergencies based on the accident (March 14)
  - 100mSv → 250mSv
    - ICRP 1990 Recommendations were taken into consideration.

- Radiation control measures by the operators after the accident
  - Many APDs* became unusable due to tsunami.
    - TEPCO made leaders of operational group wear APDs on behalf of the entire group.
    - On April 14, TEPCO resumed the previous system.

- System of radiation control measures in J Village
  - From March 17, J Village was utilized as a place for preparing workers for entry into Fukushima Dai-ichi NPS.

* ADP: Alarm Pocket Dosimeter

The Status of Radiation Exposure for Workers

(1) Radiation exposure doses for workers (external and internal doses)

March (average 22.4 mSv of 3,715 workers)

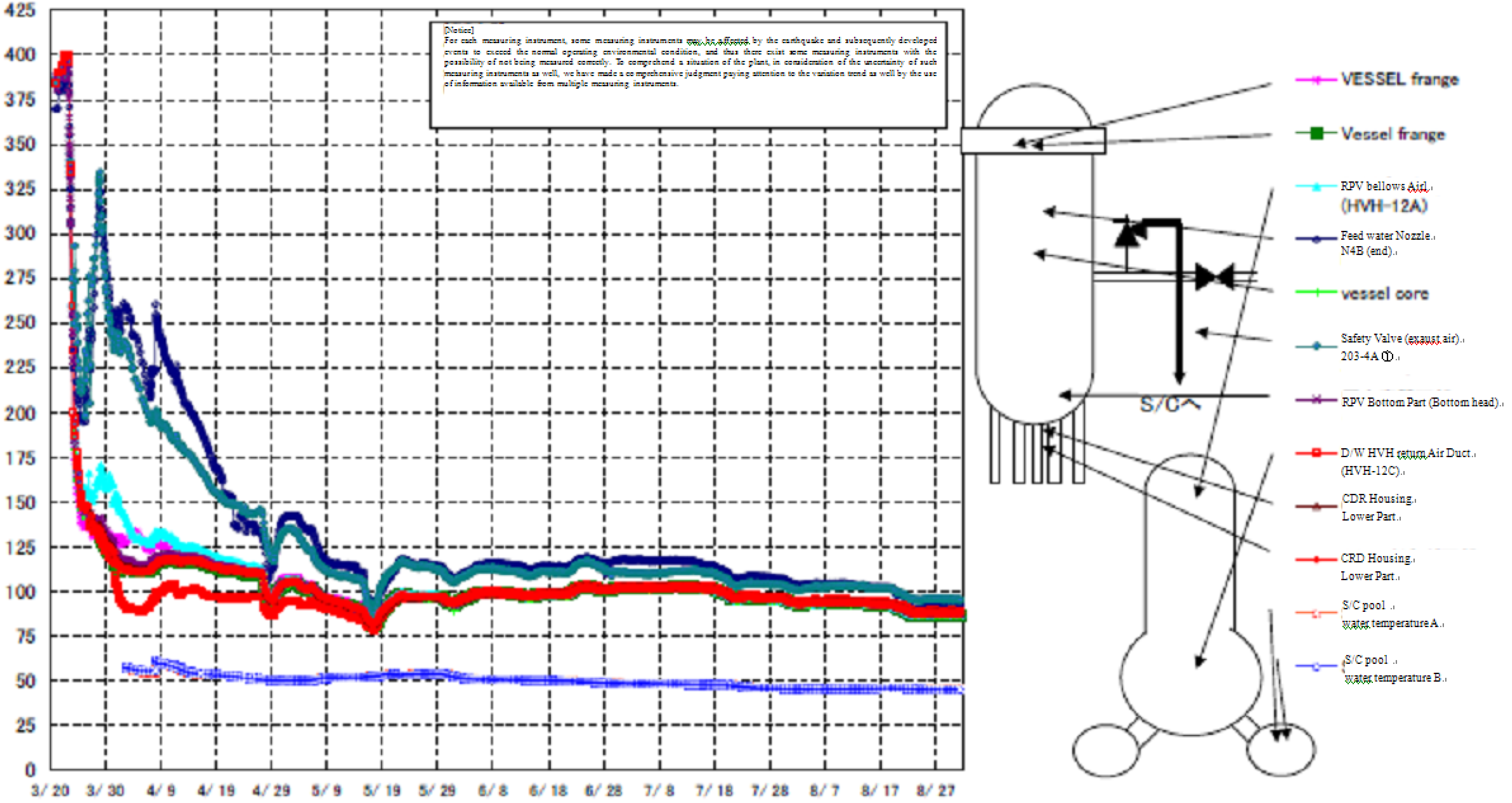
April (average 3.9 mSv of 3,463 workers)

May (average 3.1 mSv of 2,721 workers)

(2) In March, there were six workers whose exposure dose exceeded the 250 mSv emergency dose limit for workers (among them, the maximum exposure dose was approximately 670 mSv).

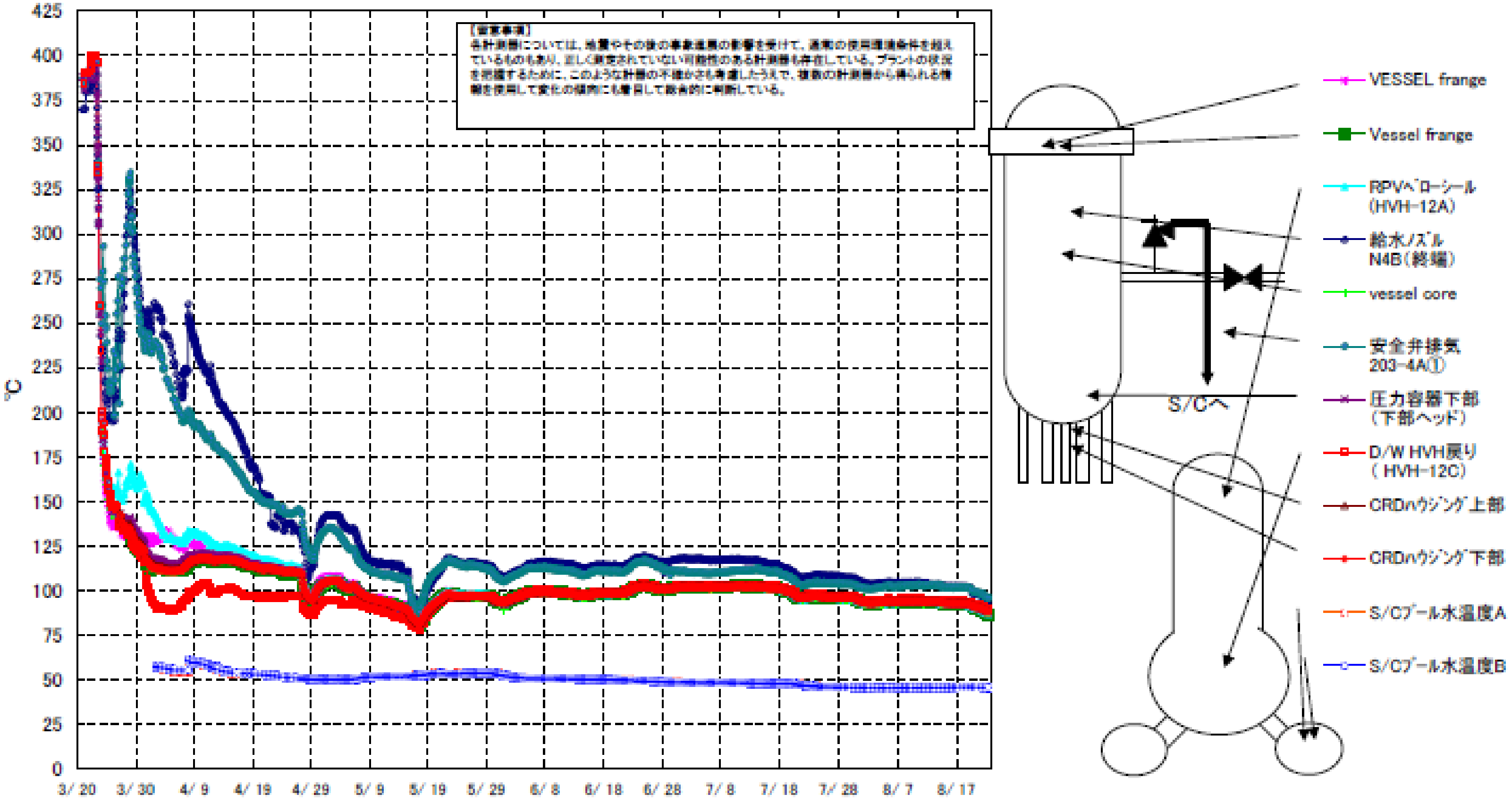
5. Settlement of the accident

Unit 1: Reactor Pressure Vessel (RPV) Temperature Transition



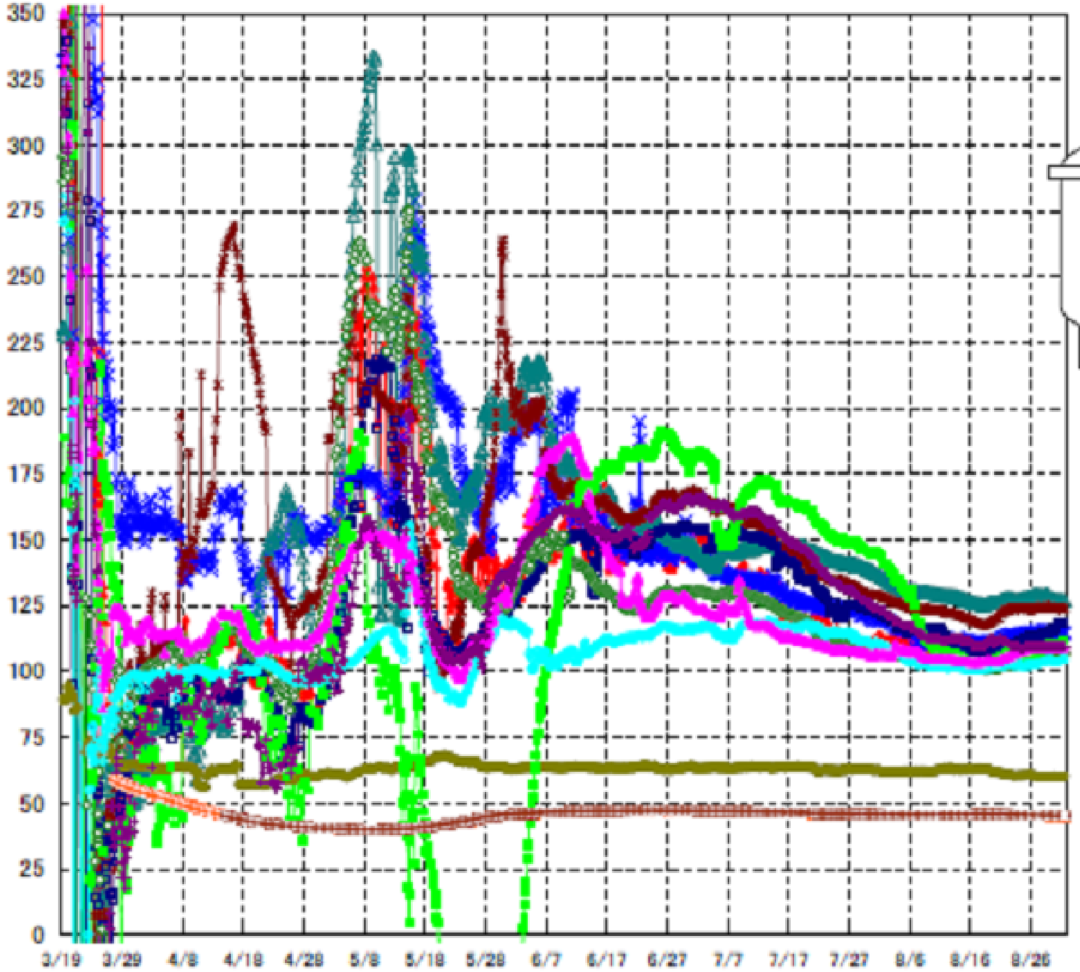
[Notice]
For each measuring instrument, some measuring instruments may be affected by the earthquake and subsequently developed events to exceed the normal operating environmental condition, and thus there exist some measuring instruments with the possibility of not being measured correctly. To comprehend a situation of the plant, in consideration of the uncertainty of such measuring instruments as well, we have made a comprehensive judgment paying attention to the variation trend as well by the use of information available from multiple measuring instruments.

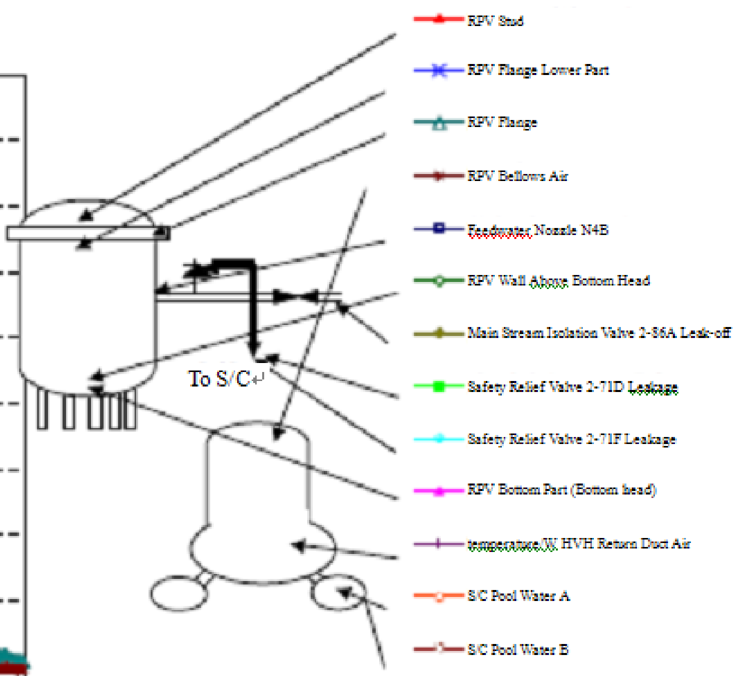
Unit 2: RPV Temperature Transition



【留意事項】
各計測器については、地震やその後の事象進展の影響を受けて、通常の使用環境条件を超えているものもあり、正しく測定されていない可能性のある計測器も存在している。プラントの状況を把握するために、このような計器の不確かさも考慮したうえで、複数の計測器から得られる情報を使用して変化の傾向にも着目して総合的に判断している。

Unit 3: RPV Temperature Transition





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Steps for settlement of the accident

- Step 1 (stead decline of radiation dose etc.)
  →achievement on 19 July

↓

- Step 2 (cold shutdown of reactors etc.)
  →on-going(Achievement is aimed by the end of this year.）

↓

- Mid-term targets(sweeping away of the debris etc.)

Main Issues in Step 2

Target: “the release of radioactive materials is under control and the radiation dose is being significantly held down,”

(1) Issue 1

Cooling the reactors: Evaluation of necessary flow rate of injecting water to achieve “cold shutdown condition”.

(2) Issue 2

Cooling the spent fuel pools: Achieving more stable cooling in all of the Units 1 through 4.

(3) Issue 3

Treating accumulated water: Decreasing the total amount of accumulated water and increasing the treatment volume to increase the water injection into the reactors.

(4) Issue 4

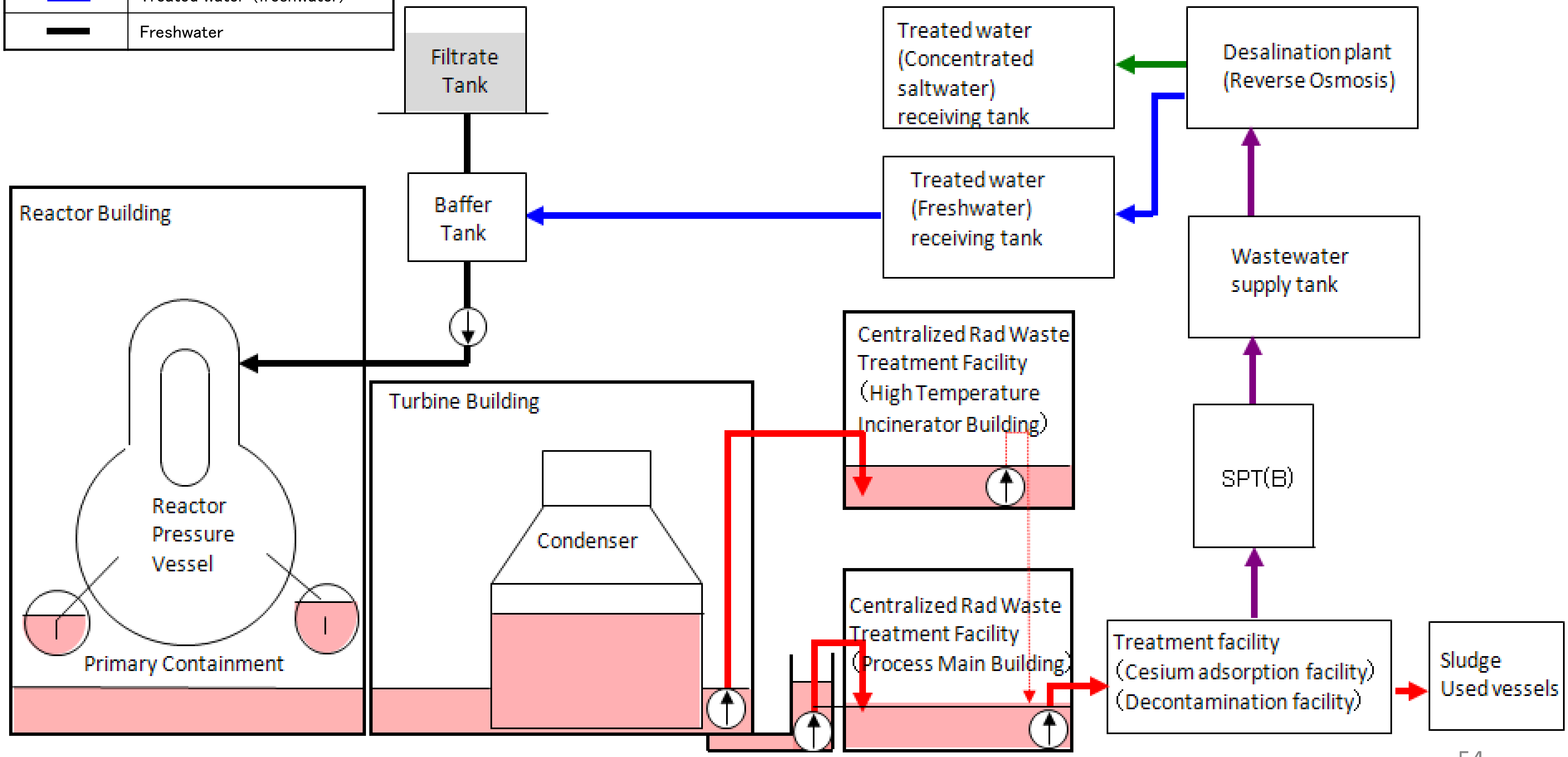
Shielding groundwater: Preventing the spread of contamination into the sea.

(5) Issue 5

Preventing the spread of radioactive materials in the atmosphere/soil: Mitigation of release of radioactive materials.

Storage and treatment of high level radioactive accumulated water

	Lines
🟥	High level radioactive water
🟪	Treated water（saltwater）
🟩	Treated water（concentrated saltwater）
🟦	Treated water（freshwater）
⬛	Freshwater



Filtrate Tank

Baffer Tank

Reactor Building

Reactor Pressure Vessel

Primary Containment

Turbine Building

Condenser

Treated water (Concentrated saltwater) receiving tank

Treated water (Freshwater) receiving tank

Desalination plant (Reverse Osmosis)

Wastewater supply tank

SPT(B)

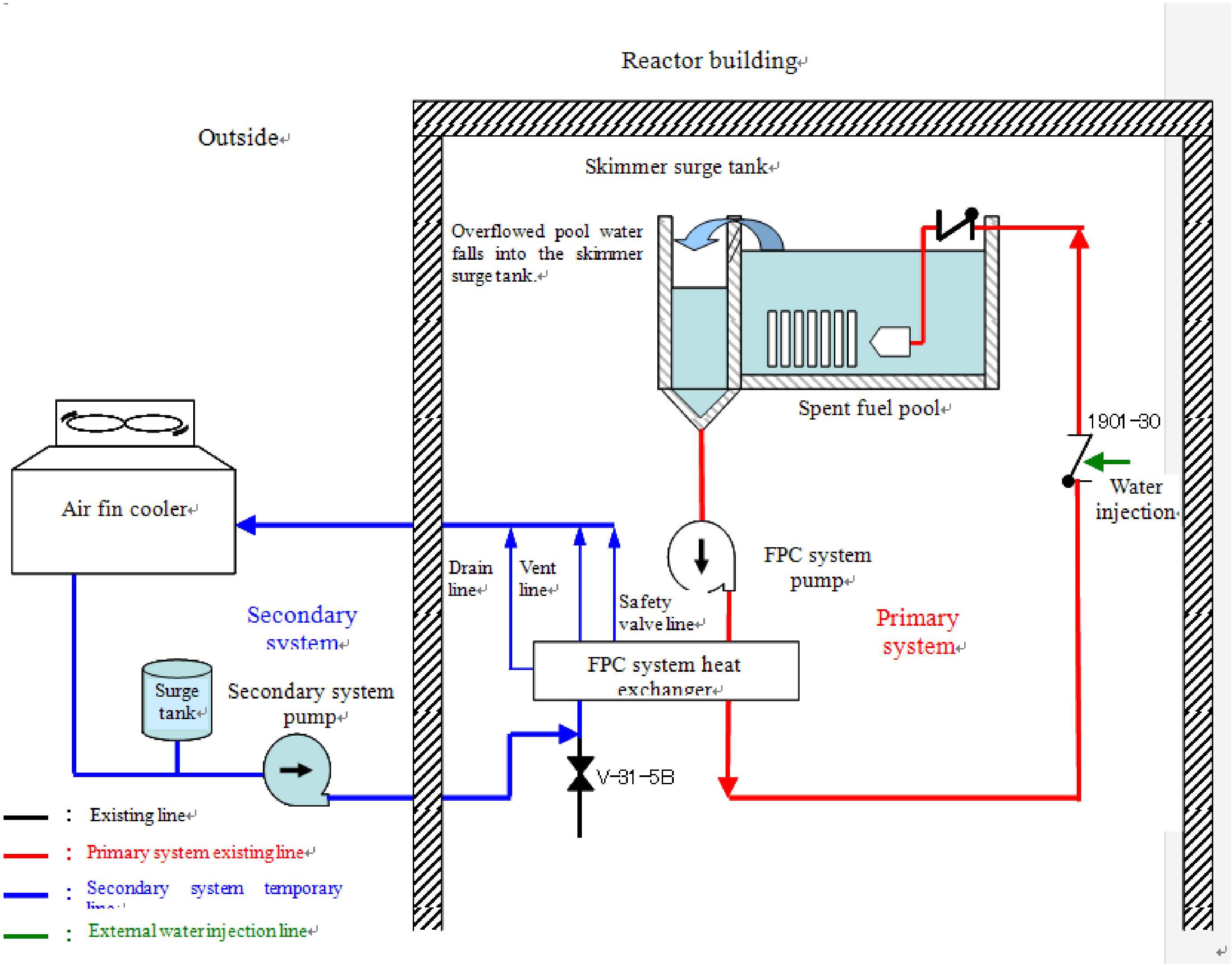
Centralized Rad Waste Treatment Facility（High Temperature Incinerator Building）

Centralized Rad Waste Treatment Facility（Process Main Building）

Treatment facility（Cesium adsorption facility）（Decontamination facility）

Sludge Used vessels

Spent Fuel Pool: Alternative Cooling System (Unit 1)



6. Plans for the NPS site after restoration from the accident

Plan for the NPS site

☐ To identify the leak path at the PCV , to repair the leak path , and to develop necessary technology

↓

☐ To flood water into the PCV etc.

↓

☐ To take out the melted fuel and damaged fuel

↓

☐ To decommission the RPV, PCV etc.

Identification of challenges

- Mid-term challenges
  - management of the groundwater on the site
  - integrity management of buildings and equipment
  - construction of reactor building containers
  - the removal of spent fuel from the spent fuel pools

- Long-term challenges
  - the reconstruction of primary containment boundaries
  - extraction and storage of debris
  - management and disposal of radioactive waste, and decommissioning.

Identification of technical challenges and corresponding research and development

(example)

☐ Technical challenges

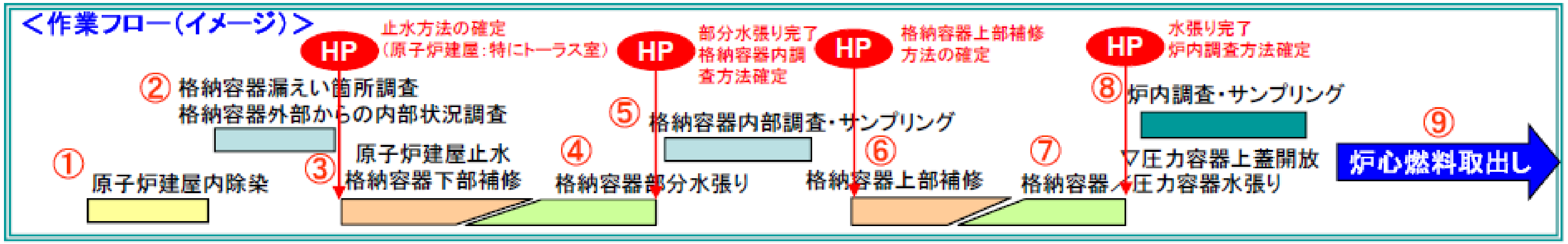
- the development of engineering and construction methods to locate the leakage points of the PCVs and then repairing them to stop water, thereby enabling the PCVs to be filled with water after the construction of boundaries

☐ Research and development

- the development of robots for remote inspection around the PCVs and for repairs
- the development of engineering and construction methods for repairing assumed leakage points to prevent water from escaping

Image of work flow to take out fuels in the reactor(1/3)

炉心燃料取出しに向けた作業フローイメージ（1／3）



＜作業フロー（イメージ）＞

HP 止水方法の確定（原子炉建屋：特にトーラス室）

HP 部分水張り完了 格納容器内調査方法確定

HP 格納容器上部補修方法の確定

HP 水張り完了 炉内調査方法確定

① 原子炉建屋内除染

② 格納容器漏えい箇所調査 格納容器外部からの内部状況調査

③ 原子炉建屋止水 格納容器下部補修

④ 格納容器部分水張り

⑤ 格納容器内部調査・サンプリング

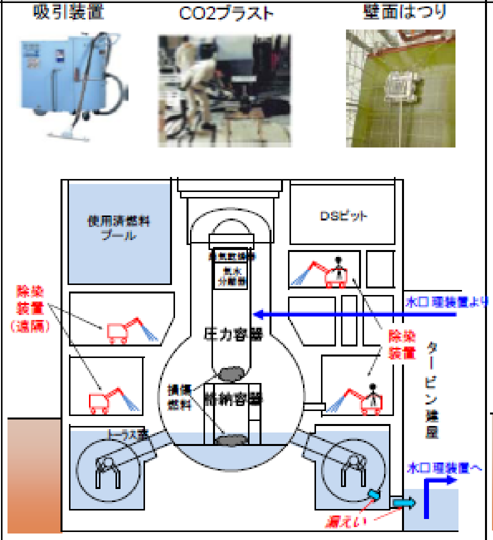
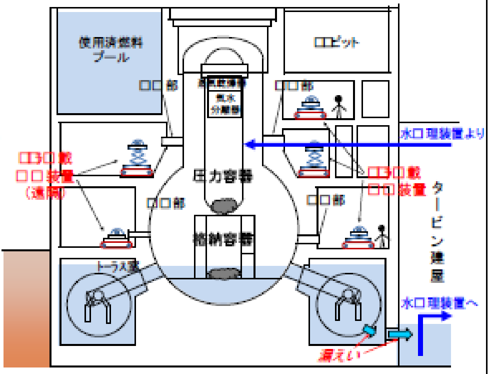
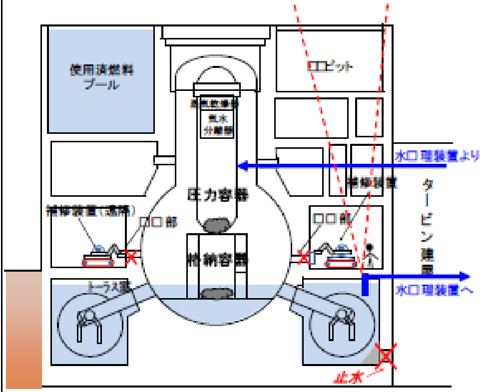
⑥ 格納容器上部補修

⑦ 格納容器／圧力容器水張り

⑧ 炉内調査・サンプリング

▽圧力容器上蓋開放

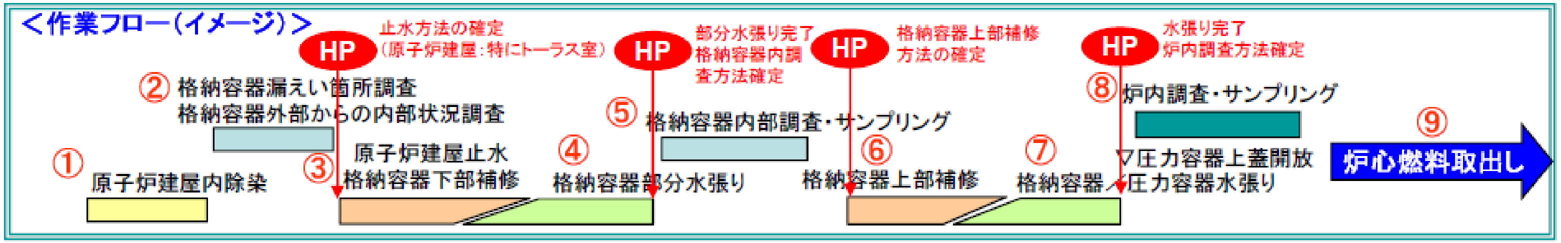
⑨ 炉心燃料取出し

フロー	① 原子炉建屋内除染	② 格納容器漏えい箇所調査 格納容器外部からの内部状況調査	③ 原子炉建屋止水 格納容器下部補修
イメージ			原子炉建屋止水後は、循環注水冷却の取水源をタービン建屋滞留水からトーラス室に変更 
内容	格納容器へのアクセス性を向上するため、高圧水、コーティング、表面はつり等により、作業エリアを除染。	格納容器及び原子炉建屋の漏えい箇所を、手動または遠隔の線量測定やカメラ等で調査。また、格納容器外部からγ線測定、音響調査等により、格納容器内部の状況を推定調査。	損傷した燃料の取り出し作業は、水中で実施することが最も合理的と考えられることから、格納容器の漏えい箇所を補修・止水。まずは格納容器内調査に向け、下部を優先して実施。
技術開発課題	・放射線量が高い箇所について、遠隔除染方法等の検討が必要。	・漏えい箇所調査方策・装置の開発 ・格納容器外部からの内部調査方策・装置の開発	・格納容器及び原子炉建屋の漏えい箇所の補修・止水技術・工法の開発 ・代替方策の検討・開発

※現時点で最も合理的な方策を記載。今後の技術開発成果によって適宜見直していくことが必要。

Image of work flow to take out fuels in the reactor(2/3)

炉心燃料取出しに向けた作業フローイメージ（2／3）



＜作業フロー（イメージ）＞

HP 止水方法の確定（原子炉建屋：特にトーラス室）

HP 部分水張り完了 格納容器内調査方法確定

HP 格納容器上部補修方法の確定

HP 水張り完了 炉内調査方法確定

① 原子炉建屋内除染

② 格納容器漏えい箇所調査 格納容器外部からの内部状況調査

③ 原子炉建屋止水 格納容器下部補修

④ 格納容器部分水張り

⑤ 格納容器内部調査・サンプリング

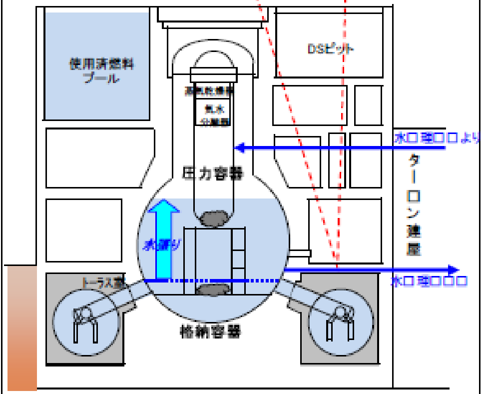
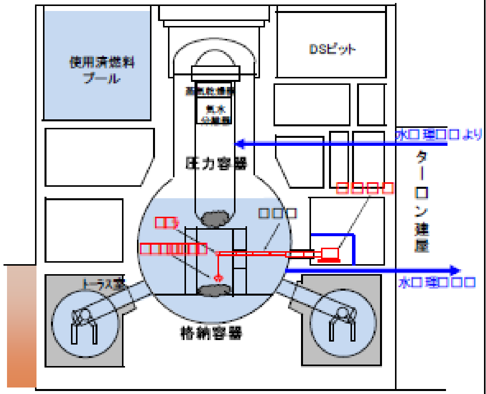
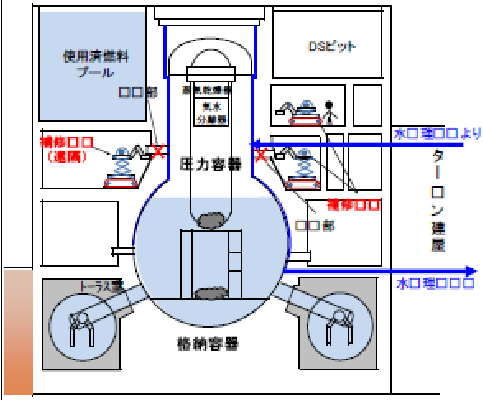
⑥ 格納容器上部補修

⑦ 格納容器／圧力容器水張り

▽圧力容器上蓋開放

⑧ 炉内調査・サンプリング

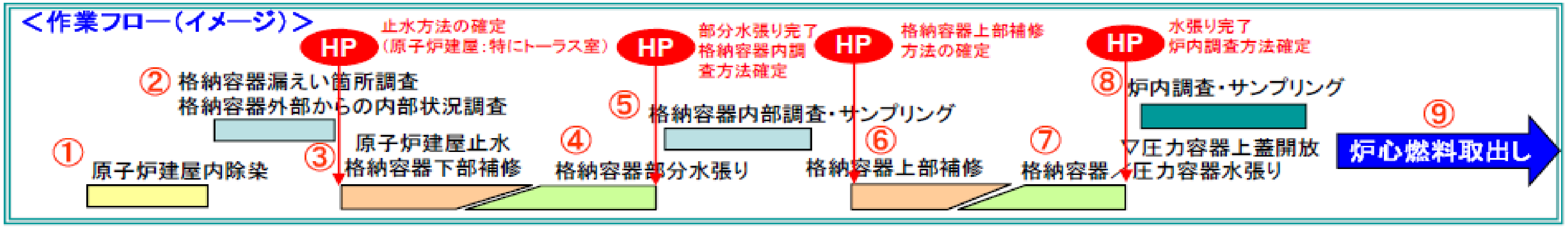
⑨ 炉心燃料取出し

フロー	④ 格納容器部分水張り	⑤ 格納容器内部調査・サンプリング	⑥ 格納容器上部補修
イメージ	格納容器下部のバウンダリ構築後は、循環注水冷却の取水源をトーラス室から格納容器に変更  	 	
内容	格納容器内部調査の開始に向け、格納容器下部に部分的な水張りを実施。	格納容器内を調査し、圧力容器から流れ出たと推定される破損燃料の分布状況の把握、サンプリング等を実施。	格納容器を満水まで水張りすべく、上部の漏えい箇所を、手動または遠隔にて補修。
技術開発課題	格納容器下部のバウンダリ構築（トーラス室にグラウト充てんする案も含む）が大前提	高線量である格納容器内の遠隔調査方法及びサンプリング方法の開発	格納容器漏えい箇所の補修・止水技術・工法の開発（③と同様）

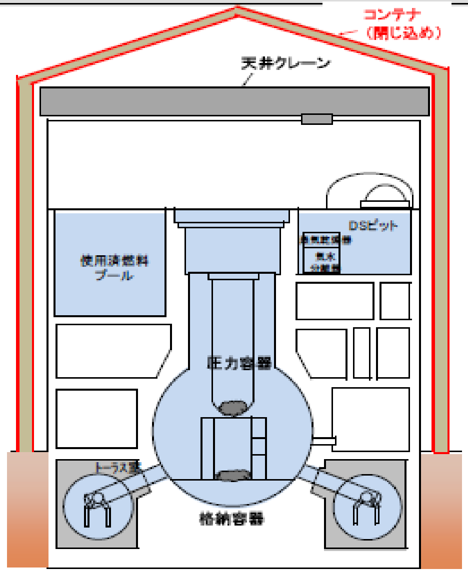
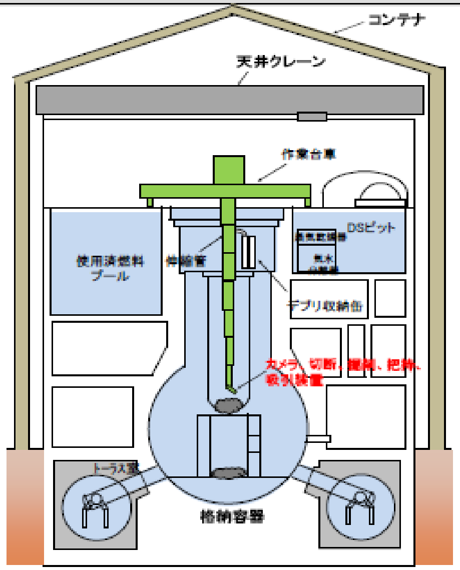
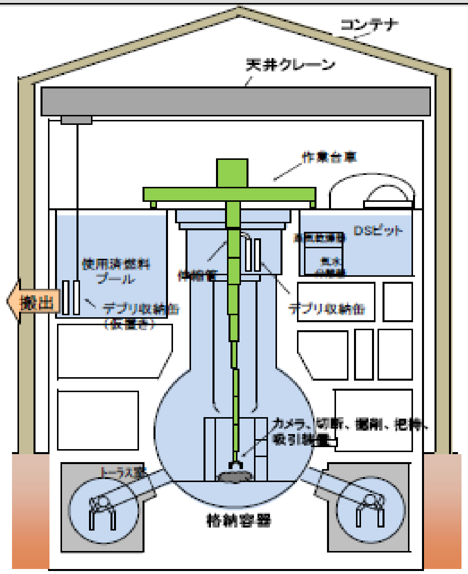
※現時点で最も合理的な方策を記載。今後の技術開発成果によって適宜見直していくことが必要。

Image of work flow to take out fuels in the reactor(3/3)

炉心燃料取出しに向けた作業フローイメージ（3／3）



＜作業フロー（イメージ）＞

フロー	⑦ 格納容器／圧力容器水張り ⇒ 圧力容器上蓋開放	⑧ 炉内調査・サンプリング	⑨ 炉心燃料取出し
イメージ			
内容	十分遮へいが担保できる水位まで格納容器／圧力容器を水張り後、圧力容器上蓋を取り外し。（閉じ込め性担保のため、上蓋取り外し前には本格コンテナを完成）	炉内を調査し、破損燃料や炉内構造物の状態把握、サンプリング等を実施、	圧力容器／格納容器内の損傷燃料の取り出しを実施。
技術開発課題	（⑥により格納容器バウンダリ構築が大前提）	高線量である炉内の遠隔調査方法及びサンプリング方法の開発	TMIに比べ、より高度な取り出し技術・工法の開発

※現時点で最も合理的な方策を記載。今後の技術開発成果によって適宜見直していくことが必要。

Chapter 2 Effects of the accident and countermeasures

1．Emergency responses for residents

2．Health management for residents

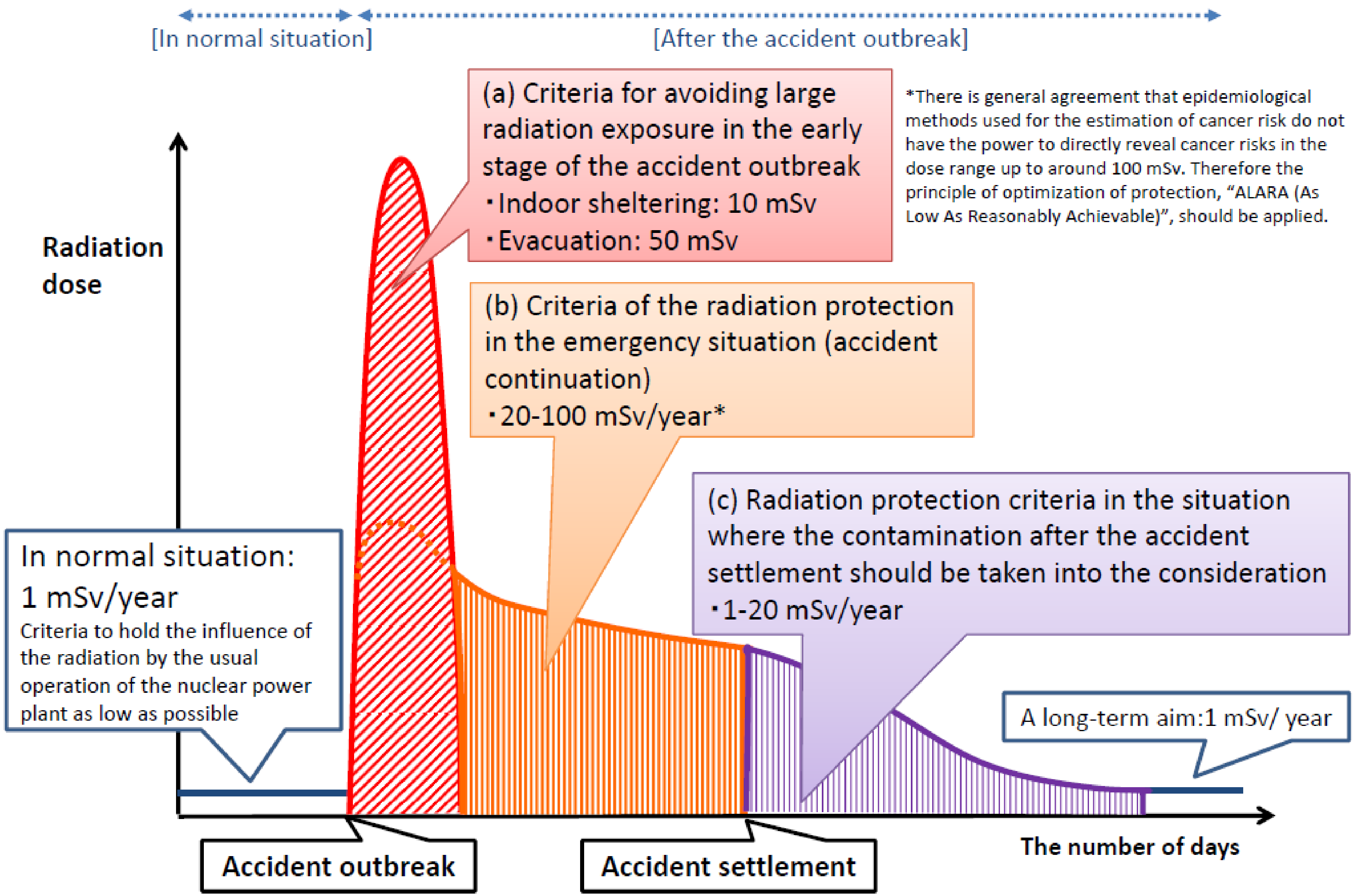
3．Measures for agricultural products and drinking water

4．Measures for remediation at off-site

5．Nuclear liability

1. Emergency responses for residents

The idea of the criteria of the radiation dose for the radiation protection



[In normal situation]

[After the accident outbreak]

(a) Criteria for avoiding large radiation exposure in the early stage of the accident outbreak

- Indoor sheltering: 10 mSv
- Evacuation: 50 mSv

*There is general agreement that epidemiological methods used for the estimation of cancer risk do not have the power to directly reveal cancer risks in the dose range up to around 100 mSv. Therefore the principle of optimization of protection, "ALARA (As Low As Reasonably Achievable)", should be applied.

(b) Criteria of the radiation protection in the emergency situation (accident continuation)

- 20-100 mSv/year*

(c) Radiation protection criteria in the situation where the contamination after the accident settlement should be taken into the consideration

- 1-20 mSv/year

In normal situation:
1 mSv/year
Criteria to hold the influence of the radiation by the usual operation of the nuclear power plant as low as possible

A long-term aim:1 mSv/ year

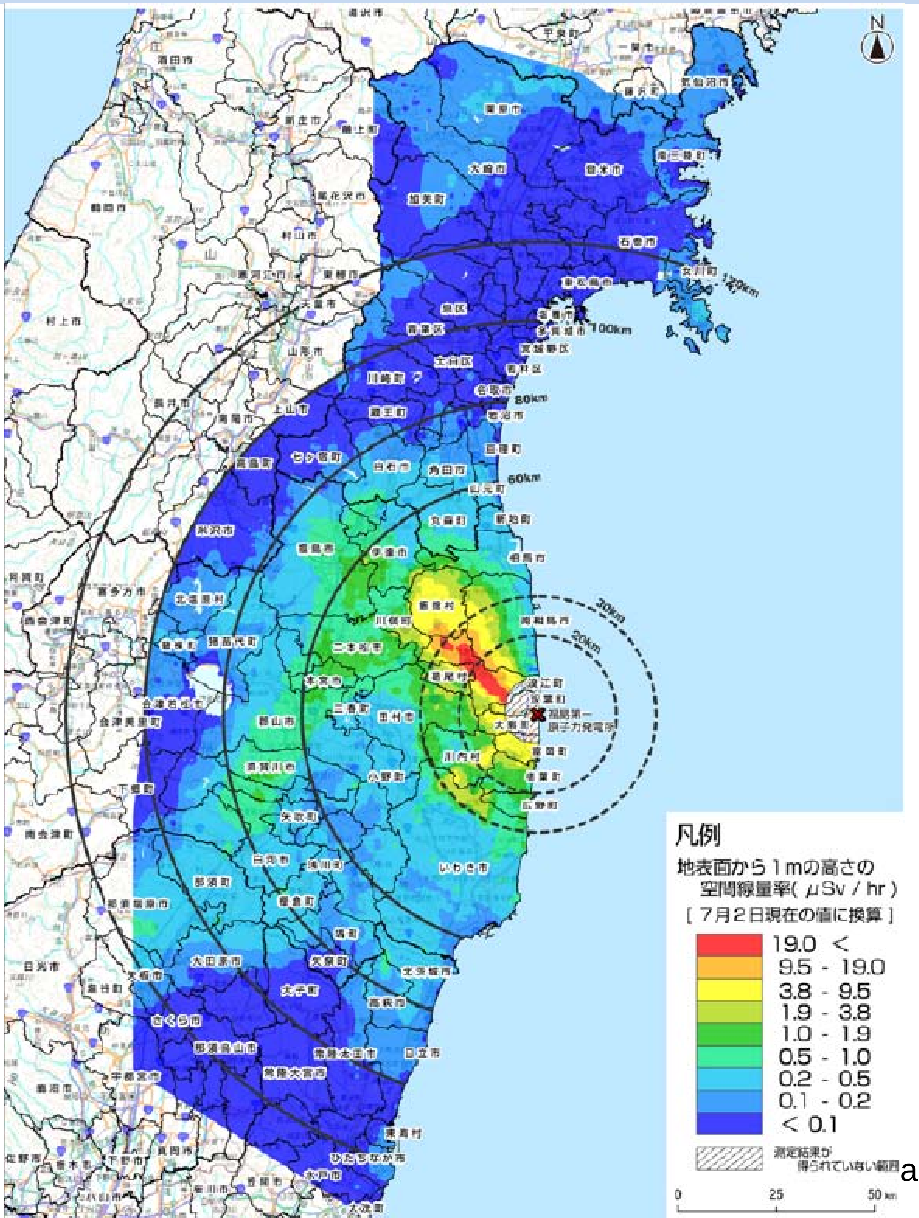
Authority of the radiation dose standard

Standard for the radiation dose	Authority
(1)Integrated radiation dose in the normal situation. • Public radiation exposure dose limit. 1 mSv/year	• Notice of Ministry of Economy, Trade and Industry • "Public notices which provides the dose limit based on the provisions of the rules about establishment operation etc. • Of the practical use nuclear reactors for electricity generation" Article 3:radiation dose out of the peripheral surveillance area. • ICRP recommendation Publication 60 (1990):Dose limit of the public radiation exposure.
(2)Integrated dose at the time of the accident	
(a) Standard for avoiding large radiation exposure in the early stage of the accident outbreak 10mSv (indoor sheltering) 50m Sv (evacuation)	• The guidance of the Nuclear Safety Commission • "About the disaster prevention measures such as nuclear energy facilities" • IAEA safety requirements GS-R-2 "Preparedness and Response for a Nuclear or Radiological Emergency" (2002)
(b)Standard of the radiation Protection in the emergency situation(accident continuation) 20-100 mSv	• ICRP recommendation Publication 103 (2007) • IAEA safety requirements GSG2 "Preparedness and Response for a Nuclear or Radiological Emergency" (2011)
(C)The radiation protection Standard in the situation where the pollution after the accident has come to a settlement should be taken into the consideration 1-20 mSv/year	• ICRP recommendation Publication 103 (2007) • Reference level for protecting the public in the situation where the pollution after the accident has come to a settlement should be taken into the consideration (existing situation)

ICRP: International Commission on Radiological Protection

Result of airborne monitoring by MEXT and DOE

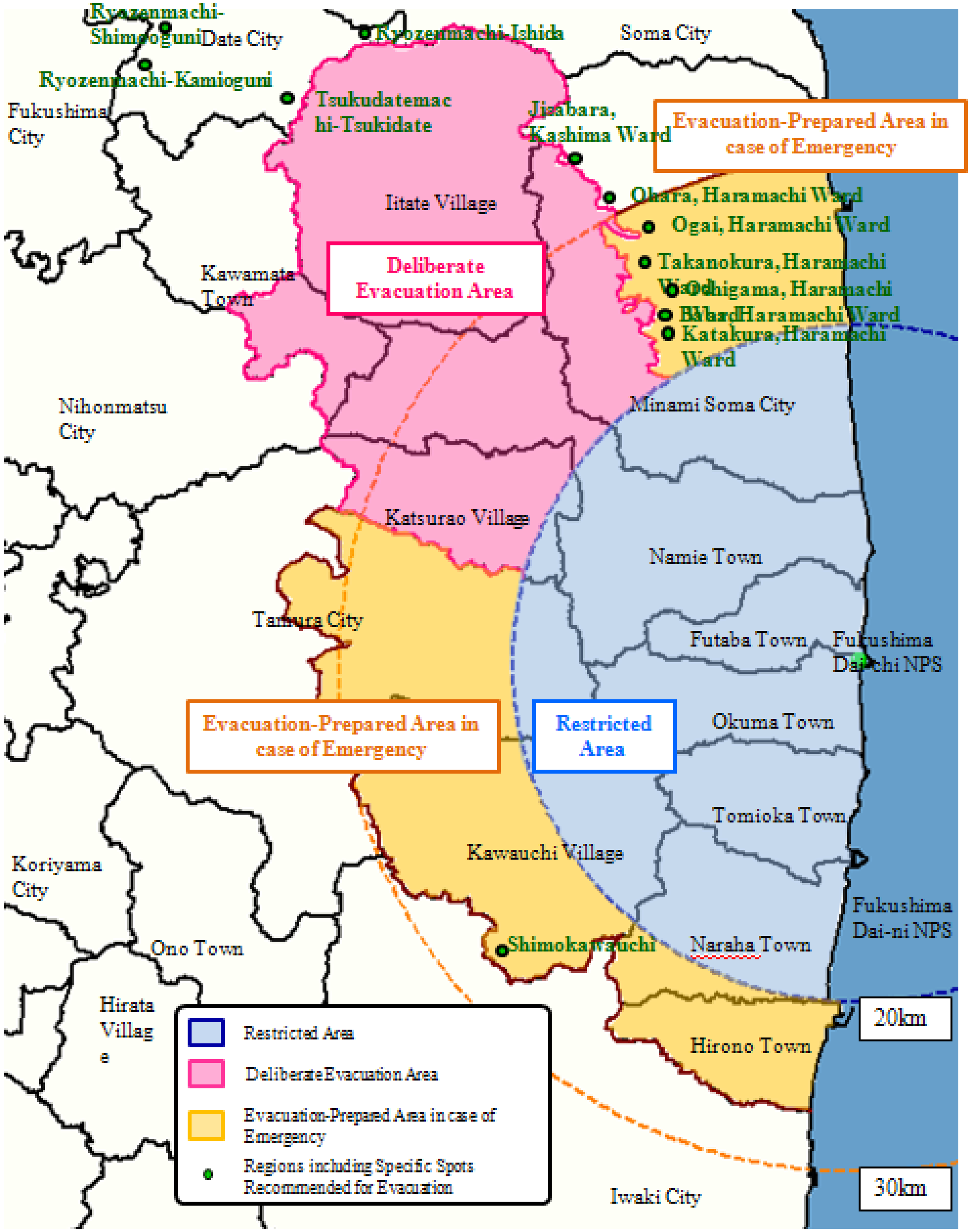
Readings of air dose monitoring inside 100km,120km zone of Fukushima Dai-ichi NPS and Northern Miyagi Prefecture



as of July 2,2011

Map of Restricted Area, Deliberate Evacuation Areas, Evacuation-prepared Areas in Case of Emergency, Specific Areas Recommended for Evacuation

(As of August 3, 2011)



Response regarding Evacuation Areas, etc.

(1) Restricted Area: On April 22, a Restricted Area was established and all access to the area was prohibited. Now, temporary access is allowed for residents and those acting in the public interest.

(2) Deliberate Evacuation Areas: On April 22, Deliberate Evacuation Areas were established in areas where dose was increasing. Most residents had already evacuated.

(3) Evacuation-prepared Areas in Case of Emergency: On April 22, areas for which preparations must be made to evacuate in the event of an emergency were established for those areas where such preparation was required. On September 30 lifting of such restrictions were made.

(4) Specific Areas Recommended for Evacuation: In June, Specific Areas Recommended for Evacuation were established for areas with high dose. The number of such areas is currently 227 (245 households).

2. Health management for residents

Survey for residents

Situation

Actions	Results
Screening Survey	Most of the 195,354 people checked as of May31 were under the 100,000cpm limit.
Survey for thyroid exposure	Among the 1,080 children from 0 to 15 years old surveyed, there were no children who exceeded the screening criteria of 0.2 μSv/h

Source JAEA

Survey on Health Care of Residents in Surrounding Areas

- The “Fukushima Prefecture Health Monitoring Survey,” targeting the approximately two million residents of Fukushima Prefecture, has been started.
  - A basic survey is being implemented based on records of behavior.
  - Then, a detailed survey will be implemented based on the basic survey (expected to target approximately 200,000 people).
  - Ultrasonography of the thyroid gland is being conducted for all Fukushima residents 18 years of age or younger.

３. Measures for agricultural products and drinking water

Agricultural Products

Actions	Contents
Intake Restriction	The Ministry of Health, Labor and Welfare(MHLW) notified to each prefecture on March 17 as followings: **(1) "Guideline values for food and drink intake restrictions"** provided by NSC Japan should be provisional limit value for radioactive materials contained in food stuffs. (2) Any food stuffs that contain radioactive materials exceeding these values should not be consumed pursuant to Item2, Article6 of the Food Sanitation Law.
Distribution Restriction	The Prime Minister, the Director-General of the Nuclear Emergency Response Headquarters, issued instructions on March 21 relevant governors of prefectures about distribution restrictions under the provisions of Paragraph3, Article20 of Act on Special Measures Concerning Nuclear Emergency Preparedness.
Lift of Distribution Restriction	On April4, the Headquarters decided that weekly inspections should be conducted in the distribution-restricted areas and the restrictions can be lifted if inspection findings continue to be below provisional limit values three consecutive times.

Measures to Address Agricultural Products, etc. : Individual Items

(1) Tea: Tea, which appears to have a large amount of radioactive cesium, is “deeply cropped.”

(2) Beef: There was some beef from cattle which appear to have eaten straw containing radioactive cesium. After this discovery, information calling for attention while handling rice straw was distributed.

(3) Rice: In areas with high concentrations of radioactive cesium in the soil, a preliminary survey was implemented in the step before harvesting. The concentration measurements after harvesting are planned based on the survey results. No radioactive materials exceeding the provisional regulatory values have been detected (as of August 31).

Drinking Water

Actions	Contents
Intake Restriction	MHLW issued a notice to the waterworks office of the each prefectural government on March19 and 21 that drinking tap water that contains radioactive materials exceeding the guideline values etc. set by the NSC should be avoided.
Inspection of Tap Water	On April4, MHLW requested local governments to carry out the inspection of tap water mainly in Fukushima Prefecture and its neighboring ten prefectures more than once per week, while daily inspection should be conducted if the readings exceed the guideline values, etc. or they are likely to exceed them.

Guideline values for food and drink intake restrictions

(Nuclear Safety Commission)

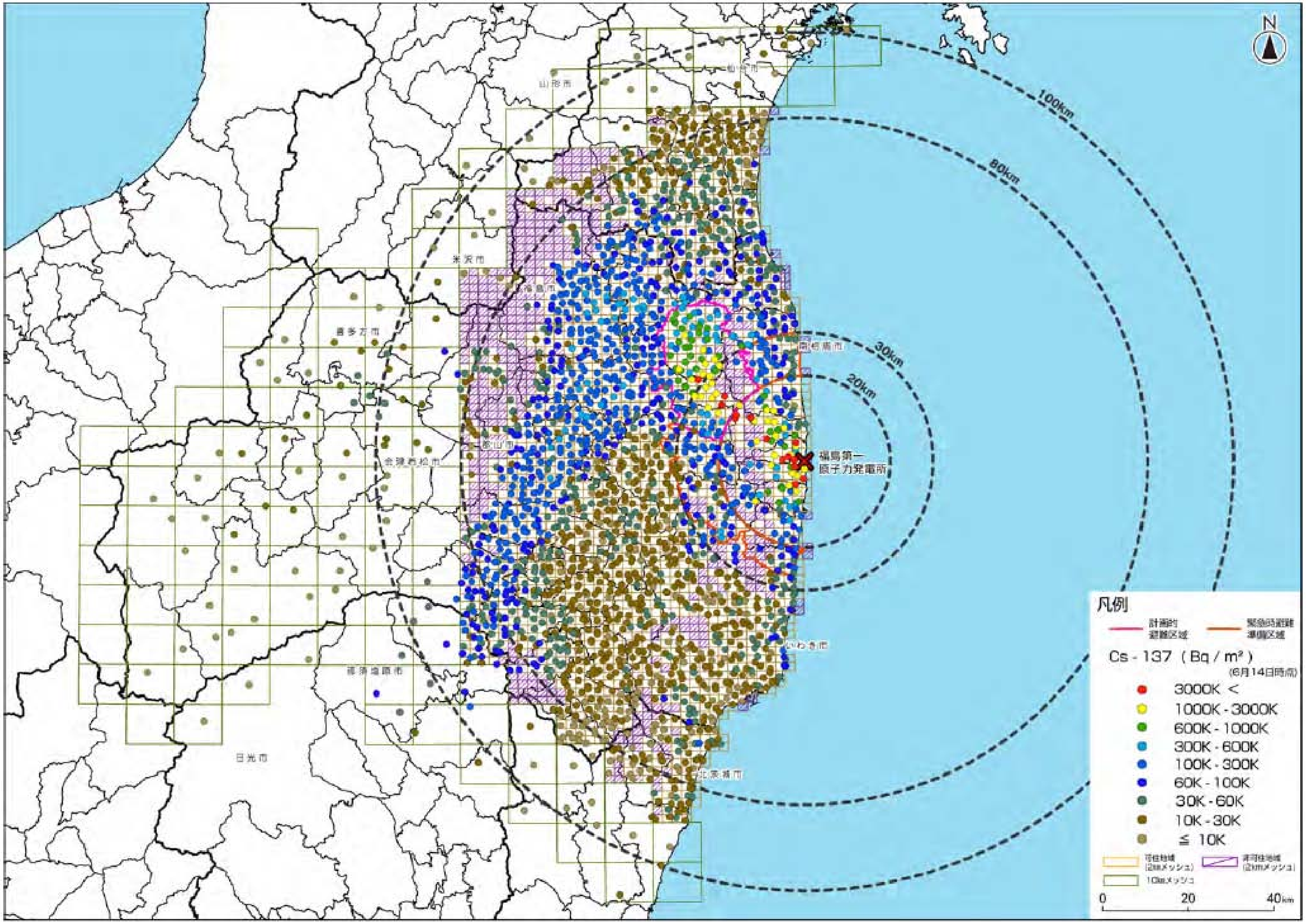
	Radioactive Iodine(^{131}I)	Radioactive Cesium	Uranium	Total of ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{241}Am, ^{242}Cm, ^{243}Cm, ^{244}Cm
Drinking water	> 3x10^2Bq/kg	> 2x10^2Bq/kg	> 20Bq/kg	> 1Bq/kg
Milk, dairy products				
Vegetables and fruits	> 2x10^3Bq/kg (excluding root vegetables and potatos)	> 5x10^2Bq/kg	> 1x10^2Bq/kg	> 10 Bq/kg
Grains	-			
Meat, Egg, Fish, etc				

4. Measures for remediation at off-site

Results of the measurements of amount of accumulation of radioactive materials (Cs-137) in the soil

セシウム137の土壌濃度マップ

図()-o-o　（文科省）



Legal establishment of measures for decontamination of radioactive materials

☐ “Act on Special Measures concerning Handling of Radioactive Pollution”

- The Diet enacted this act on August 26,2011.
- Measures for contamination of the environment due to this accident are described in this act.

(1) measures to be taken by the national and local governments and relevant licensees

(2)Basic principles to be established by the national government

(3)Designation of areas where it is necessary to take measures including decontamination to be made by the national government

Basic principles for decontamination

☐ "Basic Policy for Emergency Decontamination Work"

- The Nuclear Emergency Responses Headquarters established this on August 2011.
- Targets in next two years are described.

(1) with a central focus on areas where the estimated annual exposure dose exceeds 20 mSv, the national government directly promotes decontamination with the goal of reducing the estimated annual exposure dose to below 20 mSv,

(2) particularly, by putting high priority on thorough decontamination work in children's living areas

☐ Demonstration experiment and accumulation of data are made prior to full-scale decontamination.

Demonstration of decontamination in school

(unit: μSv/h)

Decontaminated area	**Decontamination**		**Decontamination methods**
	Before	After	
Scupper on roof of school building	35	1.9	Removal of soil and fallen leaves, cleaning by scrubber and high-pressured water
End of rainwater pipe	40	4.2 3.7	Removal of soil and moss + water washing
Overgrown walkway	25	3.8 1.2	Removal of soil and grass + cleaning by high-pressured water
Side ditch	13	1.6	Removal of soil and grass

(Measured position: 1cm height from soil surface)

Dose measurement

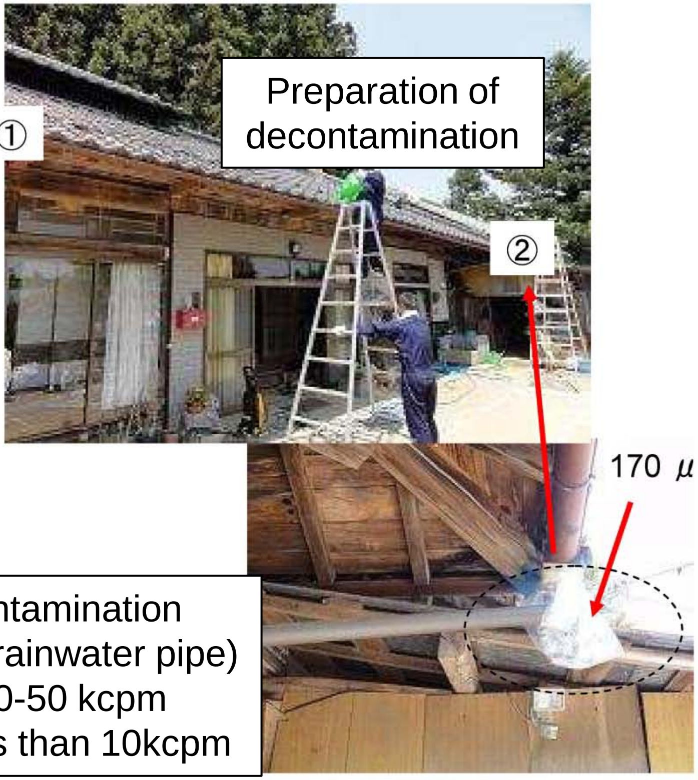
Cleaning by high-pressured water

(Source: Cabinet Office based on Materials in Atomic Energy Commission Meeting)

Decontamination of roof of private house

Cleaning by high-pressured water

Cleaning by high-pressured water



Preparation of decontamination

Decontamination
(Back of rainwater pipe)
Before: 40-50 kcpm
After: less than 10kcpm

	Before	After
End of rainwater pipe near ①	45 - 65	14
End of rainwater pipe near ②	50 – 170	
Average	10 - 35	

(Source: Cabinet Office based on Materials in Atomic Energy Commission Meeting)

5. Nuclear liability

Activities of nuclear liability related to the accident at the TEPCO's Fukushima Nuclear Power Stations

☐Existing legal framework for nuclear liability (two laws including "Law for Nuclear Liability")

+

☐Additional legal framework corresponding to the specialty such as large-scale accident, long continuation of accident (new two laws)

Implementation of compensation for nuclear damage

［Responses based on “Law for Nuclear Liability”］

☐ **Liability of nuclear damage(Article 3, Article 4)→concentration on TEPCO**

☐ **Amount of measures for nuclear damage(Article 7)→The national government paid 120 billion yen to TEPCO because the cause of the accident was earthquake and tsunami.**

☐ **Support from the national government (Article 16)**

→The national government enacted two new laws.

☐ **Measures to be taken by the national government →Measures are not taken because the earthquake and tsunami were not extraordinarily large.**

Two new laws related to nuclear liability concerning the accident at the TEPCO’s Fukushima Nuclear Power Stations

（１）”Act on the Agency of Support for Nuclear Liability”

⇒Establishment of the system for support of amount of compensation for nuclear damage

（２）”Act on Urgent Measures for Nuclear Damage related to the Accident of year Heisei 23”

⇒Early aids to the suffers

Review Committee on Conflict related to Nuclear Damage

- ☐ Mediation for reconciliation on conflict related to nuclear liability

  →"Center for Resolution of Conflict related to Nuclear Liability"

- ☐ Establishment of general guidelines for resolution of conflict related to nuclear liability

  →"Intermediate Guidelines"

Chapter 3

Lessons Learned from the Accident Thus far

●Lessons in category 1

- Strengthen preventive measures against a severe accident

●Lessons in category 2

- Enhancement of response measures against severe accident

●Lessons in category 3

- Enhancement of nuclear emergency responses

●Lessons in category 4

- Reinforcement of safety infrastructure

●Lessons in category 5

- Thoroughly instill a safety culture

Lessons in category 1
Strengthen preventive measures against a severe accident

(1)Strengthen measures against earthquake and tsunamis

(2)Ensure power supply

(3)Ensure robust cooling functions of reactors and PCVs

(4)Ensure robust cooling functions of spent fuel pools

(5)Thorough accident management (AM) measures

(6)Response to issues concerning the siting with more than one reactor

(7)Consideration of NPS arrangement in basic designs

(8)Ensuring the water tightness of essential equipment facilities

Lessons in category 2
Enhancement of response measures against severe accidents

(9)Enhancement of measures to prevent hydrogen explosions

(10)Enhancement of containment venting system

(11)Improvements to the accidents response environment

(12)Enhancement of the radiation exposure management system at the time of the accident

(13)Enhancement of training responding to severe accident

(14)Enhancement of instrumentation to identify the status of the reactors and PCVs

(15)Central control of emergency supplies and equipment and setting up rescue teams

Lessons in category 3
Enhancement of nuclear emergency responses

(16)Responses to combined emergencies of both large-scale natural disasters and prolonged nuclear accident

(17)Reinforcement of environmental monitoring

(18)Establishment of a clear division of labor between relevant central and local organizations

(19)Enhancement of communications relevant to the accident

(20)Enhancement of responses to assistance from other countries and communications to the international community

(21)Adequate identification and forecasting of the effect of released radioactive materials

(22)Clear definition of widespread evacuation areas and radiological protection guidelines in nuclear emergency

Lessons in category 4
Reinforcement of safety infrastructure

(23)Reinforcement of safety regulatory bodies

(24)Establishment and reinforcement of legal structures, criteria and guidelines

(25)Human resources for nuclear safety and nuclear emergency preparedness and responses

(26)Ensuring the independence and diversity of safety systems

(27)Effective use of probabilistic safety assessment (PSA) in risk management

Lessons in Category 5
Thoroughly instill a safety culture

(28) Thoroughly instill a safety culture

Concept of the Nuclear Safety and Security Agency

(provisional name)

(1) Centralize nuclear safety regulatory roles, which thus far have been divided among various ministries

(2) Develop a crisis management structure for the first response system, such as positioning experts to respond to emergencies

(3) Supervise the environmental monitoring function, including SPEEDI

(4) Ensure high-quality staffing, including establishment of an “International Nuclear Safety Training Institute” (provisional name)

(5) Be responsible for nuclear safety and nuclear security

Additional measures for safety assessment of nuclear power stations

☐ **Safety assurance**

- **National government required operators**

  ①urgent measures for safety, ②assurance of external power supply, ③measures for severe accident, etc.

☐ **Comprehensive safety assessments**

- **Comprehensive safety assessments are now being conducted based on new procedures and rules, with reference to the stress tests introduced in Europe, for enhancing the safety of nuclear power stations and ensuring safety and reliance for citizens and residents. And this comprehensive safety assessment comprises of preliminary assessment and secondary assessment.**

Chapter 4 Challenges

(1)Assessment of vulnerabilities［Scientific assessment of vulnerabilities in the social system］

(2) Cooperative activities between natural scientists and social scientists［Active participation of social scientists］

(3)Identification of lessons learned
［Squeeze of lessons learned and its development to the world］

(4)New directions for research
［Identification of new challenges in the scientific research］

(5)Human resource development
［Challenge to develop human resource capable of contribution to the world］

(1)Assessment of vulnerabilities［Scientific assessment of vulnerabilities in the social system］

(1)Assessment of vulnerabilities［Scientific assessment of vulnerabilities in the social system］

- **Have we done enough assessment of vulnerabilities at the nuclear power stations?**

→ Assessment of vulnerabilities in the facilities and the operations of the nuclear power stations , external events to the nuclear power stations from the viewpoint of safety assurance

→ Assessment of vulnerabilities in the assurance of power supply, the assurance of cooling, hydrogen accumulation etc.

→ Utilization of risk assessment ,probabilistic safety assessment(PSA)

(2) Cooperative activities between natural scientists and social scientists［Active participation of social scientists］

(2) Cooperative activities between natural scientists and social scientists［Active participation of social scientists］

・Have we had enough cooperation between the natural scientists and social scientists at the social countermeasures for the accident at the TEPCO’s Nuclear Power Stations?

→ Cooperation between natural science and social science at lifting evacuation areas

→ Cooperation between natural science and social science at measures for effects of the radioactive materials including decontamination activities

(3)Identification of lessons learned［Squeeze of lessons learned and its development to the world］

(3)Identification of lessons learned

［Squeeze of lessons learned and its development to the world］

・Have scientific community done enough efforts to squeeze lessons learned?

→ Identification of lessons learned in every aspect of the accident

(4)New directions for research［Identification of new challenges in the scientific research］

(4)New directions for research
［Identification of new challenges in the scientific research］

・What kinds of research activities should we pursue for the development of society after the experience of this accident?

→ Challenges of research in the field of nuclear safety

→ Challenges of social science in the measures for accident

(5)Human resource development［Challenge to develop human resource capable of contribution to the world］

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［Challenge to develop human resource capable of contribution to the world］

・Have we had enough human resource to tackle with the accident?

→ Human resource capable of scientific assessment of the vulnerabilities

→ Human resource capable of development of cooperation between the natural science and social science