Japanese Earthquake and Fukushima nuclear accident – radiation protection issues

Toshimitsu Homma
Japan Atomic Energy Agency

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Emergency response system in Japan

- After TMI accident, “Emergency Preparedness Guide for nuclear power plants” by NSC in 1980 specified technical criteria such as EPZ, intervention levels
- Impact of Chernobyl accident in 1986 in Japan on ER system not so significant (differences between reactor types were emphasized)
- Tokaimura criticality accident in 1999 addressed several weaknesses such as prompt initial actions, collaboration of national and local governments and the clarification of licensee’s responsibilities.

- “Act on Special Measures Concerning Nuclear Emergency Preparedness” enacted in December 1999.

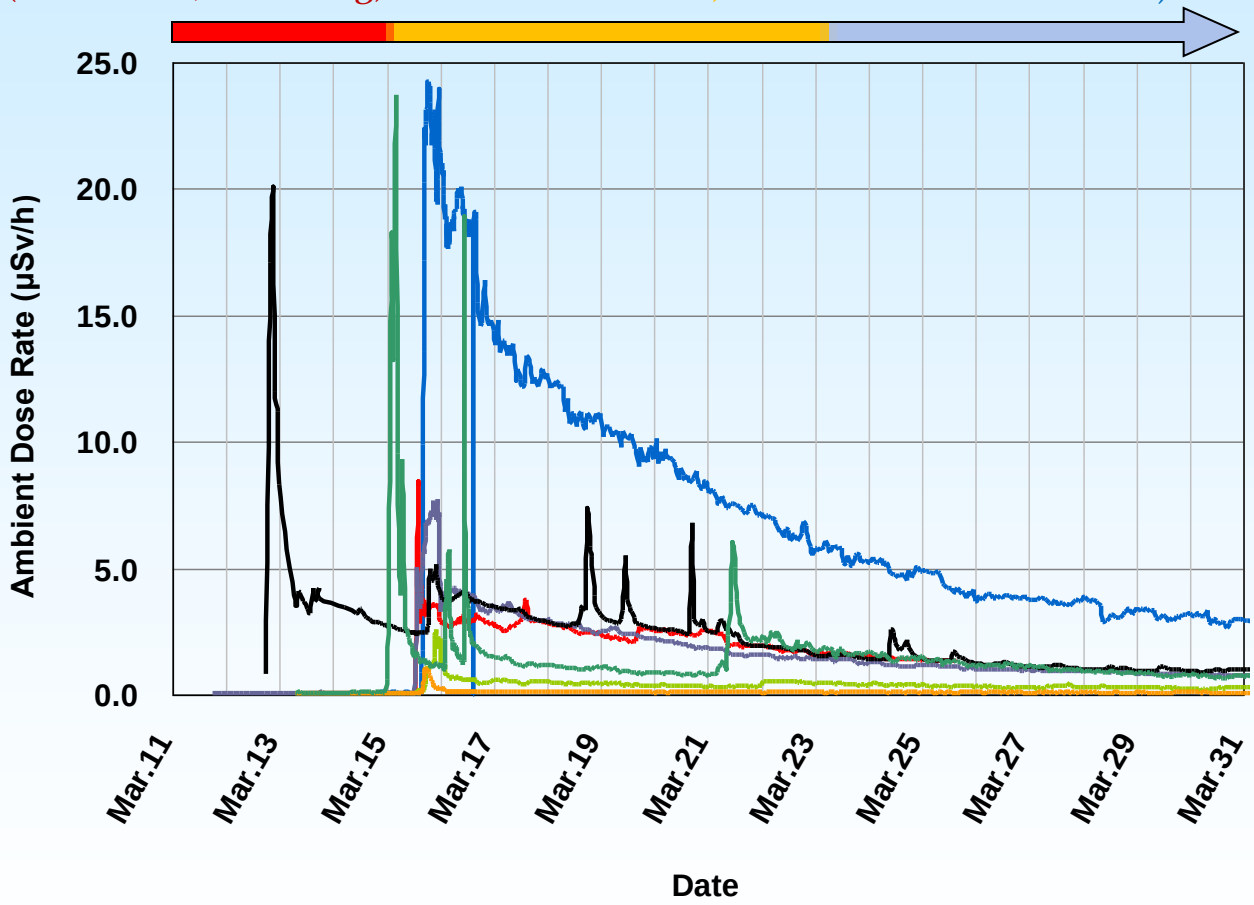
- Emergency response system in Japan
  - Decision making to initiate off-site protective actions relies heavily on **computer-based prediction systems**
- NSC “Emergency Preparedness Guide”
  - Criteria for **long term protective actions** such as temporary relocation and termination criteria are not prepared

Radiological situation and corresponding protective actions

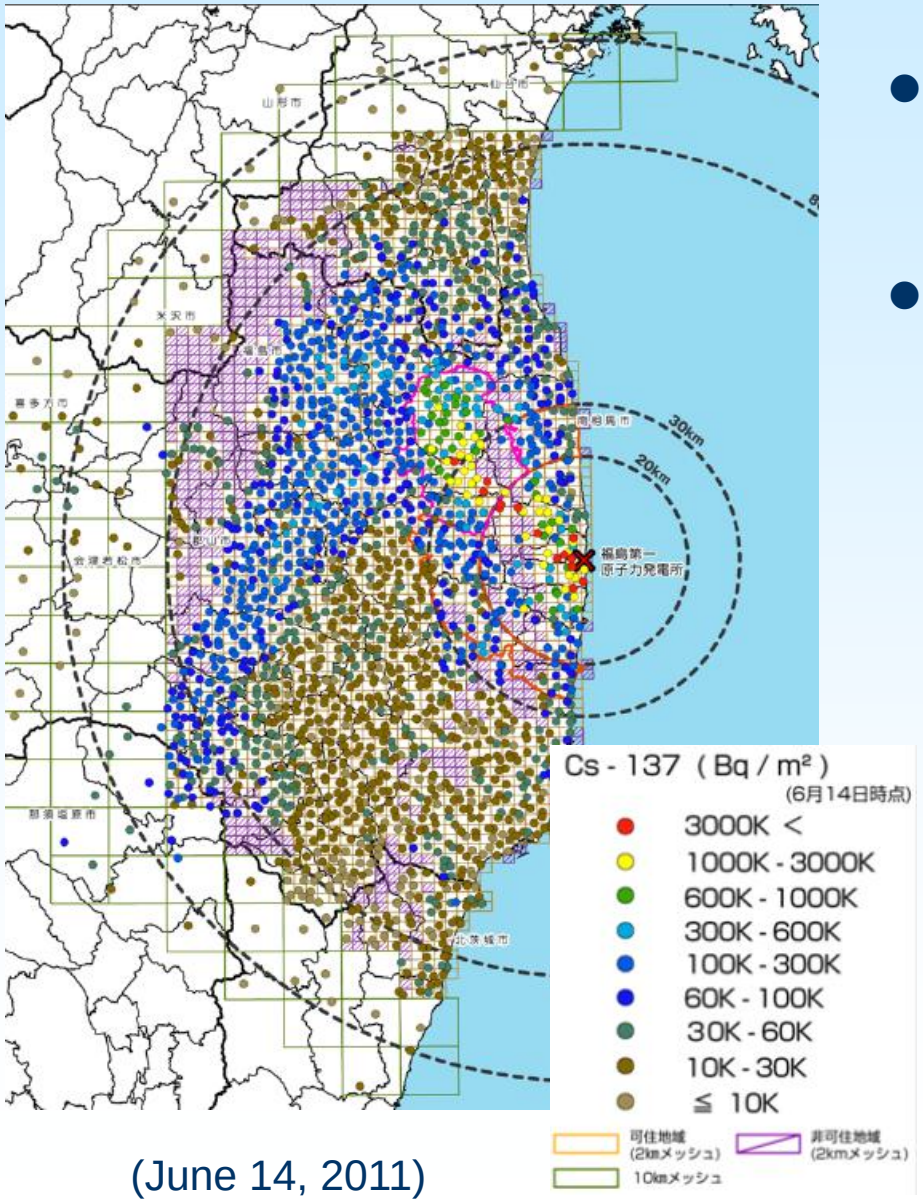
Precautionary urgent protective actions (evacuation, sheltering)

Urgent protective actions (foodstuff and water restrictions)

Early protective actions (preparation for temporary relocation)



Radioactive contamination



(June 14, 2011)

- Cs soil contamination map by MEXT
  - ✓About 2200 points (2 km ×2 km)
  - ✓Max: Cs-137 15MBq/m^2
- Area with Cs-137 deposition density range (km^2)

Cs-137 (kBq/m^2)	<185 37<	<555 185<	<1480 555<	>1480
Fukushima	3248	844	264	132
Russia	49,800	5,700	2,100	300
Belarus	29,900	10,200	4,200	2,200
Ukraine	37,200	3,200	900	600

Urgent protective actions

March 11

- 14:46 Earthquake occurred (NISA EP Headquarters in Tokyo)
- 19:03 Government declared the state of Nuclear Emergency
- 20:50 Evacuation of residents within a 2 km radius (1900 people)
- 21:23 **Evacuation** of residents within a **3 km radius** (6000 people)
  Sheltering of residents within a 10 km radius **(Unit 1 not cooled)**

➡ **Completed at 1:45 on 12th**

March 12

- 05:44 **Evacuation** of the residents within the **10km radius** (51,000 people)
- 15:36 Hydrogen explosion at Unit 1 **(Pressure in PCV increased)**
- 18:25 **Evacuation** of the residents within the **20km radius** (78,000 people)

(Risk at multiple reactors) ➡ **Completed at 14:00 on 15th**

March 14

- 11:01 Hydrogen explosion at Unit 3

March 15

- 06:10,14 sound around S/C at Unit 2, explosion at Unit 4 SFP
- 11:00 **Sheltering** of the residents from **20 to 30 km radius**

March 16

- Local ERH issued “the direction of administration of stable iodine during evacuation” to the Prefecture Governors and heads of municipalities

March 25

- Promoted voluntary evacuations of the residents from 20 km to 30 km

FP release to the environment by SA code

- **MELCORE results by JNES** as **cross-check** to MAAP results by TEPCO
- 1F1: Early core melting and melt through of RPV bottom head less than 6 hours
- 1F2: Core melting about 8 hrs after termination of RCIC resulting RPV melt through
- 1F3: Core melting after termination of HPCI and RPV melt through resulted

Unit 2

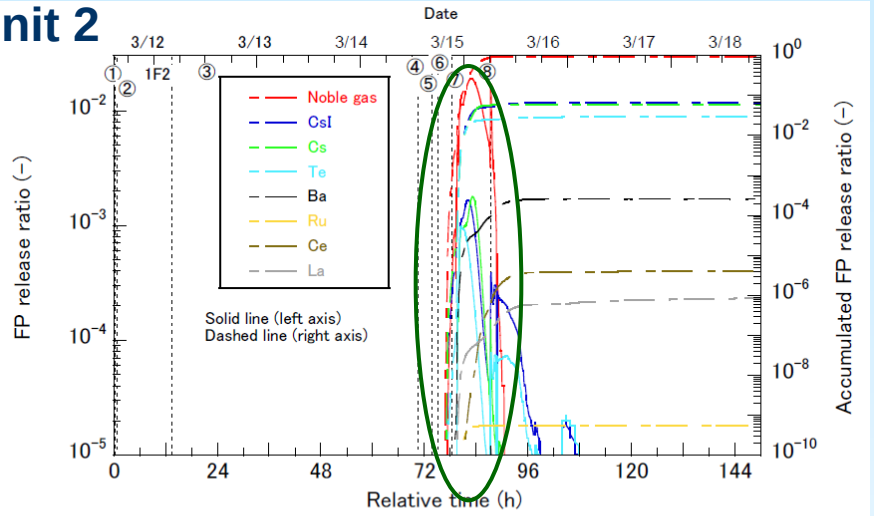


Fig. 2-2-10 FP release ratio to the environment (2/2) (unit 2) [TEPCO-2]

①RCIC start manually, ②SBO, ③Water source change from CST to S/P, ④RCIC stop, ⑤Sea water inject., ⑥RPV depressurized, ⑦S/R valve-2 open, ⑧Impact sound

Unit 1

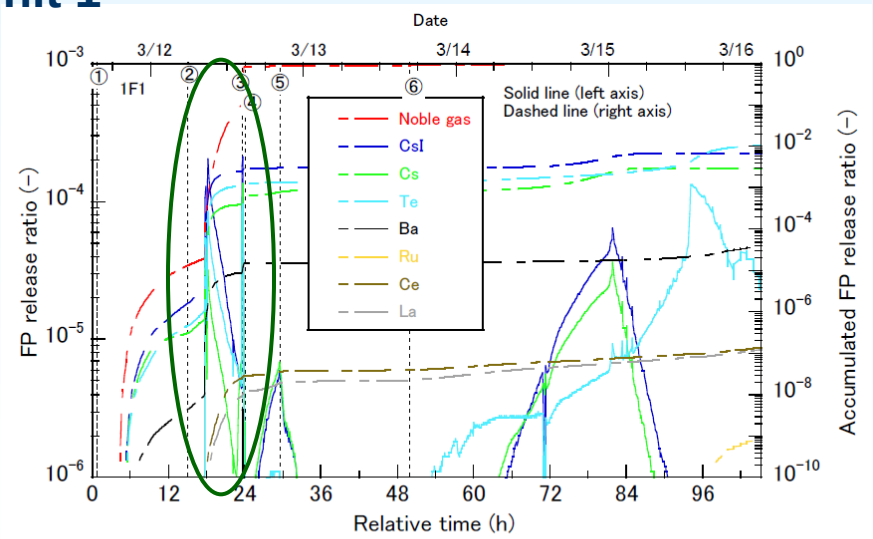


Fig. 1-3-10 FP release ratio to the environment (3/3) (unit 1) [case 2]

①IC stop, ②PCV failure (assumption), ③W/W ventilation (open), ④W/W ventilation (close), ⑤ sea water inject., ⑥expansion of PCV failure (assumption)

Unit 3

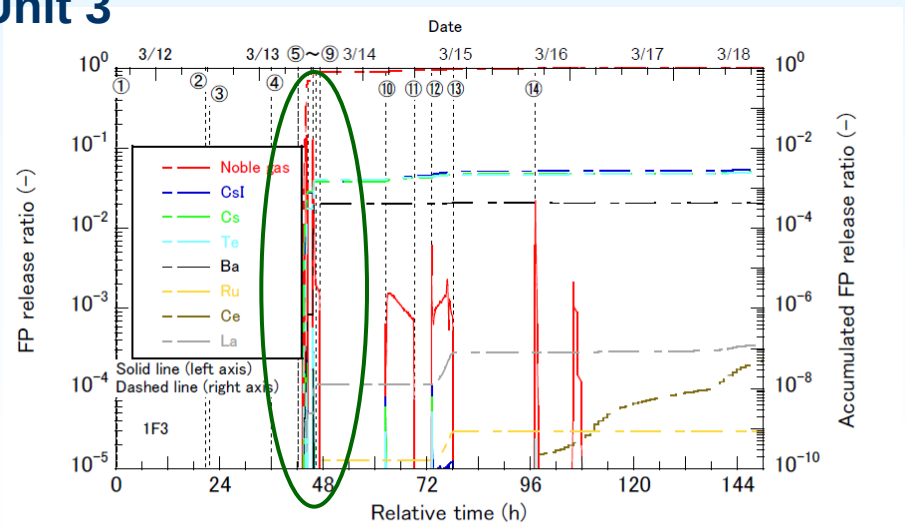


Fig.3-2-10 FP release ratio to the environment (2/2) (unit 3) [TEPCO-2]

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)

Radionuclide releases to the atmosphere

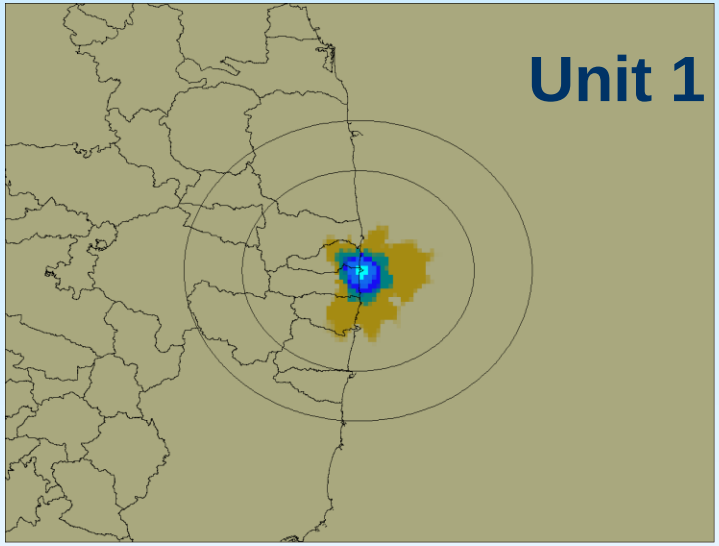
- INES preliminary estimates
  - NISA I-131: 1.6×10^{17} Bq (about 0.02 of total inventory, Unit 1-3)
    Cs-137: 1.5×10^{16} Bq (about 0.02 of total inventory, Unit 1-3)

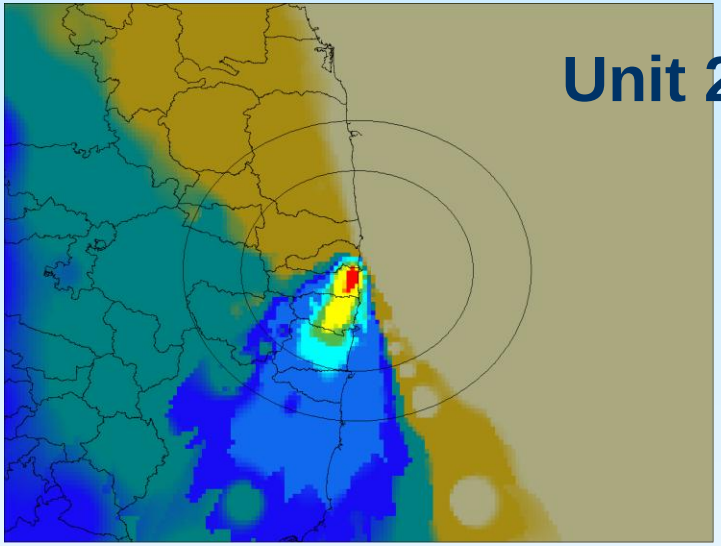
  (Chernobyl I-131: 1.8×10^{18} Bq, Cs-137: 8.6×10^{16} Bq)

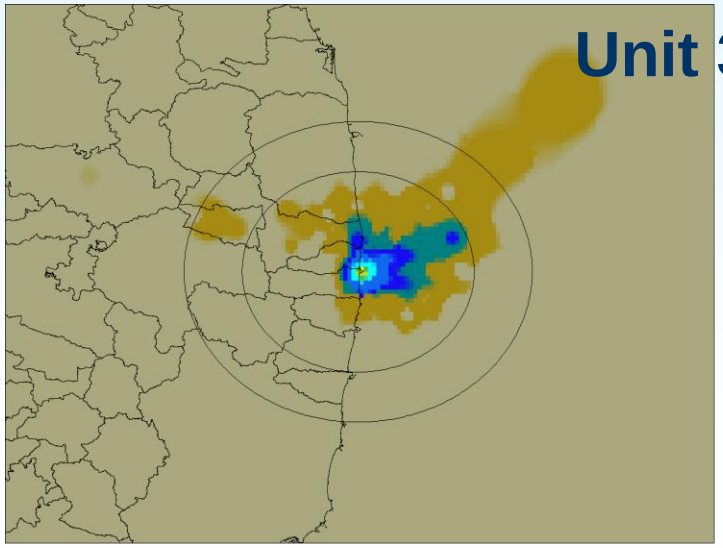
- Estimated maximum release fractions to inventory by SA codes

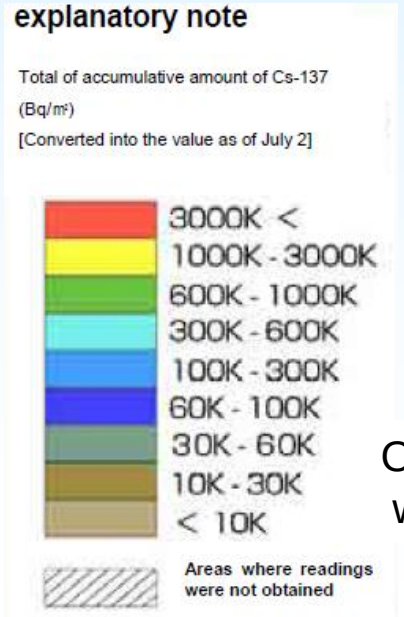
	Noble gas	I	Cs	Te	Ba	Ru	Ce	La
Unit 1	0.99	6.6×10^{-3}	2.9×10^{-3}	2.4×10^{-2}	1.2×10^{-4}	6.4×10^{-9}	1.1×10^{-6}	1.1×10^{-6}
Unit 2	0.97	6.7×10^{-2}	5.8×10^{-2}	5.1×10^{-2}	4.9×10^{-4}	7.6×10^{-10}	1.3×10^{-5}	1.2×10^{-6}
Unit 3	0.99	8.2×10^{-3}	5.9×10^{-3}	2.7×10^{-3}	6.1×10^{-4}	8.6×10^{-10}	5.0×10^{-8}	1.3×10^{-7}
Chernobyl	1.0	0.6-0.5	0.4-0.2	0.6-0.25	0.06-0.04	>0.035	0.015	0.015

Cs-137 contamination calculated by models





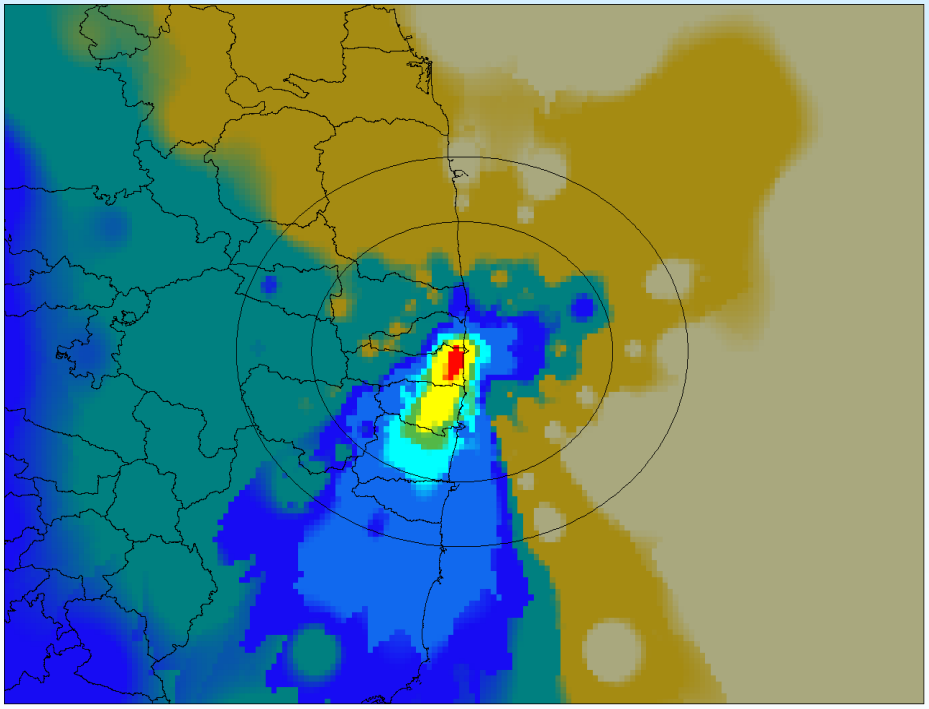




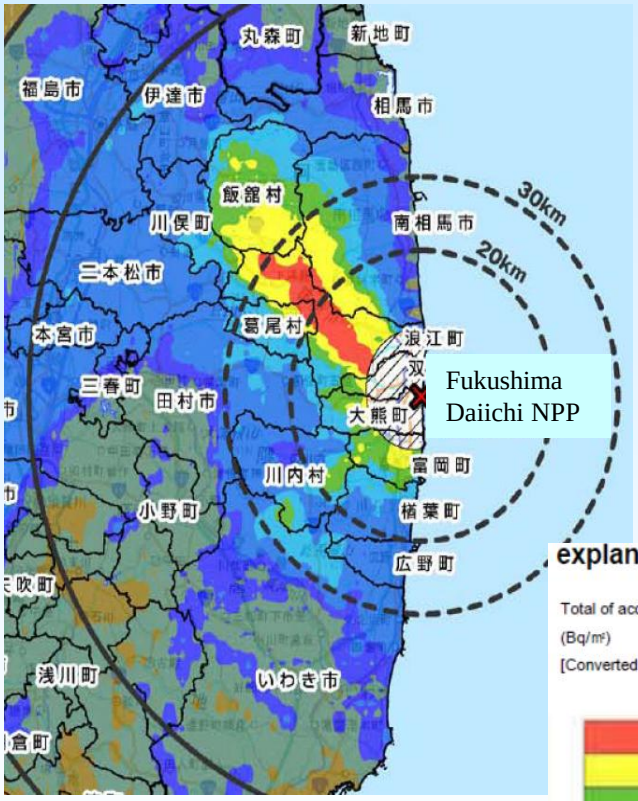
OSCAAR calculations
with MELCOR source terms

Comparison of Cs-137 contamination by models with monitoring data

Total releases from Unit 1, 2 and 3



OSCAAR calculations with MELCOR source terms



Airborne monitoring

- The difference highlights the difficulty of protective action recommendation based on computer-based dose predictions.

Strategy of precautionary urgent protective action

- In emergency exercises, recommendations of taking urgent protective action are made based on **real-time dose predictions** by computer-based prediction systems (ERSS, SPEEDI) with intervention levels.
- In the Fukushima case, Government implemented evacuation and sheltering based on **plant conditions**.

ICRP 109 (**§** 9)

- To implement urgent protective actions, there is no time to undertake detailed exposure assessments in real time. It is therefore necessary to determine, in advance, a set of internally consistent criteria for taking such actions, and, based on these criteria, to derive appropriate **"triggers"** for initiating them in the event of an emergency.

IAEA GS-R-2, GSG-2

- Precautionary urgent protective actions are taken on the basis of **conditions at the facility** to prevent severe deterministic health
- GSG-2 provides **emergency classification system** and examples of EAL (Emergency Action Level)

Foodstuffs and drinking water restrictions

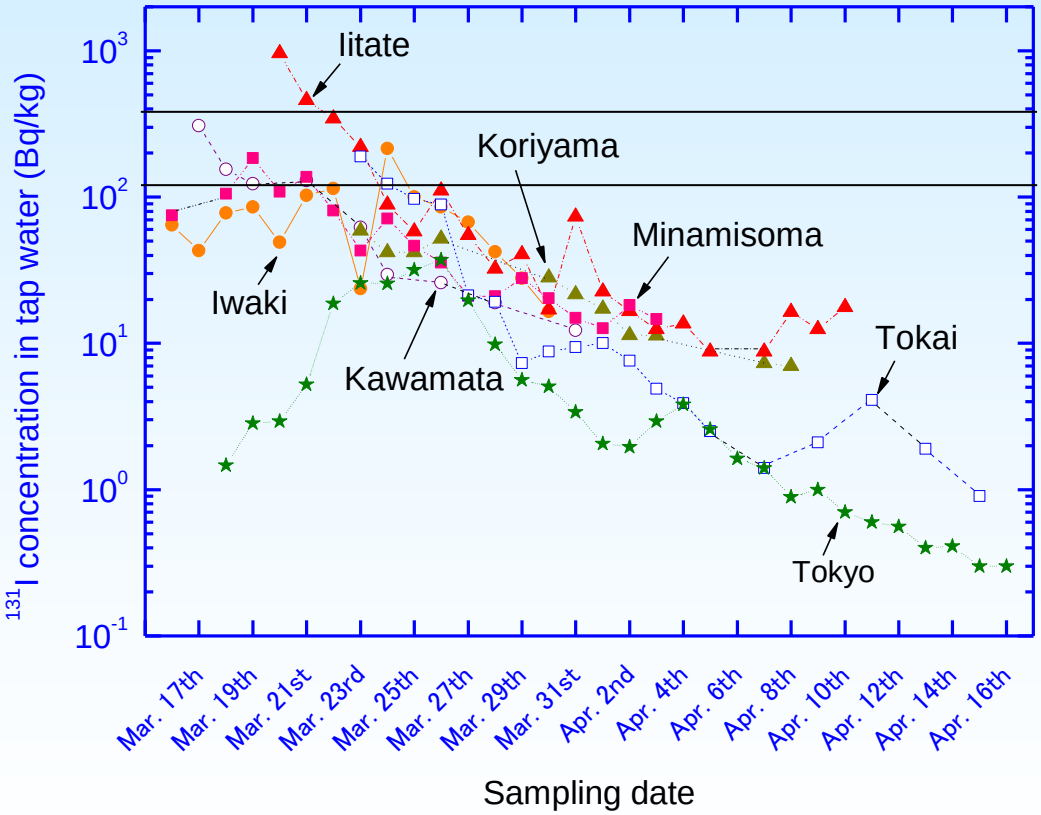
- March 17: Ministry of Health, Labour and Welfare (MHLW)
  Adopt NSC' criteria as **provisional regulatory values**
- March 19 and 21: MHLW
  Request actions against **water supply** and for **infants' ingestion** of tap water
- March 21: Nuclear Emergency Response Headquarters (NERH)
  Instruction to **restrict distribution** of foods
- March 25: Ministry of Agriculture, Forestry and Fisheries
  Instruct methods of **waste disposal** of vegetables and raw milk
- April 4: NERH
  Concepts of establishing and **cancelling** items and areas on restriction of distribution and/or consumption of foods
- April 5: MHLW
  Provisional regulation values for radioactive iodine in **fishery products** (2000 Bq/kg)
- April 22: NERH
  Restrict **rice farming** in evacuation area, planned evacuation area and emergency evacuation preparation area (5000 Bq/kg soil)

Protective actions for drinking water

- Actions against water supply (MHLW, 3/19)
  - ➢To refrain from drinking water (I: 300 Bq/kg, Cs: 200 Bq/kg)
  - ➢Use the tap water for domestic use (Iitate: 3/21 - 4/1)
- Actions for infants' ingestion of tap water (MHLW, 3/21)
  - ➢To refrain from giving infants formula milk dissolved by tap water (100 Bq/kg)

  (Fukushima, Ibaraki, Chiba, Tokyo, Tochigi, 3/21 – 4/1, 5)

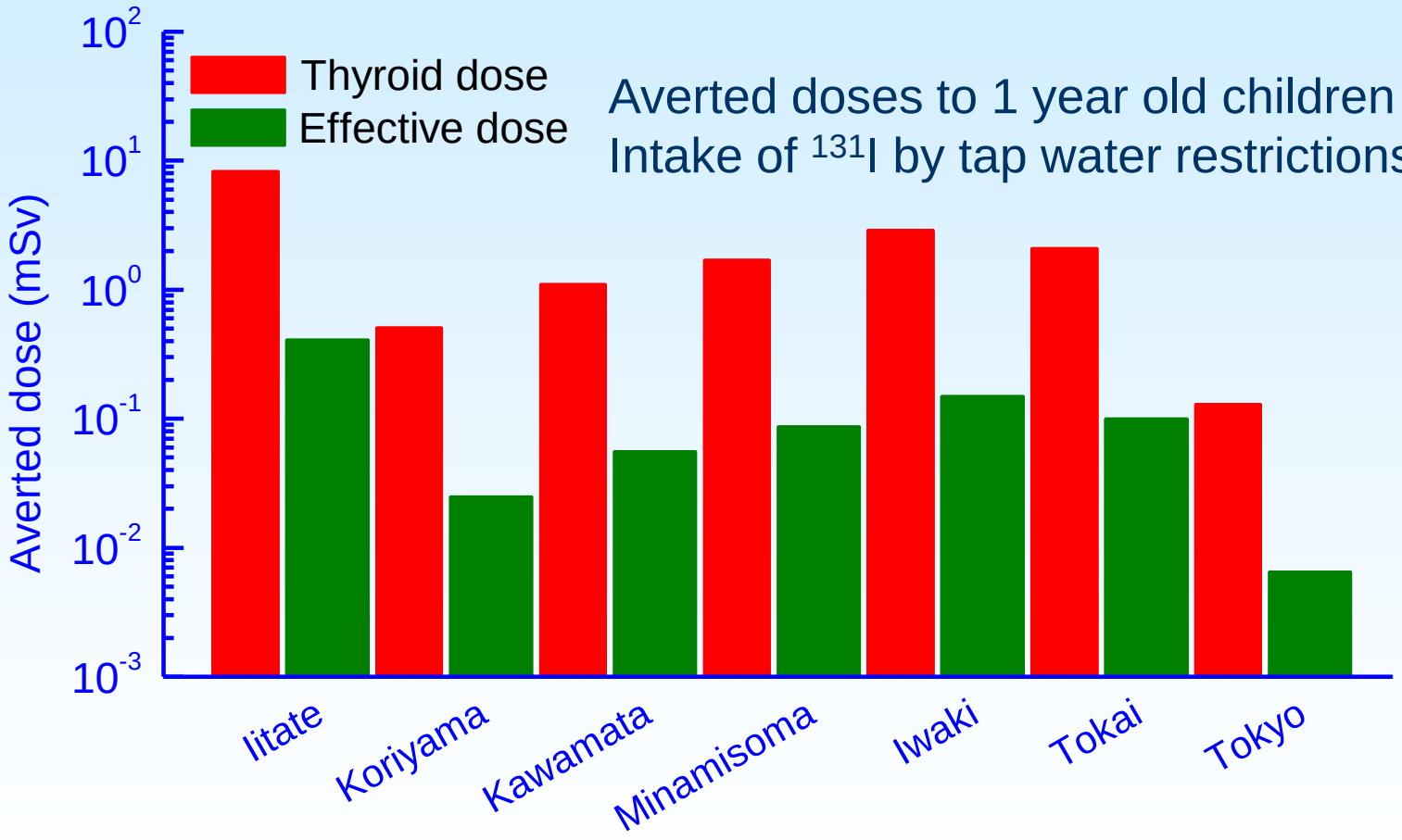
Concentration of ^{131}I in tap water



Apparent half-life of 131I in tap water: 2.8±1.2 days

(S. Kinase *et al*., Trans. A. Energy Soc. Japan, 10(3) 149, 2011)

Averted doses by drinking water



(S. Kinase *et al*., Trans. A. Energy Soc. Japan, 10(3) 149, 2011)

Foodstuffs contamination

- 1106/102271=1% food exceeding provisional limits (Feb. 2, 2012)

Food category	No. samples	Concentration of Cs (Bq/kg)				period
		< 100	100 – 300	300 – 500	500<	
vegetables	3666	3660	6	0	0	Jul–Oc
fruits	2005	1820	130	33	2	10/31
rice	3217	3208	7	1	1	11/17
wheat	549	522	22	4	1	10/31
tea leaf	1768	476	869	262	161	10/31
mushroom (c)	1329	991	144	78	116	10/31
mushroom (n)	381	311	41	5	24	10/31
milk	964	964	0	0	0	Ap–Oc
beef	24530	23464	614	302	150	11/6
pork	255	250	5	0	0	11/6
chicken	87	87	0	0	0	11/6
egg	168	168	0	0	0	11/6
fishery products	5286	4234	697	169	186	11/6

c: cultivation, n: natural

Proposed criteria on food restrictions

Category	Previous		New
	I	Cs	Cs
Drinking water	300	200	10
Milk, dairy			50
Vegetables	2000	500	100
Grains	–		
Meat, eggs, fish			
Infant food	–	–	50

- Previous: NSC's action level ⇨ MHLW's provisional regulation value (March 17)
  - Reference level: I - 50mSv thyroid equivalent dose
    Cs - 5 mSv effective dose
- New: MHLW proposed (from next April), Food sanitation Act
  - Reference level: 1 mSv (Cs-134, Cs-137, Sr-90, Ru-106, Pu-238,239,240,241)

Criteria for use in food and water restrictions

- Radioactivity in food and drinking water has cause significant public anxiety and also rumor effect.

Early stage

- Quick response is needed to avert ingestion dose from elevated levels of radioactivity.

  ⟹ OILs for gamma dose from contaminated surface (GSG-2)

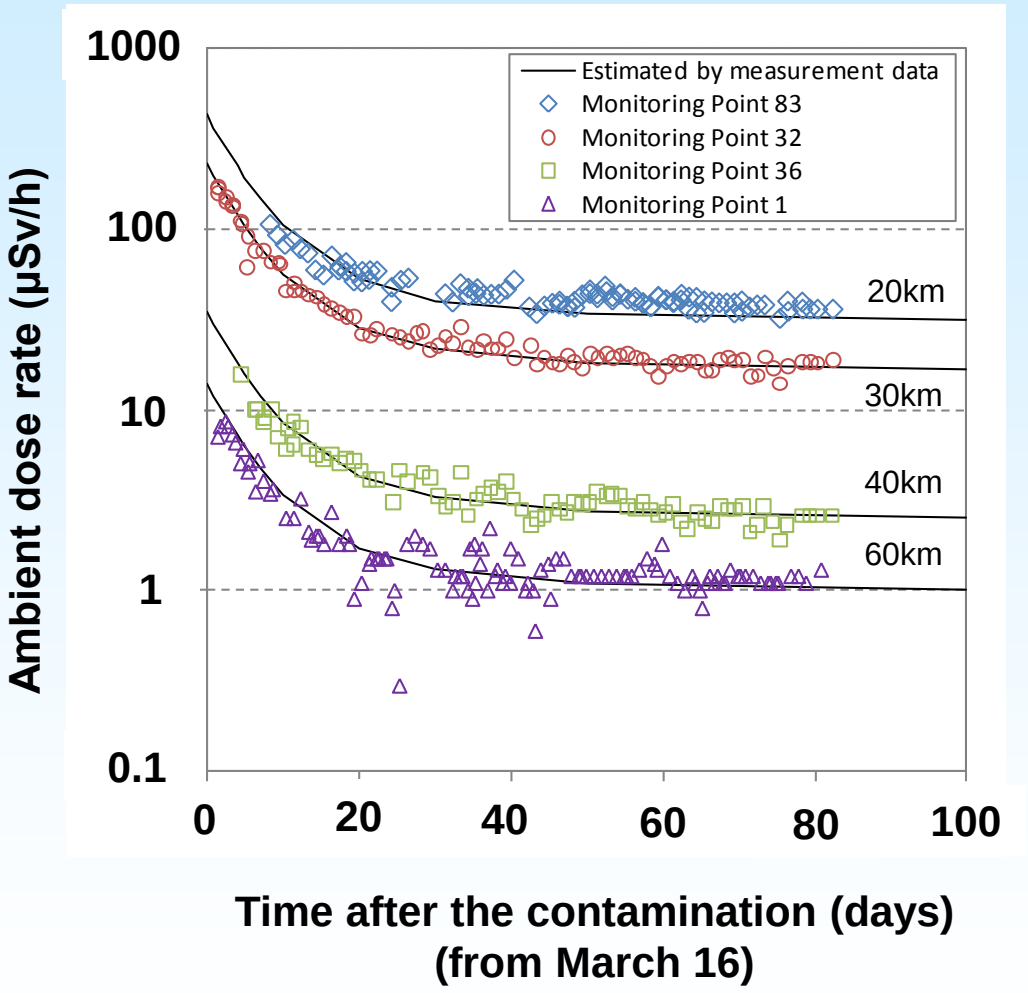
Intermediate and longer term stage

- Criteria for foodstuff restrictions should be considered in the process of **optimization for the whole protection strategy**.
  - Radiological and nutritional impact
  - **Reference level** and contribution of ingestion dose to the total dose

$$DIL = \frac{RL}{f \times I \times DF}$$

  - Realistic estimates based on **dietary habits** and **market dilution**
  - Harmonization to internationally agreed standards for trade

Ambient dose rate at north-west hot spot areas



Nuclides	Composition
Mo-99	0.43
I-131	11.
Te-129m	1.1
Te-132/I-132	8.4
Cs-134	0.92
Cs-136	0.21
Cs-137	1
Ba-140	0.057
La-140	0.062

IAEA Update Log on March 30

- IAEA advised Japanese Government to carefully assess the situation.
  - The total deposition of I-131 and Cs-137 has been calculated based on measurements in soil sampled from 18 to 26 March at distances of 25 to 58 km from the NPP
  - I-131 : 0.2 - 25 MBq/m^2, Cs-137 : 0.02-3.7 MBq/m^2.
- One of the IAEA operational criteria for evacuation was exceeded in Iitate village.

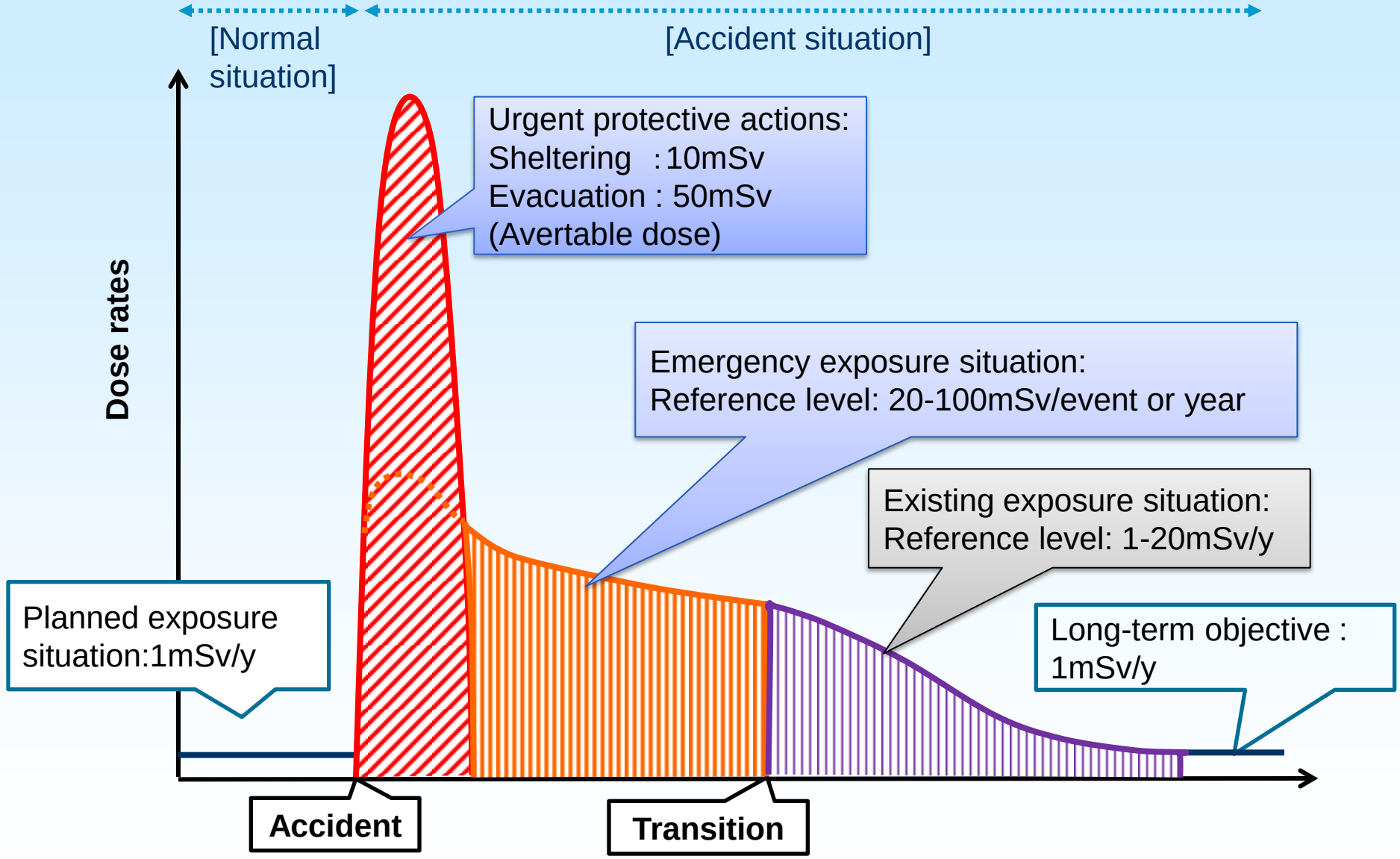
	A) Type, B) GC, C) Exposure pathways	Dose rate	Ground deposition	
			I-131	Cs-137
OIL1	A) Ground deposition monitoring for urgent protective action (eg. evacuation) B) 100mSv (7 days) C) Ground shine; inhalation of resuspension; and inadvertent ingestion of soil.	200 μSv/h at 1 m	10 MBq/m^2	5 MBq/m^2
OIL2	A) Ground deposition monitoring for early protective action (eg. relocation) B) 100mSv (1 year) C) Ground shine; inhalation of resuspension; and inadvertent ingestion of soil.	100 μSv/h at 1m	1 MBq/m^2	1 MBq/m^2

Modifying initial protective actions

Provisions for a Deliberate Evacuation Area and Evacuation-Prepared Area (April 10, 2011, by NSC)

- Deliberate Evacuation Area
  - The residents in this area, where annual cumulative dose after the oneset of the accident would potentially reach 20mSv, are to be advised to evacuate
- Evacuation-Prepared Area
  - For the area 20 and 30 km radius from the plant still remain for emergency sheltering or evacuation due to the plant conditions
  - The residents in this area need to be always prepared themselves for sheltering or evacuation in case of further emergency
  - The residents in this area are recommended to continue their voluntary evacuation, in particular, children, pregnant women, those who need nursing care and inpatients

Radiological protection criteria



Transition from emergency to existing situation

Deliberate Evacuation Area (Emergency exposure situation)

- The residents in this area, where annual cumulative dose after the onset of the accident would potentially reach 20mSv, are to be advised to evacuate.
- A level of 20 mSv was selected with consideration of ALARA in the dose band of 20 to 100mSv.

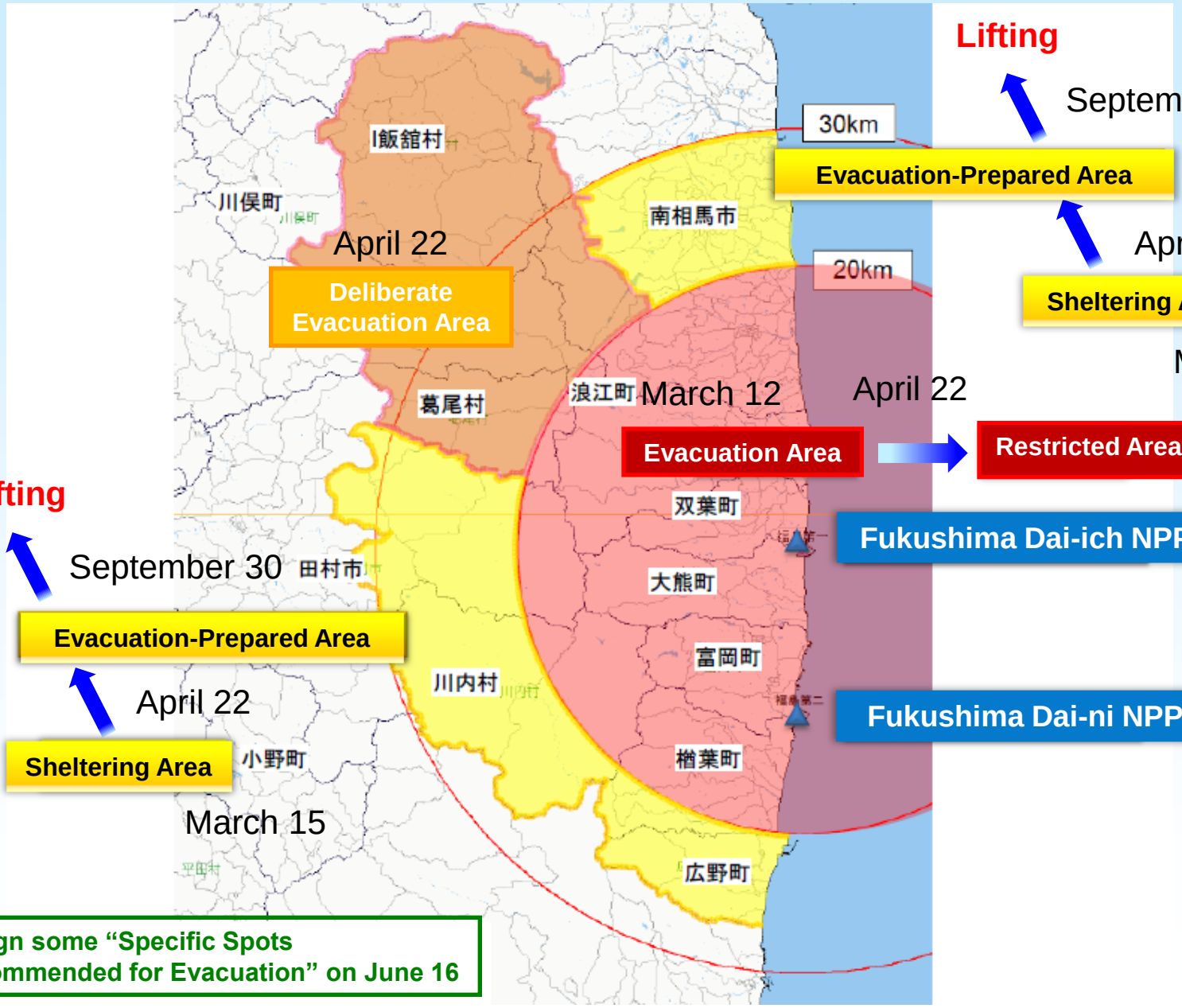
ICRP 109(**§** X)

- this transition may take place at different geographical locations at different times, such that some areas are managed as an emergency exposure situation whilst others are managed as an existing exposure situation.

Use of playground of schools (Existing exposure situation)

- MEXT selected 20mSv/y in the dose band of 1 to 20mSv on Aril 19.
- A level of 20mSv was selected as a starting point for optimization

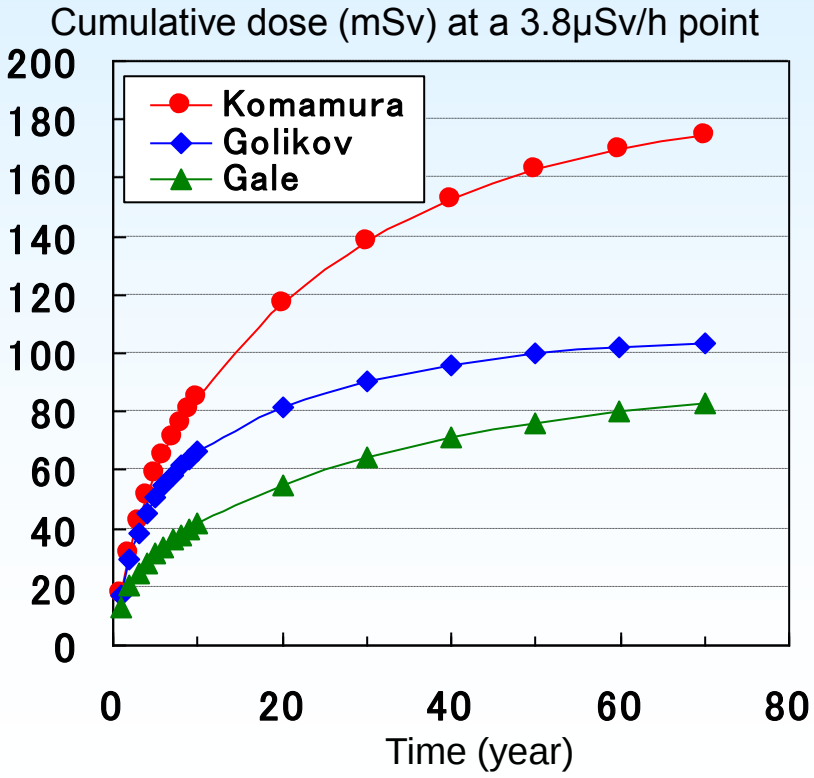
Protective action areas

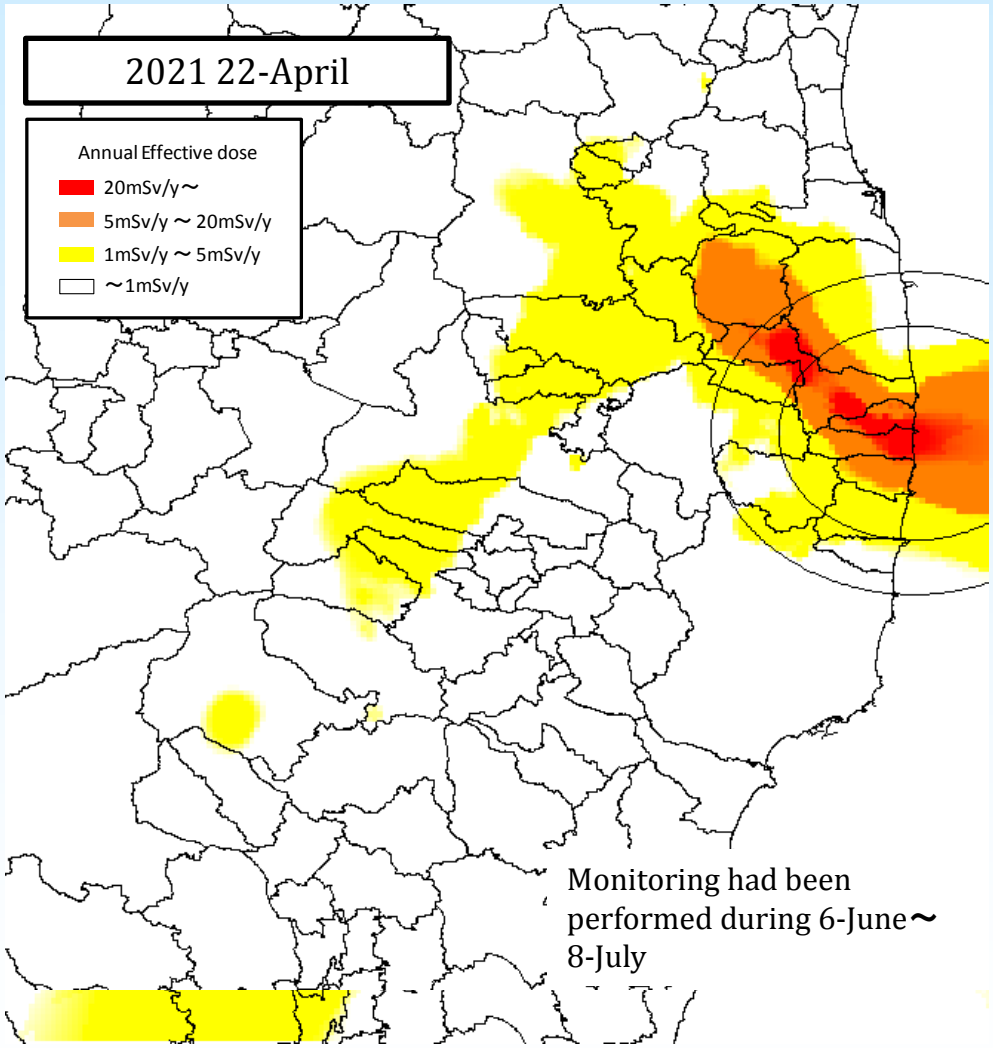


Assign some “Specific Spots Recommended for Evacuation” on June 16

Future radiological situation

- Groudshine dose from soil
  ^{134}Cs:^{137}Cs = 1 : 1
- Weathering
  - Komamura - ^{137}Cs fallout (18.4 year)
  - Golikov - Chernobyl experience
  - Gale - ^{137}Cs experiments





Standpoint for termination of urgent protective actions by NSC (August 4, 2011)

- Basic standpoint
  - The criteria for the application of current actions are no more applicable .
  - Necessary preparations for new protective actions should be made.
  - A framework for involvement of related local governments and residents with the process should be constructed and utilized properly.
- Evacuation-Prepared Area
  - Possibility of urgent sheltering or evacuation is extremely small.
  - Necessary decontamination and monitoring should be implemented.
- Evacuation Area (within a 20 km zone)
  - Possibility of urgent sheltering or evacuation is extremely small.
  - Annual dose is expected to be 20 mSv or less, ALARA, a long-term goal of 1 mSv/y
- Deliberate Evacuation Area
  - Annual dose is expected to be 20 mSv or less, ALARA, a long-term goal of 1 mSv/y
  - An optimized plan of protective actions is clearly made.

Procedures for termination of evacuation

Evacuation-Prepared Area

National Authority

■Stability of nuclear reactor facility

✓ The possibility of a hydrogen explosion and the effects of a reactor cooling failure are low.

✓ External and internal doses are lower than the criteria of the emergency preparedness guideline in Japan

Local Government

■ Safety of schools and public facility

✓ Implementation of decontamination and detailed monitoring

These results were also reported to the NSC at Augst-9

Taking into account current situations of affected areas and Inhabitant's preference

■ Reviewing a Restoration Plan

Termination of Evacuation-Prepared Area(September 30)

provide the necessary supports for homecoming taking into account Restoration Plans

⇄

Implementation of Restoration Plan

Deliberate Evacuation Area

National Authority

■ Until local residents return home after lifting the evacuation directive, the national government will take the initiative in decontamination work

⇅ collaborate

Local Government

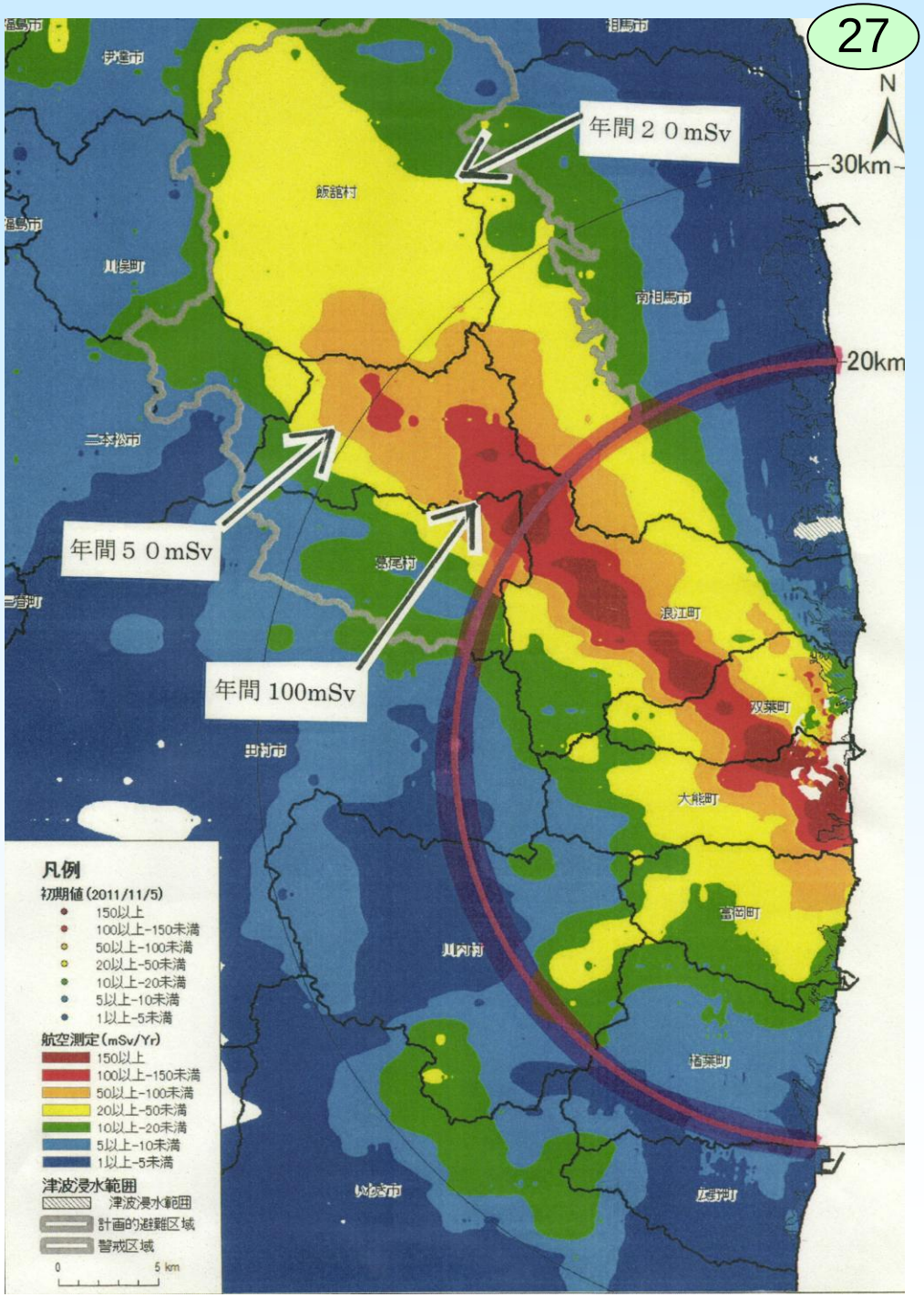
■Pilot projects will be performed for effective and efficient decontamination techniques .

■The government aims at quickly reducing areas with emergency exposure situation (i.e. additional dose is exceeding 20mSv y^{-1})

Termination of current restricted area

*Lifting of **Evacuation - Prepared Zone** (102 km²) < 20 mSv/y*
Decontamination ●10 – 20 mSv/y (Dec. 2012) ●5 – 10 mSv/y (March 2013) ●1 – 5 mSv/y (March 2014)
***Restricted Zone** (72 km²)* *20 mSv/y < < 50 mSv/y*
● Decontamination will be implemented at the level below 20 mSv/y by the end of March 2014.
***"Difficult to Return" Zone** (93 km²)* *50 mSv/y <*
● It will decide on measures while observing the effectiveness of model decontamination work.

(NERH, Dec 26, 2011)



Lessons learned

- A general lesson learned from the Fukushima accident is that there was an implicit assumption that such severe accidents could not happen and thus enough attention had not been paid to preparedness for the accidents by operators and authorities.
- The consistent policies and criteria for implementation of urgent and long-term measures including return to normality should be established in the preparedness process for severe nuclear emergencies with low probability.
- Arrangements should be established for taking precautionary urgent protective actions before a release on the basis of plant conditions.
- International guidance should be developed for the application of operational criteria for use during the emergency response phase.
- Practical recommendations should be needed for control of contaminated foodstuffs and water with internationally harmonized criteria.

Conclusions

- The revised Recommendations for a System of Radiological Protection described in ICRP Publication 103, 109 and 111 have been very helpful and useful for implementing emergency protective actions in the Fukushima Daiich nuclear accident.

- We still need to prepare and implement further actions with respect to existing exposure situation in accordance with ICRP recommendations for system of radiation protection.