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Lessons Learned: Radiation Protection for Emergency Response and Remediation / Decontamination Work Involved in TEPCO Fukushima Daiichi NPP Accident

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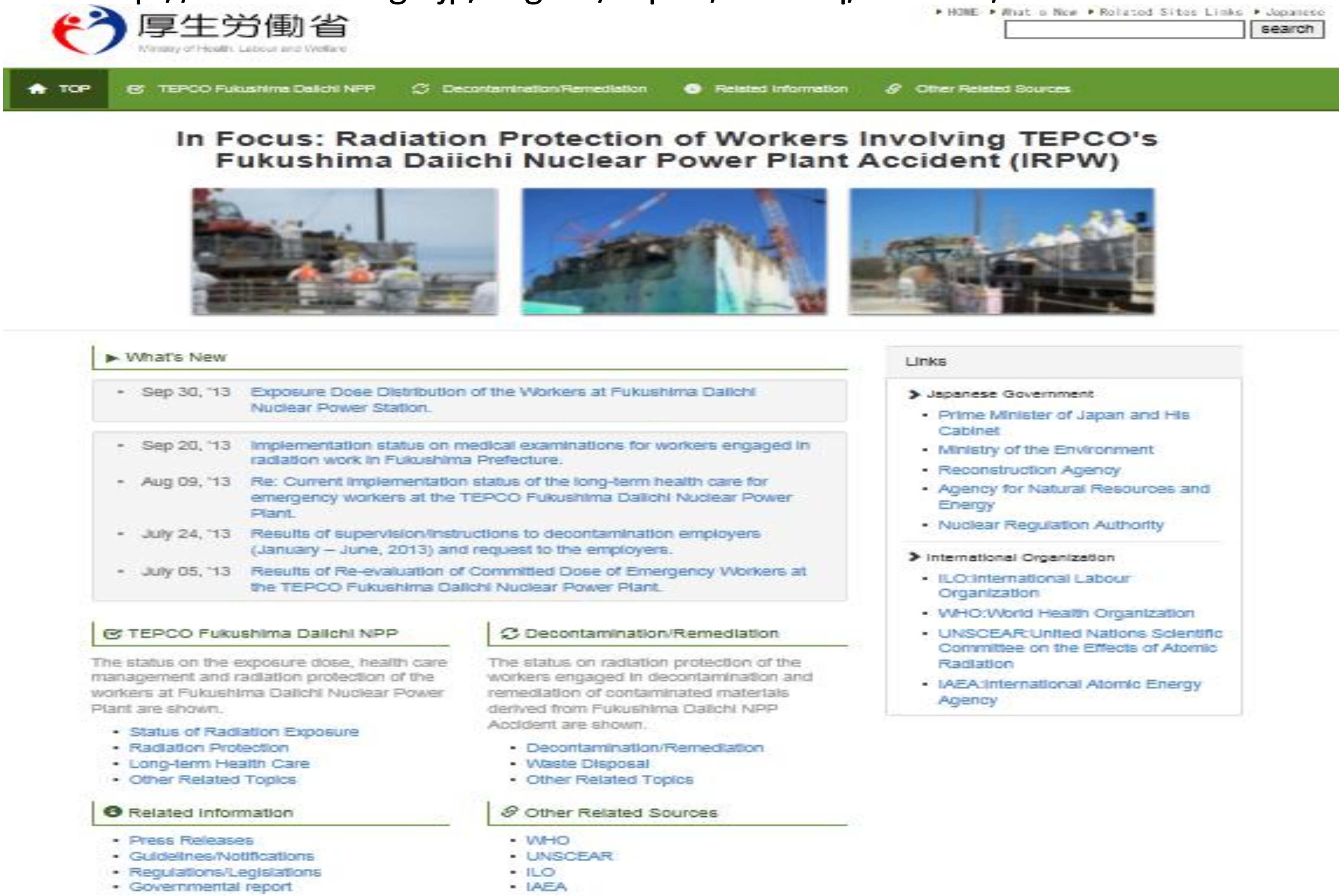
1. Introduction

- In response to the **Fukushima Daiichi NPP accident** resulting from the Great East Japan Earthquake on March 11, 2011, TEPCO undertook **emergency work**.
- During the emergency work, the MHLW
  - experienced various problems **in management, control and reduction of radiation exposure**, and **medical and health care management**.
  - issued a series of compulsory **directives** and **administrative guidance** to TEPCO.

- To rehabilitate the **contaminated areas**, the government decided to carry out **Decontamination**.
  - MHLW needed to provide **sufficient radiation protection** for decontamination work.
- The paper aims to
  - describe the **lessons learned** from the experiences to provide guidance regarding **preparedness** for a similar accident, and
  - provide useful **information as a reference** for **legislation** regarding radiological protection in an "**existing exposure situation**."

2. Methodology

http://www.mhlw.go.jp/english/topics/2011eq/workers/index.html



3.1. Trend of Workers' Dose at Emergency and Current Status of Effective Dose for Fukushima Daiichi NPP Workers

Table 1. Cumulative Effective Dose of All Workers since the Accident

Effective Dose (mSv)	Cumulative dose for workers: 2011.3-2014.9		
	TEPCO	Contractors	Total
> 250	6	0	6
> 200 to ≤ 250	1	2	3
> 150 to ≤ 200	25	2	27
> 100 to ≤ 150	118	20	138
> 75 to ≤ 100	281	163	444
> 50 to ≤ 75	320	1,133	1,453
> 20 to ≤ 50	620	5,035	5,655
> 10 to ≤ 20	566	4,652	5,218
> 5 to ≤ 10	476	4,462	4,938
> 1 to ≤ 5	760	8,275	9,035
≤ 1	1,160	10,377	11,537
Total	4,333	34,121	**38,454**
Maximum (mSv)	678.80	238.42	678.80
Average (mSv)	23.05	10.76	12.15

> 250 mSv: 6 workers

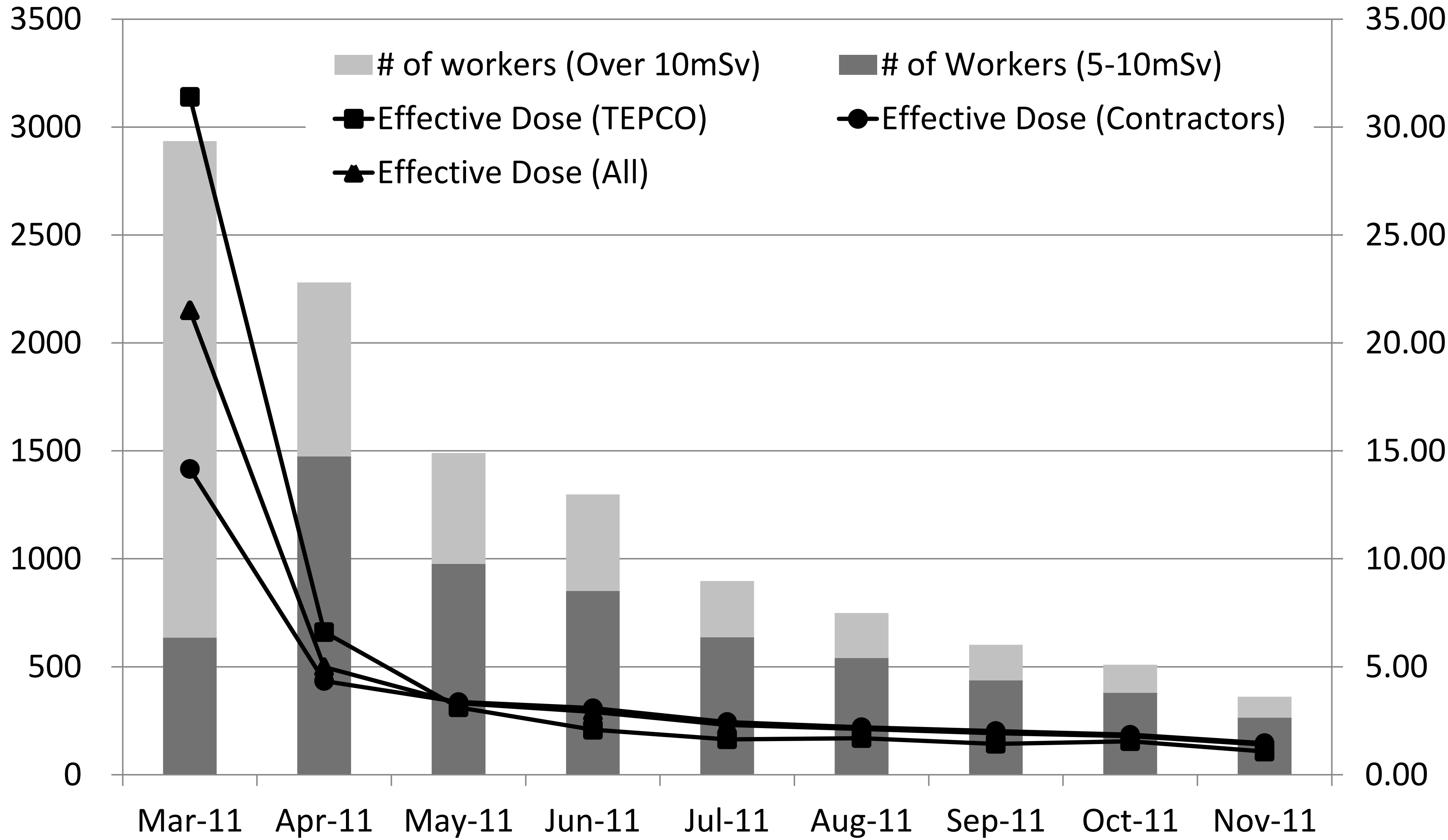
> 100 mSv: 174 workers

> 50 mSv: 0 workers

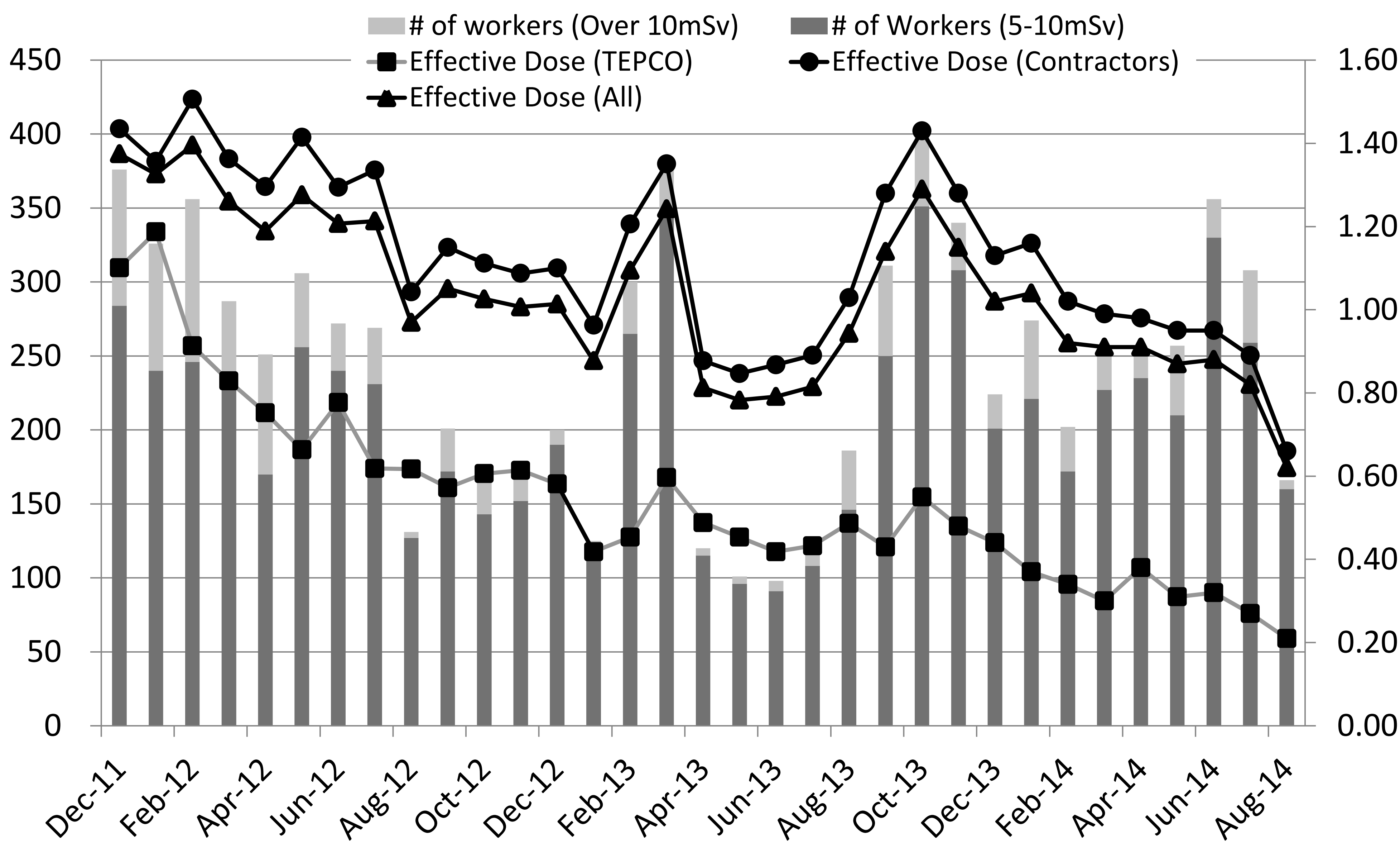
Table 2. Cumulative Effective Dose of Workers for FY2014

Effective Dose (mSv)	Cumulative dose for workers: 2014.4-2014.9		
	TEPCO	Contractors	Total
> 100	0	0	0
> 75 to ≤ 100	0	0	0
> 50 to ≤ 75	0	0	0
> 20 to ≤ 50	1	269	270
> 10 to ≤ 20	10	998	1,008
> 5 to ≤ 10	63	1,684	1,747
> 1 to ≤ 5	478	4,540	5,018
≤ 1	950	6,371	7,321
Total	1,502	13,862	**15,364**
Maximum (mSv)	20.55	39.85	39.85
Average (mSv)	1.28	3.29	3.10

Trend of Monthly Effective Dose of Fukushima Daiichi NPP Workers (Emergency Situation: 2011.3-2011.11)



Trend of Monthly Effective Dose of Fukushima Daiichi NPP (Post Emergency: 2011.12-2014.08)



3.2. Radiation Protection
(a) Inappropriate Exposure Monitoring because of Shortage of PAD

Problems that Occurred

- **<u>The tsunami damaged most PADs</u>**. Surviving dosimeters **<u>could not be recharged</u>**. PADs sent **<u>could not be set to the alarm level</u>** due to lack of calibration equipment.
- Usable PADs decreased to **<u>320 on March 15, 2011</u>**, whereas the number of emergency workers increased progressively.
- From **March 15 to March 31, 2011**, TEPCO supplied one PAD for each work group for outdoor work, where the ambient dose is relatively low.
- The group leader's dose **could not perfectly represent** the dose of a group's individual workers.

Response of MHLW and TEPCO

- MHLW provided administrative guidance on March 31 that
  - ➢ required all workers to be equipped with PADs.
- TEPCO
  - ➢ On March 31, 2011;
    - Received **100 newly purchased PADs** and **<u>found out 500 PADs already arrived</u>**.
  - ➢ On April 1, 2011, recommenced providing PADs to all of the workers.

(b) Inappropriate Dosimeter Circulation and Exposure Control

Problems that Occurred

- Due to **<u>loss of the electronic system</u>**, TEPCO implemented **<u>paper-based dosimeter circulation management</u>** until April 4 (June 8 in J-village).
  - ➢ Many cases of improper procedure, i.e. **<u>wrote down only family names or</u>** **<u>illegible writing</u>**, resulted in difficulty conducting a **<u>name-based aggregation of doses</u>**.
  - ➢ **<u>Manual entry of data and calculation</u>** by PCs, although manpower was limited.
- Temporal system was **<u>unable to print out dose records</u>**,
- making it difficult for workers to know their dose.

Response of MHLW and TEPCO

- MHLW required TEPCO to comply with the following guidance since May 23, 2011:
  - ➢ Implement **data entry and the name-based aggregation** of dose by **<u>corporate office</u>**.
  - ➢ **Collect personal identification information** and issue admission passes with **<u>PINs</u>**.
  - ➢ Required providing a **<u>printed dose record</u>** when workers returned their dosimeters.
- TEPCO:
  - ➢ Transferred tasks to the corporate office and dispatched personnel to the plant.
  - ➢ Started **<u>issuing worker ID cards</u>** on April 4, 2011 (on June 8, 2011, in J-Village).
  - ➢ On July 29, 2011, started **<u>issuing admission cards with photographs</u>**.
  - ➢ On August 8, 2011, initiated the combined use of admission cards and ID.
  - ➢ Since August 16, 2011, a system has been modified to **<u>print records of exposure dose</u>**.
  - ➢ On August 2011, started **<u>providing weekly exposure dose records</u>** to the primary contractors.

(c) Workers Who Were out of Contact

Problems that Occurred

- On June 20, 2011, TEPCO revealed that several workers appeared on the circular list **whose identities could not be confirmed**.
- The number of workers out of contact **reached 174** as the name-based aggregation proceeded.

Response of MHLW and TEPCO

- MHLW demanded TEPCO to
  - **assemble an investigation team** at the corporate office to investigate the missing workers.
- TEPCO, in close cooperation with the primary contractors,
  - located the missing workers by **double-checking the paper-based list**, examining data, investigation by **primary contractors and an investigation firm**.
  - **Released on its website the names of 13 workers** who could not be identified by the investigation.
  - As a result, 3 workers reappeared. However, the whereabouts of **the others remain unknown.**

(d) Delayed Internal Exposure Monitoring

Problems that Occurred

- TEPCO:
  - Could not **operate installed WBCs** because of **high background level**.
  - From March 22, 2011, **operated 2 vehicle counted WBCs** at the Onahama Coal Centre.
- By June 20, 2011, TEPCO failed to complete monitoring for 125 (3.4%) emergency workers engaged in March.

Response of MHLW and TEPCO

- The delay was primarily caused by a lack of WBCs, but there were several related complexities.
  - When TEPCO restarted monitoring on March 22, 2011, **many workers had already left the site**. TEPCO stationed a WBC in Tokyo, but time was required to bring workers to Tokyo.
  - Due **to the low resolution of the NaI scintillation detector**, workers had to be dispatched to the JAEA's Tokai Institute, 110 km away.
  - Workers exposed to more than 100 mSv **required medical care in the NIRS**, 200 km away.
- TEPCO had to **renew the evaluation code** in accordance with Cs-134, Cs-137 and I-131.
- On June 13, 2011, NIRS decided that **the intake date should be March 12, 2011,** to facilitate the most conservative evaluation.
  - TEPCO argued that the intake date should be **the middle of the work period at the plant**.
  - MHLW insisted that it should be **the day of the hydrogen explosion (March 12, 2011)**.
- TEPCO succeeded to:
  - On July 10, 2011, open **WBC Centre** in J-village.
  - Since September 2011, monitor all workers monthly.
  - Since October 18, 2011, operate a total of 11 WBCs,
  - including 6 newly purchased WBCs.

(e) Exceeding Emergency Dose

Problems that Occurred

- On July 7, 2011, TEPCO determined that 6 emergency workers had **exceeded the emergency dose limit (250 mSv).**
- 12 workers received more than 100 mSv of internal exposure dose.

Response of MHLW and TEPCO

- The initial report was received on May 30, 2011, 2 and a half months after the accident.
  - TEPCO gave the **first priority to the workers externally exposed to 100 mSv or more**, thus monitoring of indoor workers was delayed.
- MHLW was
  - concerned that workers exposed beyond the limit **might be found among the workers** whose internal exposure dose had not yet been determined.
- TEPCO:
  - **Relocated** workers suspected of being **internally exposed to 100 mSv or more** to non-radiation work from June 13, 2011, until the dose was determined.
  - **Permanently relocated** workers suspected of being **internally exposed to 200 mSv or more** to other sites.

(f) Internal Exposure Resulting From Inappropriate Use of Masks

Problems that Occurred

- **Internal exposures were repeatedly found** in September, 6 months after the accident.
- Internal exposure should not happen **if respirators were properly fitted**.

Response of MHLW and TEPCO

- MHLW:
  - **Measured filtration rate of masks** worn by 6 emergency workers with JNIOSH experts on September 26, 2011.
- Experts revealed:
  - Leak rate ranged between **1.1% and 56.0% with an average leak rate of 17.4%.**
  - The leak rate of workers who wore **eyeglasses was higher than other** workers.
  - 2 main factors affected leakage:
    - **Interference between respirator face seal** and faces created by eyeglasses, cotton caps and hair.
    - **Poor match between the shapes** of workers' faces and the respirator.
- TEPCO implemented the following improvements:
  - After September 27, 2011, respirators were **sorted by size and manufacturer** so that workers could choose better-fitting masks.
  - After November 17, 2011, **a fit tester was used in the training** of new workers.
  - As a result, **no significant internal exposure was observed** after October 2011.

(g) Protection against Beta-ray Exposure from Contaminated Water

Problems that Occurred

- On March 24, 2011, when workers received **beta-rays on their feet** after stepping into 30 cm deep contaminated water.
  - Workers **did not monitor the ambient dose rate** prior to work, nor wear **long protective boots**, and continued to work after PAD alarm sounded.
- In August 2011, the contaminated-water processing plant, which **filters radioactive Cs**, began operation, and some workers were accidentally exposed to **Sr-rich contaminated water**.
  - Monitored 70 μm dose was **17.1 mSv and 23.4 mSv**, whereas 1 cm dose was **0.28 mSv and 0.22 mSv**.

Response of MHLW and TEPCO

- MHLW issued a recommendation that instructed TEPCO to:
  - **Monitor the ambient dose rate** of the work area prior to the work and develop a work plan in consideration of the work area contamination.
  - **Use proper protective garments and shoes** according to contamination
  - Monitor equivalent dose of extremities by **ring badges** and **convert to effective dose** using tissue weighting factors (0.01 for skin exposure).
- TEPCO:
  - Fully enforced use of **rubber boots** at all times and wearing **liquid-proof coveralls** when workers handled contaminated water.
  - Introduced a temporary measure **attaching glass badges to the wrists** of workers because TEPCO did not have a sufficient stock of badges at that time.

(h) Worker Training

Problems that Occurred

- Until May 2011, TEPCO conducted training for newcomers **for only 30 minutes**.
  - Over-populated J-village did **not possess sufficient space** for education and training was **limited to 20 workers** at a time.
  - **3,000 new workers** required training every month.
- TEPCO started to implement **compulsory 7-hour training courses** in the summer of 2011, 5 months after the accident.

Response of MHLW and TEPCO

- On May 13, May 23 and July 22, 2011, MHLW demanded :
  - Conduct training courses for new workers regarding
    - **(a) health effects** of radiation exposure,
    - (b) use of **personal protective equipment** and
    - **(c) emergency response**.
- Beginning May 19, 2011, TEPCO:
  - Started to conduct special training at its corporate office in Tokyo for workers dispatched to the affected plant.
  - Secured **an exclusive space for education** at J-village and commenced **compulsory 7-hour special training** for new workers on **June 8**, 2011, which was 3 months after the accident.

3.3. Medical and Health Care Management
(a) Implementation of Emergency Medical Examinations

Problems that Occurred

- On March 16, 2011, the MHLW issued compulsory instruction to TEPCO to implement **special medical examinations** for screening for **acute radiation syndromes** every month.
  a) inquiries of previous exposure;
  b) inquiries of injury and gastroenterological symptoms;
  c) examinations of white blood cell count and white blood cell percentage; and
  d) dermatological examinations, such as erythema reaction
- TEPCO faced difficulties in the name-based aggregation of dose, delayed identifying the workers to receive the examinations.
  - The implementation rate from March to September **rose gradually but remained low**: **31.3%, 59.3%, 61.7%, 63.6%, 61.9%, 70.7% and 70.6%,** respectively.

Response of MHLW and TEPCO

- After TEPCO succeeded in the **name based aggregation** of exposure dose records, the implementation rate from October to December **reached 90 %.**
- Fortunately, **no acute radiation symptoms or local radiation injuries** were revealed in the examinations.
- The MHLW terminated the instruction of special examinations in December 2011, with 3 months of follow-up.

(b) Establishment of On-Site Medical Care Systems

Problems that Occurred

- Although there were **2,000 to 3,000 emergency workers per day** consecutively, TEPCO could only maintain the presence of **physicians in the daytime** for a few days each week.
- During the first month after the accident, TEPCO treated **25 injured and sick workers** and 31 workers in poor physical condition.

Response of MHLW and TEPCO

- NISA and MHLW requested:
  - **University of Occupational and Environmental Health (UOEH)** to dispatch physicians to the plant on May 15, 2011.
  - **Rosai Hospitals** to dispatch physicians to the affected site on May 26, 2011.
  - **Hiroshima University** to establish a "**Network**" to coordinate dispatch of medical staff.
- TEPCO was able to:
  - Establish the **24-hour presence of medical staff** in the plant from May 29, 2011.
  - Set up a **makeshift medical clinic** in SB of Reactor No. 5/6 and establish **48-hour rotation** of the physicians on July 1, 2011.
  - Relocate physicians from the Seismic-isolation Building to the medical clinic in J-village and provide **routine preventive care** on September 1, 2011.
  - Set up the **new medical clinic** in the Entering and Leaving Control Building and abolish the makeshift medical clinic in July 2013.

(c) Patient Transportation from the Affected Plant

Problems that Occurred

- **3 of the 5 pre-accident designated initial medical facilities** were located in the **evacuation zone** within a 20-kilometer radius of the affected plant. **A hospital** was located in the **indoor evacuation zone** and closed its in-patient ward.
- **The other hospital** was located outside the 30-km radius; however, supply of water, gas and electricity were **lost or malfunctioned**.
- On March 14, 2011, **Fukushima Medical University (FMU),** a secondary medical facility, prepared to accept patients. However, FMU is **57 km from the affected plant**, and the approach from J-Village **took 3 hours**.

Response of MHLW and TEPCO

- On April 2, 2011, **Off-site Response Center (OFC)** established the **2-stage transportation**.
  a) Contaminated patients should be **triaged and decontaminated in the plant**, transport to **J-Village** by **TEPCO's car**; and
  b) Patients should be triaged and decontaminated in the **medical clinic of J-village** and transported to **hospitals in Iwaki city** by **local ambulances**.
- MHLW consulted with and agreed that hospitals accept the condition that surface contamination level of patients was **less than 400Bq/cm2** on August 14, 2011.

(d) Prevention of Heat Illness

Problems that Occurred

- Temperatures start to rise from late May and reach **30 ℃ from June to September**.
- Heat illness could develop if emergency workers spend long hours under the blazing sun while **wearing full-face respiratory masks and HAZMAT garments**.

Response of MHLW and TEPCO

- The MHLW issued to TEPCO and primary contractors an administrative guidance document for the prevention of heat illness on June 10, 2011.
  - a) Terminate work **from 2 pm to 5 pm** in July and August.
  - b) Establish **upper consecutive working hours**.
  - c) Implement **health checks** prior to work.
  - d) Provide workers with **air-conditioned rest places**.
  - e) Conduct **education** for the prevention of heat illness.

- TEPCO took the following measures:
  - a) Distribution of **Cool Vests**, vests with attached refrigerant gel;
  - b) Provision of the **Wet-Bulb Globe Temperature (WBGT)** through the intranet; and
  - c) Display of the **warning level for heat illness**.
- As a result, **40 patients** with heat illness were observed, but no serious cases were reported.
  - The number of workers from May to September 2011 were **7,282, 7,578, 7,733, 7,482 and 7,171** respectively.

(e) Lodging and Food

Problems that Occurred

- During the emergency situation, TEPCO required emergency workers **24 hours a day**. **400 workers** had to sleep on the **floor** of the Seismic-isolated Building or **gymnasium** of the Fukushima-Daini NPP, 13 km from the affected plant.
- For the prevention of internal exposure, TEPCO restricted the food supply to workers to **boil-in-bag foods**.
- The MHLW was concerned that workers might **cause additional accidents** because of **poor physical conditions** developed due to **lack of sufficient rest and nutrition**.

Response of MHLW and TEPCO

- MHLW provided administrative guidance to TEPCO on April 20, 2011 as follows:
  - a) Ensuring **sleeping facilities**, including **beds or mattresses**;
  - b) Taking preventative measures to stop the **spread of communicative diseases**;
  - c) Supplying **nutritious foods**.

- TEPCO
  - Set up **120 double-deck beds** with bedclothes and **30 sets of showers** in the gymnasium of Fukushima Daini NPP and **42 double-deck beds** in the plant.
  - Established a **makeshift dormitory** that could accommodate **1,600 workers**.
  - Began to provide **lunch boxes** instead of vacuum-packed foods and reopened a **restaurant in J-Village and Fukushima Daini NPP** on June 18, 2012.

Long-term Health Care for Emergency Workers at the TEPCO Daiichi NPP

Because the radiation exposure dose limit had been tentatively raised to 250 mSv, long-term health care for emergency workers (approximately 20,000 workers) will be provided according to the guidelines (October 11, 2011)

1 Development of a database

- Personal identification (name, affiliation, etc.)
- Exposure dose, job descriptions
- Results of medical examinations, etc.
- Health consultation & guidance, etc.
- Others (lifestyle, etc.)

Submission (Managed by the database) →

MHLW

- Operation & management of database
- Health consultation & guidance
- Response to data inquiries
- **Epidemiological Studies**

2 Health care control items

Medical examinations commensurate to the levels of radiation exposure dose will be provided with the development of a database *1

Specific medical examination items

○ **For all emergency workers**

- Statutory medical examinations (general and ionizing radiation medical examinations)
- Health consultation/guidance including mental health.

○ **For emergency workers with doses exceeding** 50 mSv *2

- Examinations for cataracts, in addition to the aforementioned examinations.

○ **For emergency workers with doses exceeding** 100mSv *2

- Thyroid examinations, cancer screening (stomach, lung, colon) in addition to the aforementioned examinations.

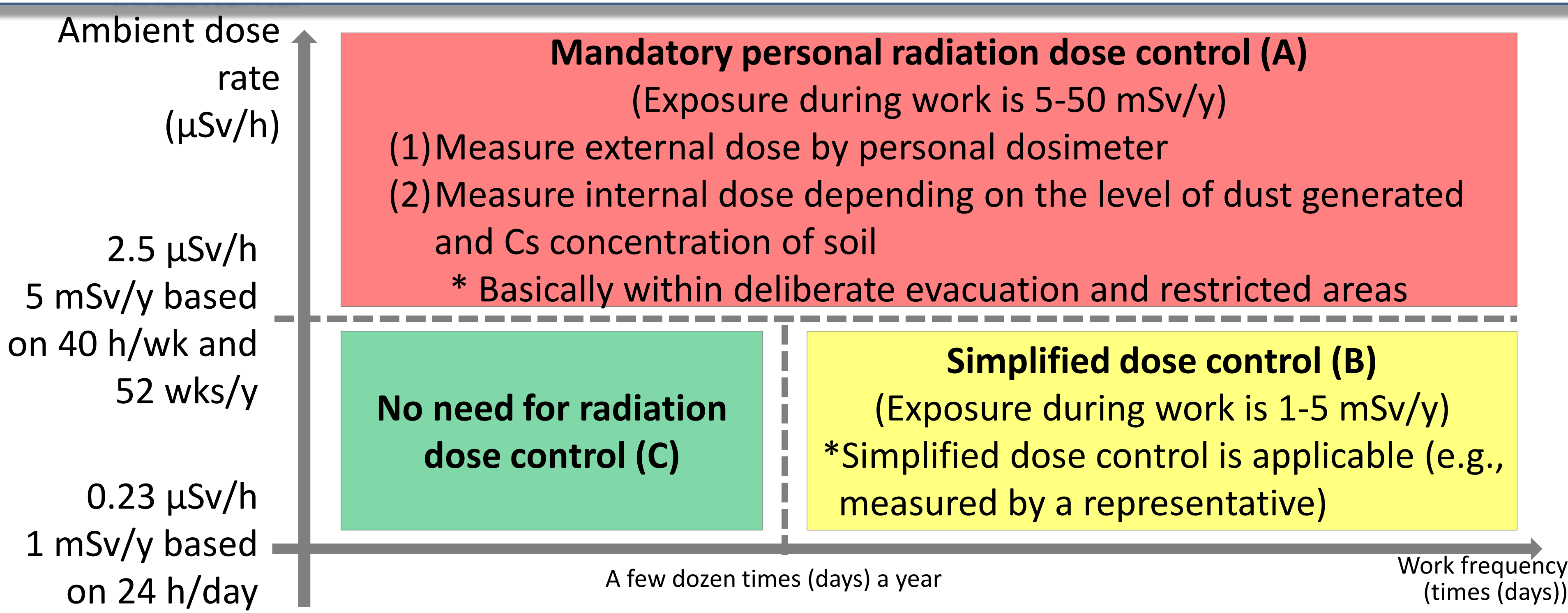
Issue a passbook upon application (for workers with doses exceeding 50 mSv and 100mSv)

Issue a database registration card (Certificate for data inquiry) (for all items)

4. Establishment of regulations for decontamination/remediation work

4.1. Radiation Prevention for Decontamination Workers

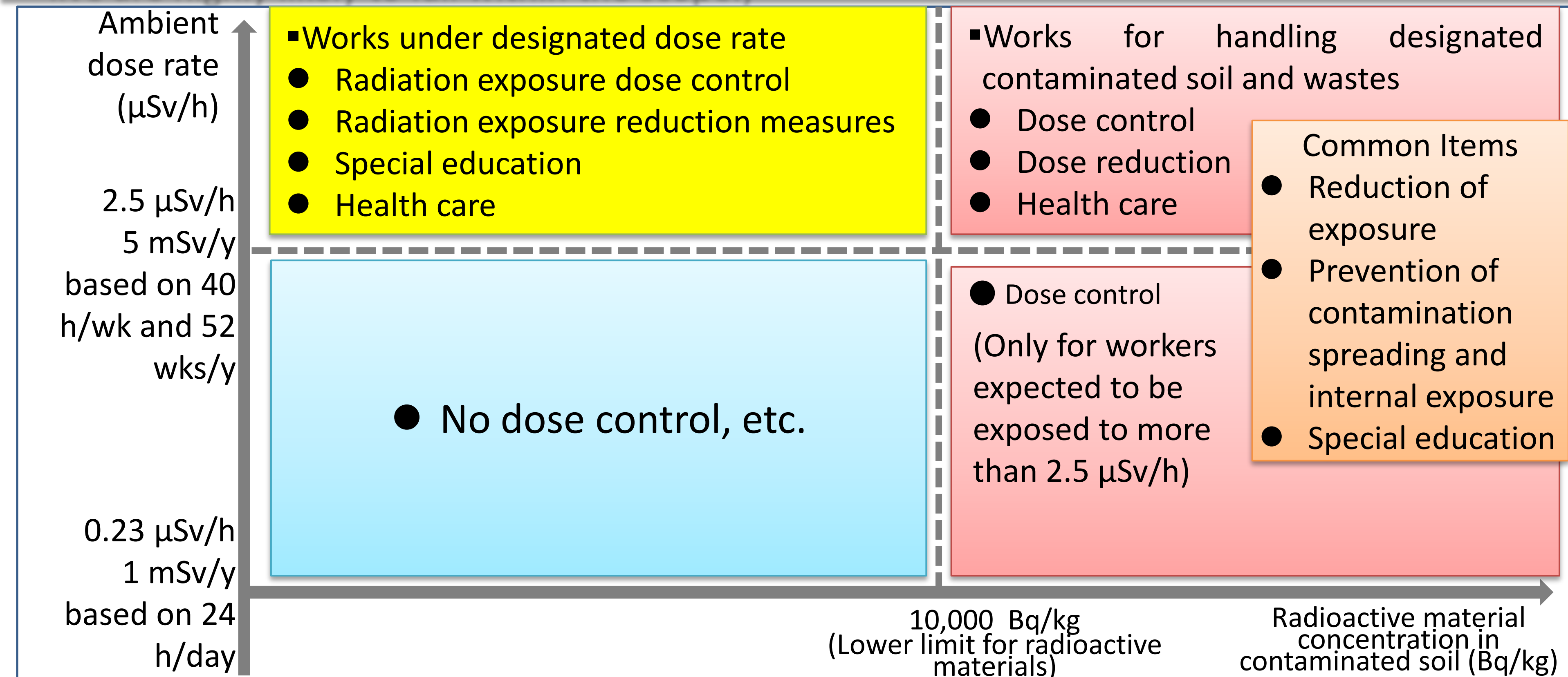
- Existing government regulations assumed that
  - the radiation sources were controlled and collected in indoor restricted areas referred to as **"planned exposure situations."**
- MHLW had not considered the possibility of a situation where
  - radiation sources were scattered and workers would have to deal with radioactive material outdoors as **"existing exposure situation."**
- MHLW decided to establish new regulations and employed the following three principles:
  - A) Ensure that the level of protection is **equivalent to or greater than the level in a planned situation** and adhere to existing regulations.
  - B) Be **practical and function smoothly** in the situation around the affected plant.
  - C) Be **consistent with RP for the inhabitants** around the work sites to avoid anxiogenic effects because decontamination projects have to be carried out in daily living areas, in full view of inhabitants.



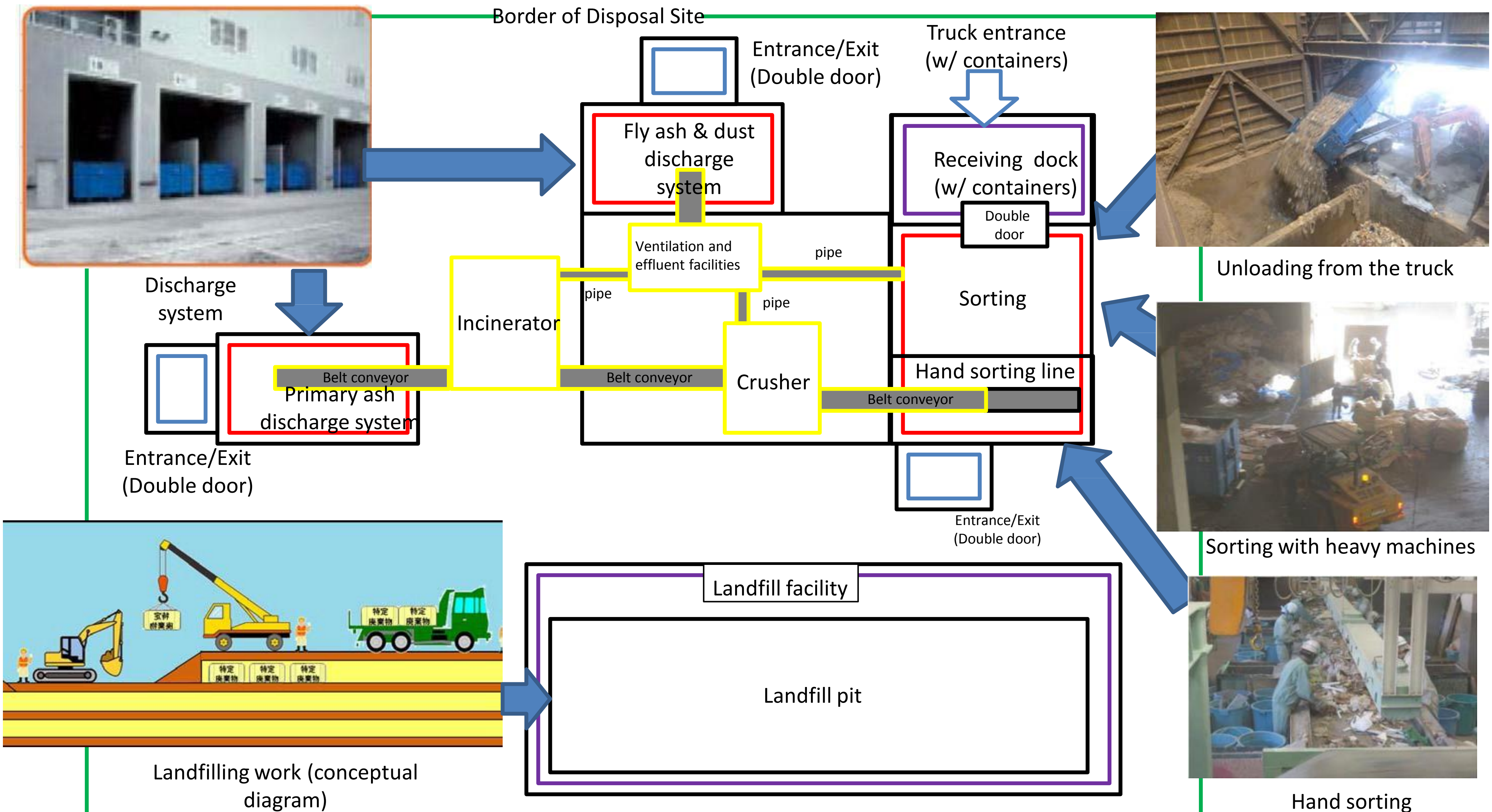
Radiation Prevention for Restoration & Reconstruction Works

Ionizing Radiation Ordinance was revised; its application was expanded (effective since July 1, 2012).

- Works involved with **soil decontamination, waste collection**, etc. (before revision)
  →Special decontamination areas (evacuation areas), intensive contamination survey areas (areas with greater than 0.23 μSv/h)
- Works for **handling designated contaminated soil and waste** (greater than 10,000 Bq/kg)
  →Infrastructure restoration, agriculture, forestry (mainly greater than 2.5 μSv/h. Incl. evacuation areas.)
- Works **under designated dose rate** (ambient dose rate exceeds 2.5 μSv/h)
  →Measurements, transportation, indoor industrial activities (manufacturing, medical or welfare facilities, and commercial activities resumed in areas in which the residents are not permitted to live are highly likely to fall within the scope.)



4.2. Disposal of Contaminated Soil and Waste
Overview of Radiation Protection in Disposal Facility



5. Discussion

5.1. Lessons learned on radiation protection and health care management

- On August 10, 2012, the MHLW issued a notice to urge nuclear operators to perform the necessary preparation to avoid similar problems of exposure as follows:
- **Radiological management** should be ensured, including the following:
  - A) NPP operators
    - need to provide assistance from the **corporate office or off-site support facilities** outside the evacuation area;
    - compile an **operations manual**, stockpile **personal protective equipment and PADs**, and prepare **emergency dose control systems** and **WBCs**.
  - **B) Primary contractors** must independently implement exposure management subcontractors' workers;
- To **reduce the exposure dose**, NPP operators should:
  - **A) Monitor the radioactive concentration** of the indoor air of the workplace during an emergency, to stockpile and use appropriate **respiratory protection** and train newcomers how to **use, fit and fit-test the respirators**;
  - B) Mandate **liquid-proof garments** when workers handle contaminated water;
  - C) Develop **well-prepared work plans** prior to the work and monitor the ambient dose rate of the work area to develop proper working procedures;
  - D) Facilitate the earlier deployment of **remote-controlled vehicles** and the utilization of **tungsten shielding vests**.

5.1. Lessons learned on radiation protection and health care (2)

- **Medical and health care management** would require the following:

  A) The government needs to
  - assist in **dispatching medical staff** to the affected plants;
  - conduct **long-term follow-up** for emergency workers, including the **health care system**, **medical examinations** and **mental health consultations**.

  B) Nuclear facility operators, medical facilities and fire departments should **make an agreement** to clarify the division of the roles played prior to the accident and should conduct **emergency drills** periodically with the full attendance of related personnel to identify and resolve problems;

  C) Operators need to
  - develop a **support base** at a safe distance from the plant and to prepare to develop **makeshift lodgings** in case of emergency;
  - come to an agreement to **share food stocks** among closely located nuclear plants and **prepare cooking equipment** that can be used in case of a blackout to provide warm foods and drinks to as many workers as possible;

5.2. Problems to be resolved in establishing new regulation in existing exposure situation

- To establish new regulation systems for the existing exposure situation, further **research and development** is warranted:
  - A) The relationship between the **radioactive concentrations** of **materials handled** and the **risk of internal exposure**:

    Risk was estimated based on the **radioactive concentration multiplied by the density of dust** at work sites. However, there were no scientific experimental data available to prove the validity.
  - B) The relationship between the **radioactive concentration of the soil** and the workers' **surface contamination** level:

    Experimental and empirical studies of this relationship would make it possible to establish an **exemption standard** for contamination screening.
- Regarding Disposal of contaminated soil and waste, two issues were raised.
  - **Balance between** the competing goals of **radiation protection** and ensuring **work efficiency**, which is necessary for the smooth disposal of 30 million tons of contaminated materials.
  - Application of the regulation to conventional waste disposal facilities, which were **not originally designed to handle radioactive substances**.

6. Conclusion

- If TEPCO had ensured **sufficient and systematic preparation** for large-scale accidents.
    - The problems that occurred **would not have occurred** or would have **remained minor**
- Based on the lessons,
    - **international guidance documents** were warranted to perform necessary preparation for radiation protection.
- It is desirable for governments responsible for radiation protection legislation to
    - develop **international guidance documents** that provide useful information in consideration of the Japanese case.

We Promise to keep Improving…

Reactor No.1

Reactor No.4

Main Building