Environmental Radiation in Fukushima

Kimiaki Saito

Fukushima Environmental Safety Center

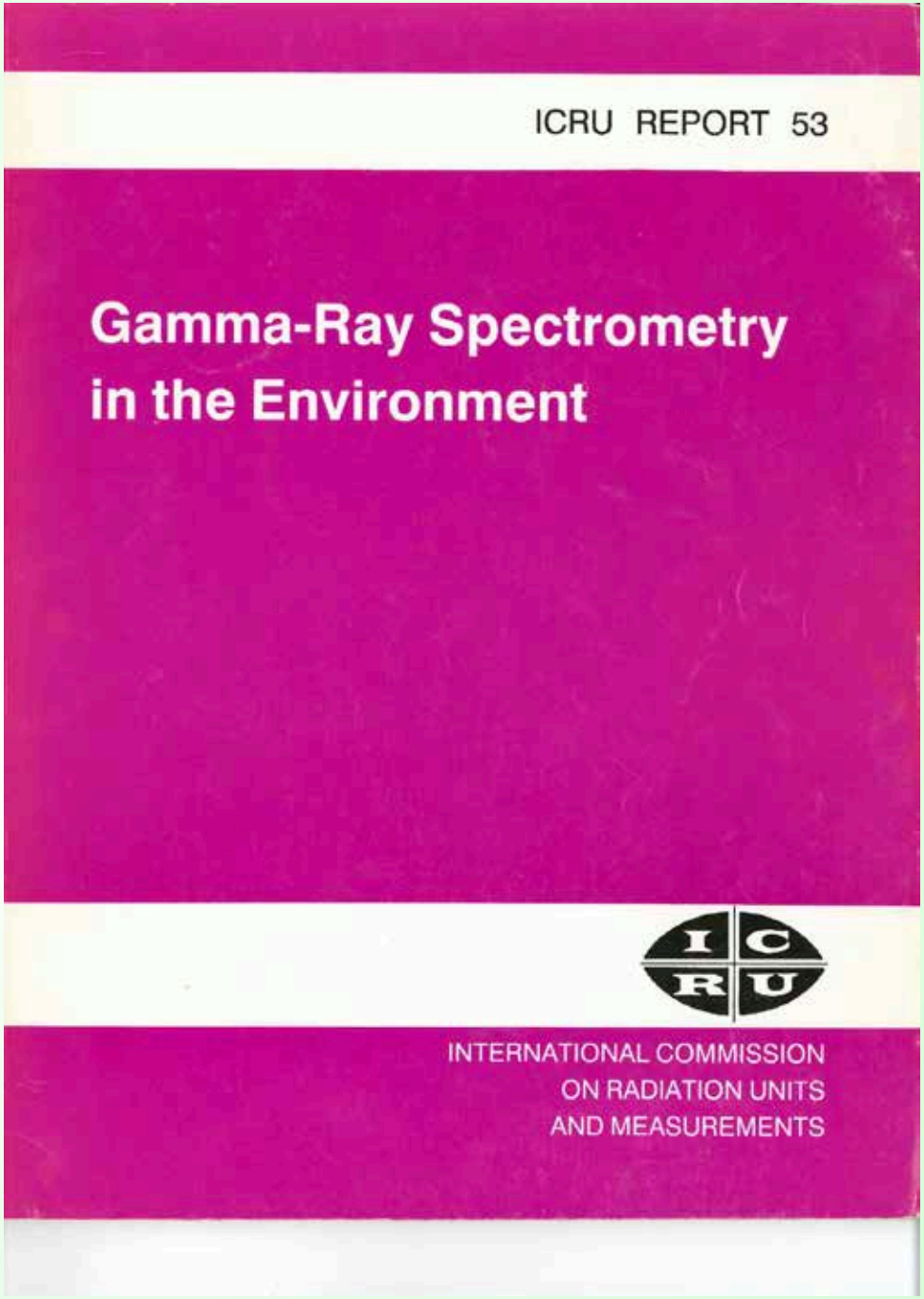
Japan Atomic Energy Agency (JAEA)

Meeting of the ICRU report committee

ICRU : International Commission on Radiation Units and Measurement

A report was published by the committee on basic data for evaluation of environmental measurements

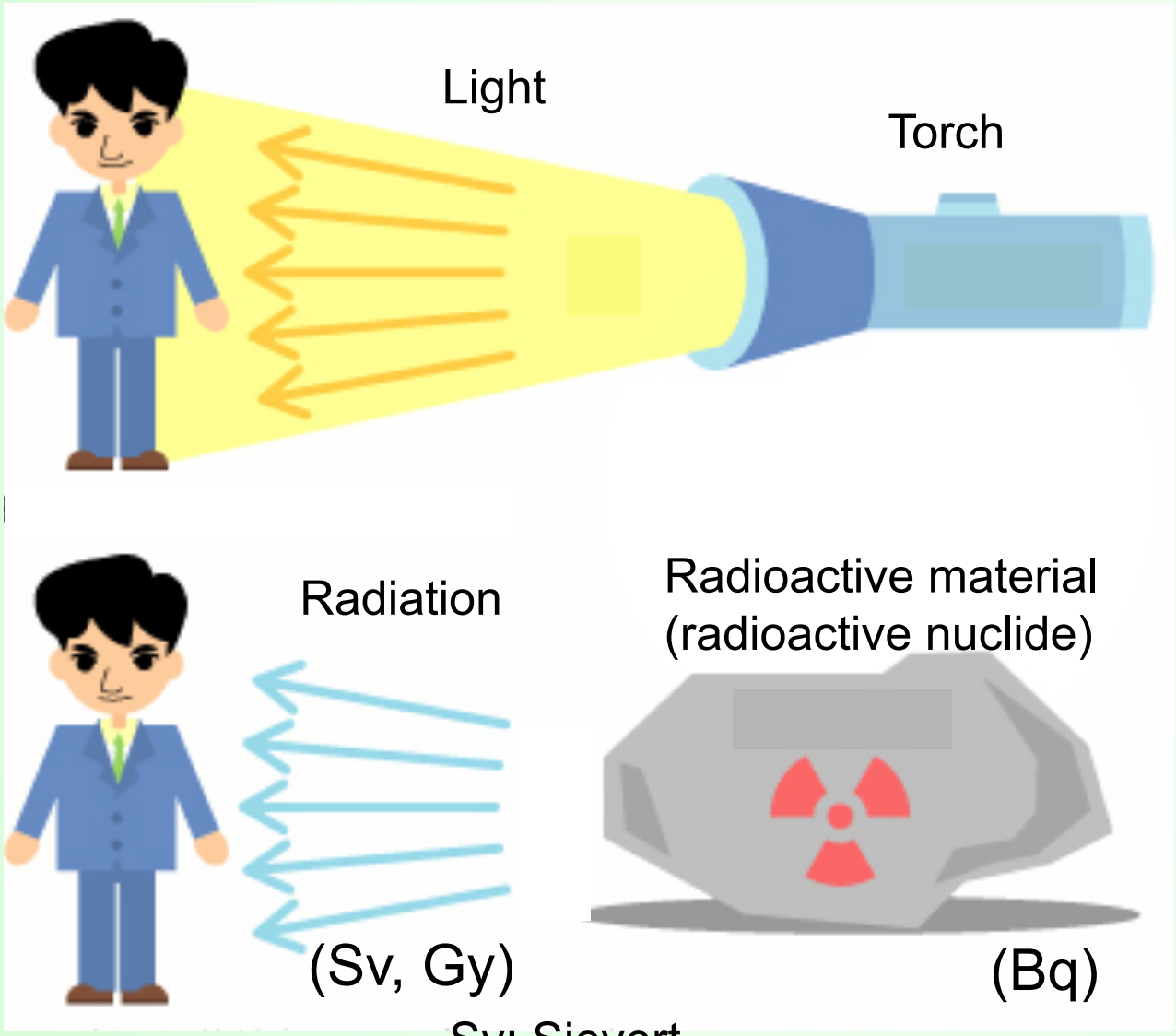
- *in situ* measurements using portable Ge detectors
- evaluate radionuclide ground deposition density and air dose rate



Overview

1. Introduction
   a) Radiation exposure in the environment
   b) About Fukushima prefecture
2. Environmental radiation in Fukushima
   a) National mapping projects
   b) Initial contamination conditions
   c) Temporal change in contamination conditions
   d) Movement of radiocesium
3. Recovery from the accident
   a) Arrangement of evacuation areas
   b) Decontamination activities
   c) Return of inhabitants

Radiation and radioactive material

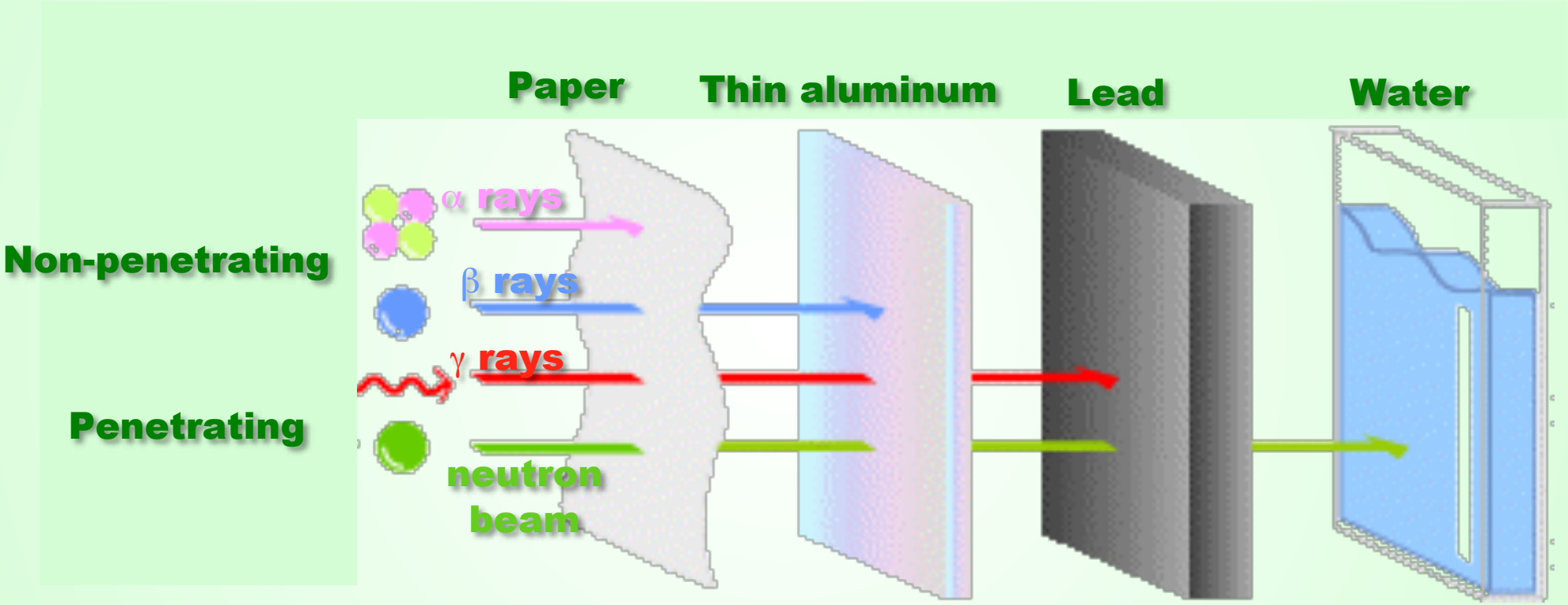


Sv: Sievert
Gy: Gray

Bq: Becquerel

- **Radioactivity originally means ability to emit radiations.**
- **Often "radioactivity" is used as "radioactive material".**

Radiations and their characteristics

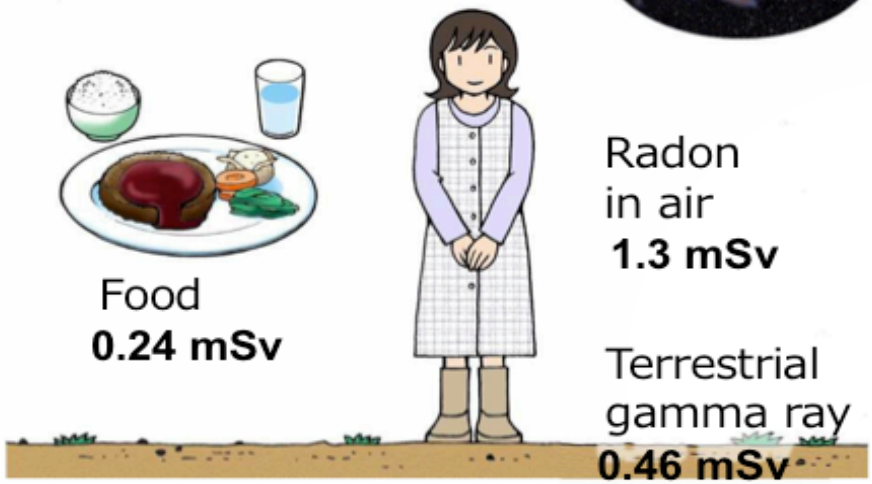


- α rays and β rays are important in internal exposures
- γ rays and neutron beam are important both in external and internal exposures

Radiation in daily life

Natural radiation

Cosmic ray
0.38 mSv

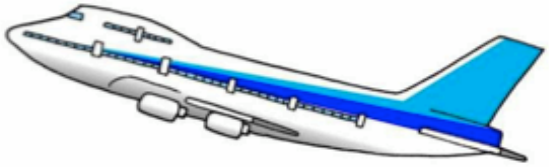


Radon
in air
1.3 mSv

Food
0.24 mSv

Terrestrial
gamma ray
0.46 mSv

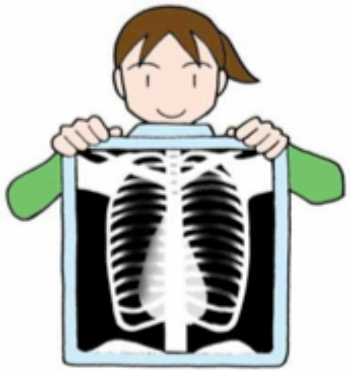
Average annual dose from natural radiation **2.4 mSv**



Round-trip flight from Tokyo to New York **~0.19 mSv**

Artificial radiation

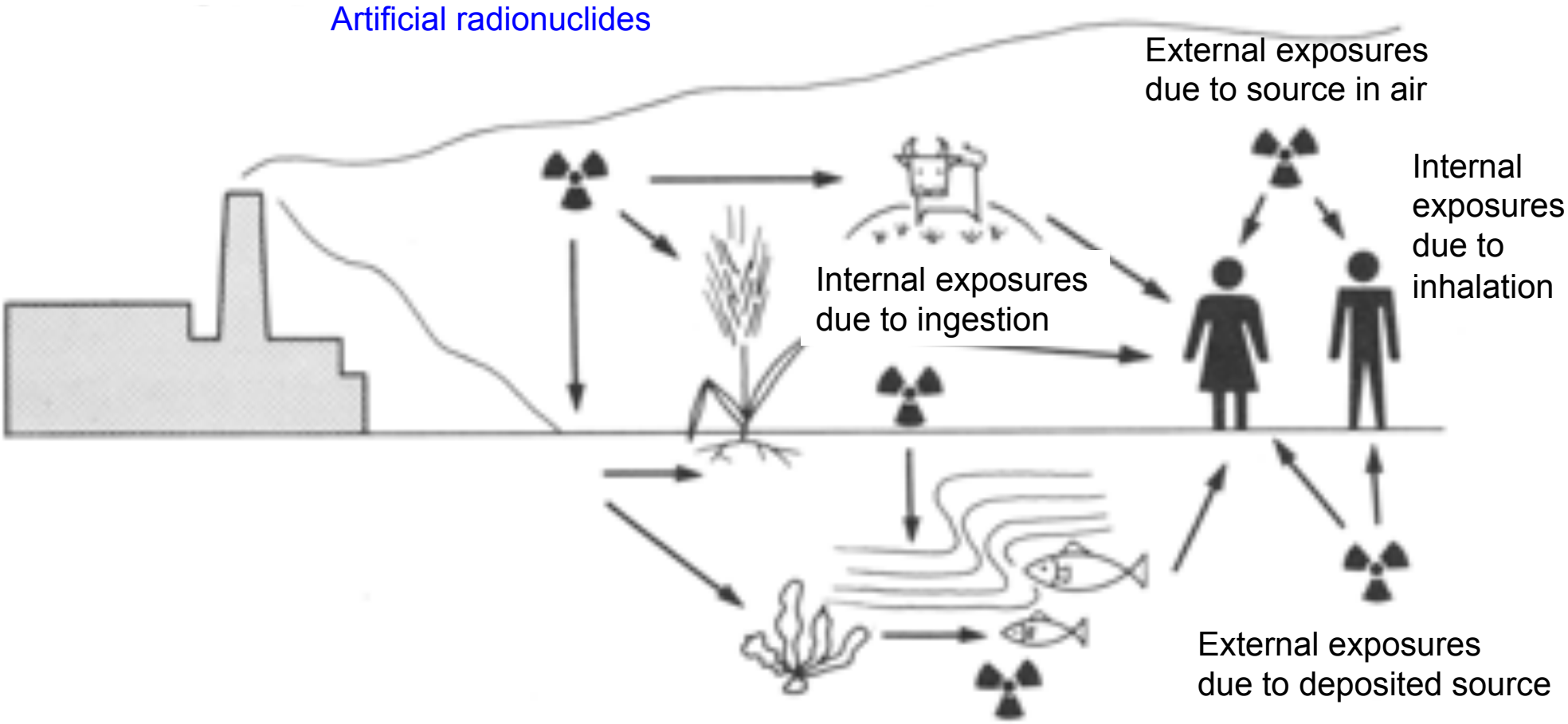
Chest CT scan **6.9 mSv**



Chest X-ray examination **0.06 mSv**

(NIRS home page)

Exposure pathways due to radionuclides released from nuclear facilities



Exposure doses are evaluated in terms of effective dose (Sv)

- **Radiation sensitivity depends on the organ or tissue.**

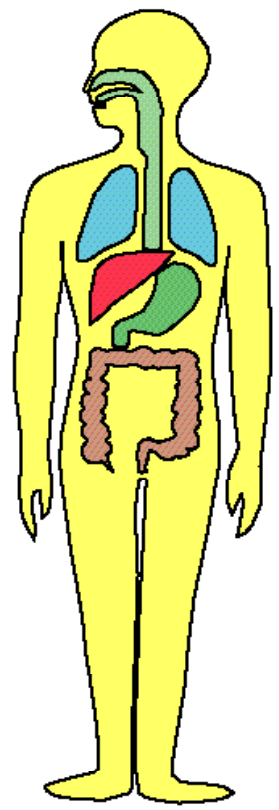
Effective dose E (ICRP'07)

$$E = \Sigma\, w_T \cdot D_T$$

D_T: Dose that an organ or tissue T receives

w_T: Weighting factor for considering radiation sensitivity

- **Radiation risk weighted whole body exposure dose**

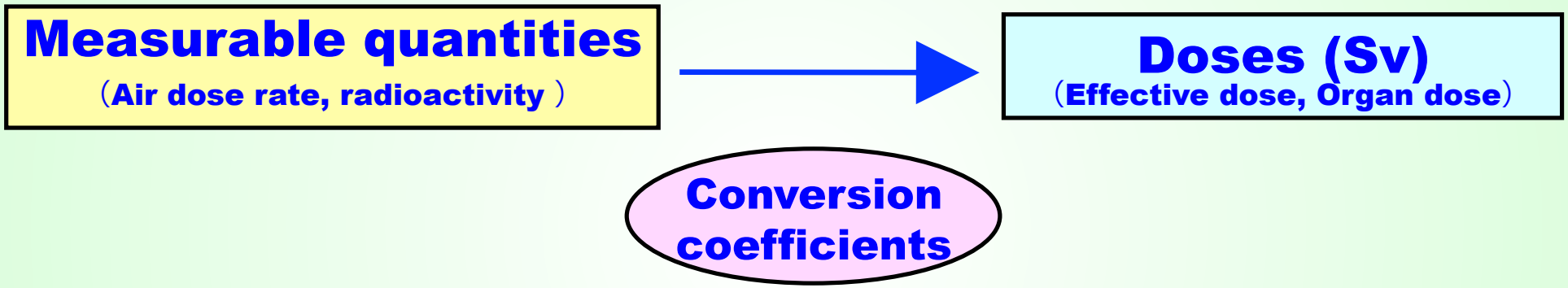


Convenient indicator able to measure radiation risk irrelevant to irradiation conditions

Widely used in dose evaluation in the environment

Evaluation of exposure doses to environmental gamma rays

- Doses are evaluated from measurable quantities.

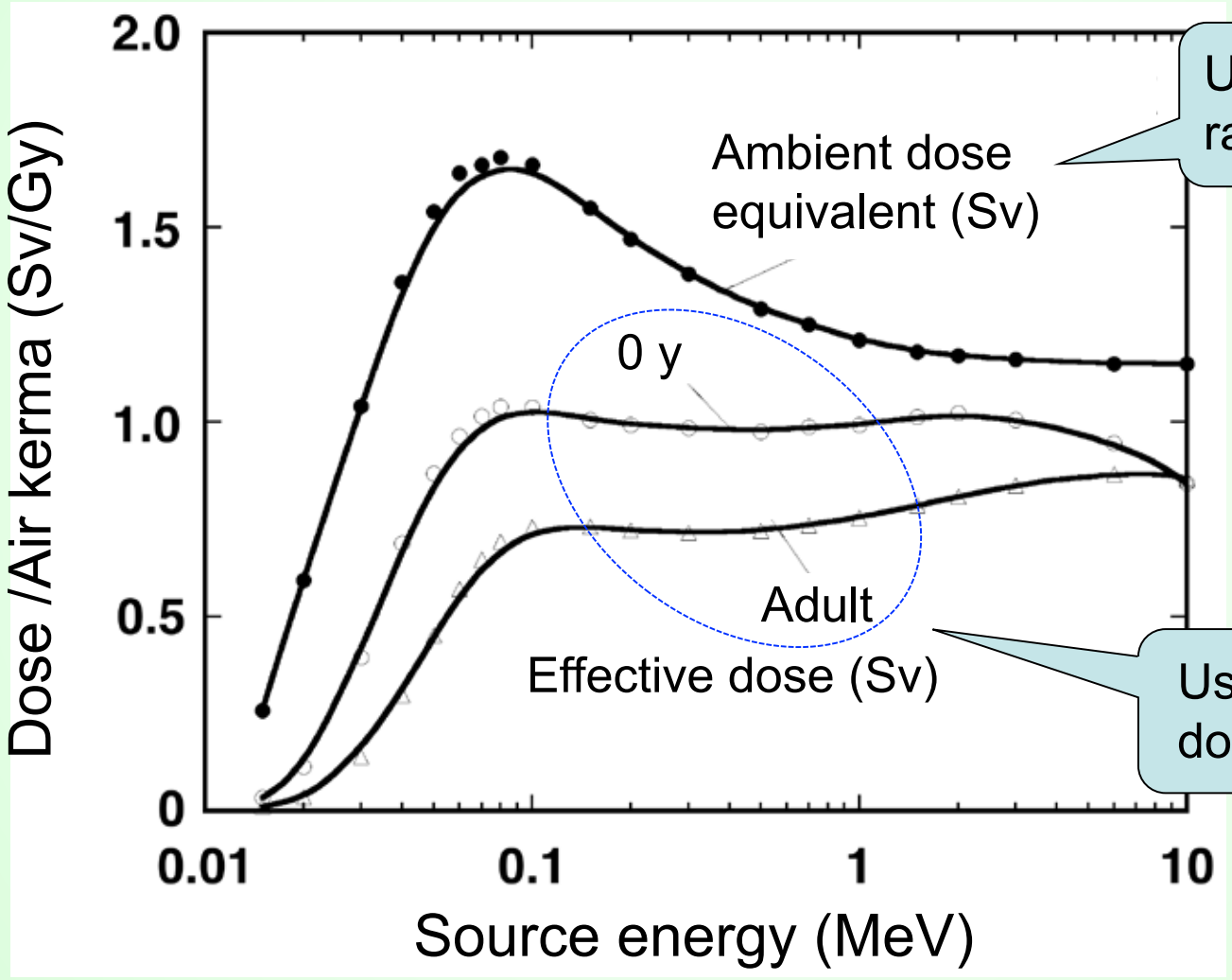


- Characteristics of environmental gamma rays need to be precisely considered to obtain the conversion coefficients.

energy spectrum, angular distribution, height dependency

Dose conversion coefficients

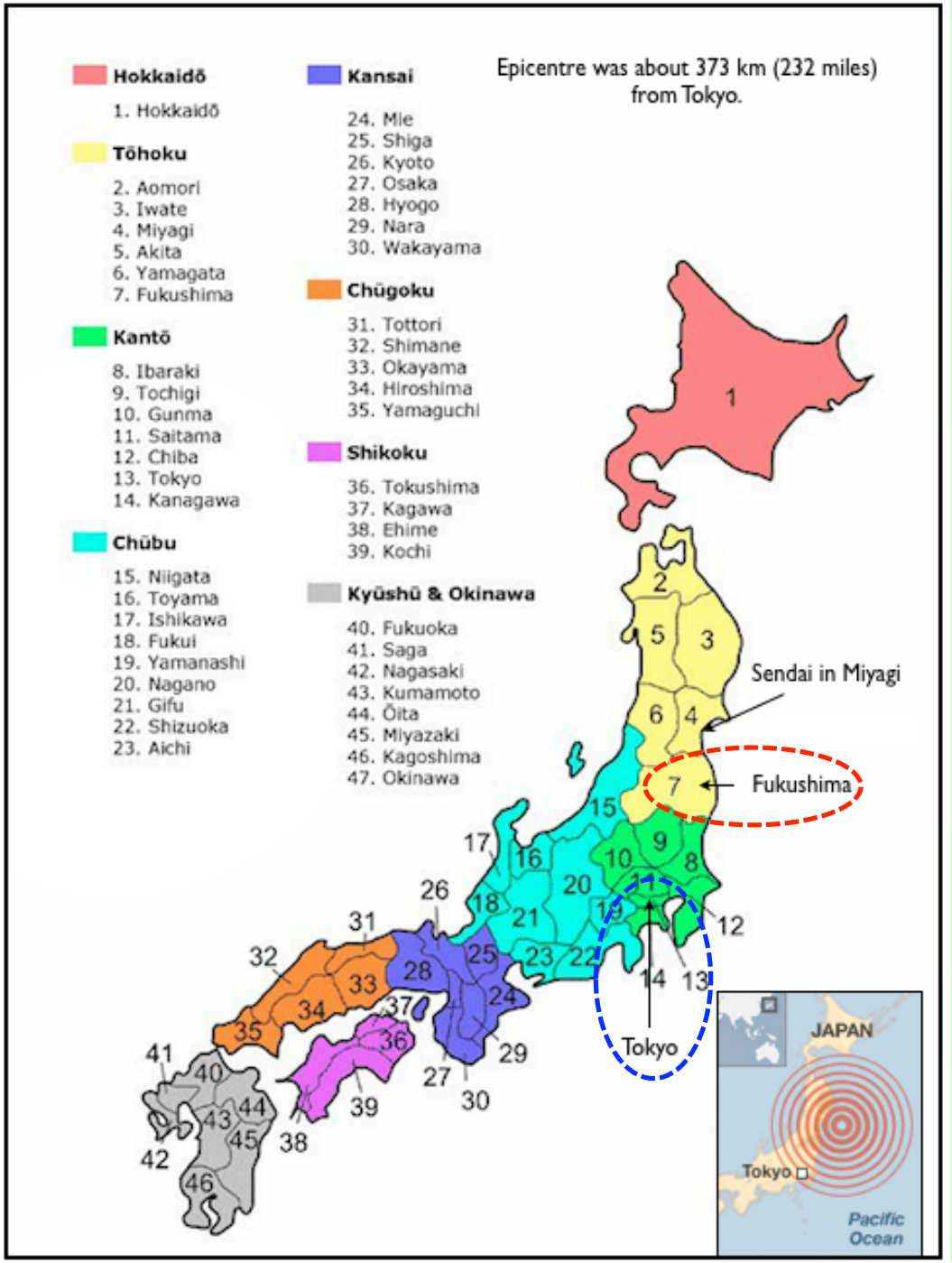
Deposited source on ground



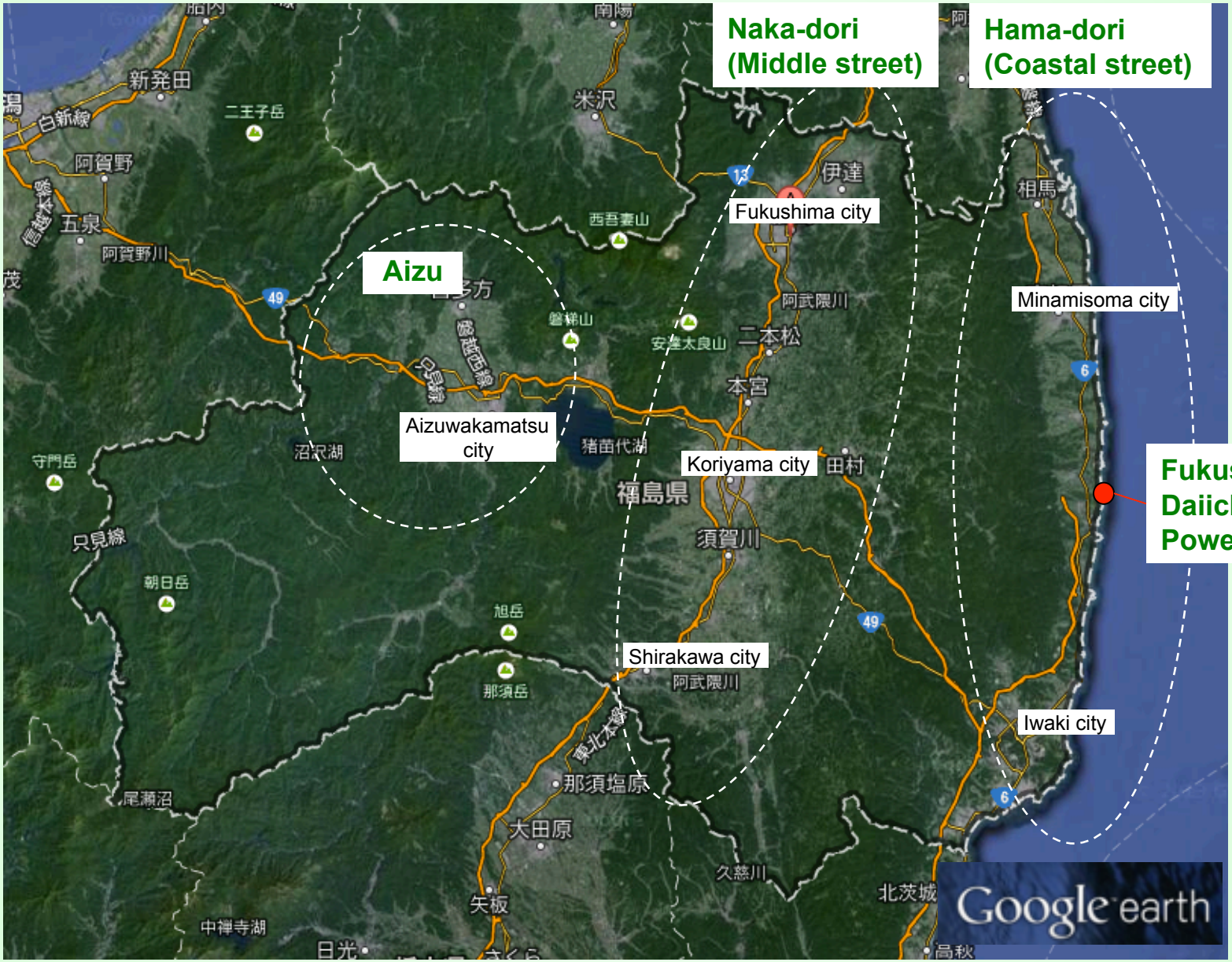
- **Ambient dose equivalent overestimates effective doses.**

Fukushima Prefecture

- Fukushima city is located 240 km north from Tokyo
- Mountainous area
- Population 1,948,184 (Sept. 1, 2013)
- The number of evacuees About 148,600 (Aug. 9, 2013)



Topography of Fukushima Prefecture

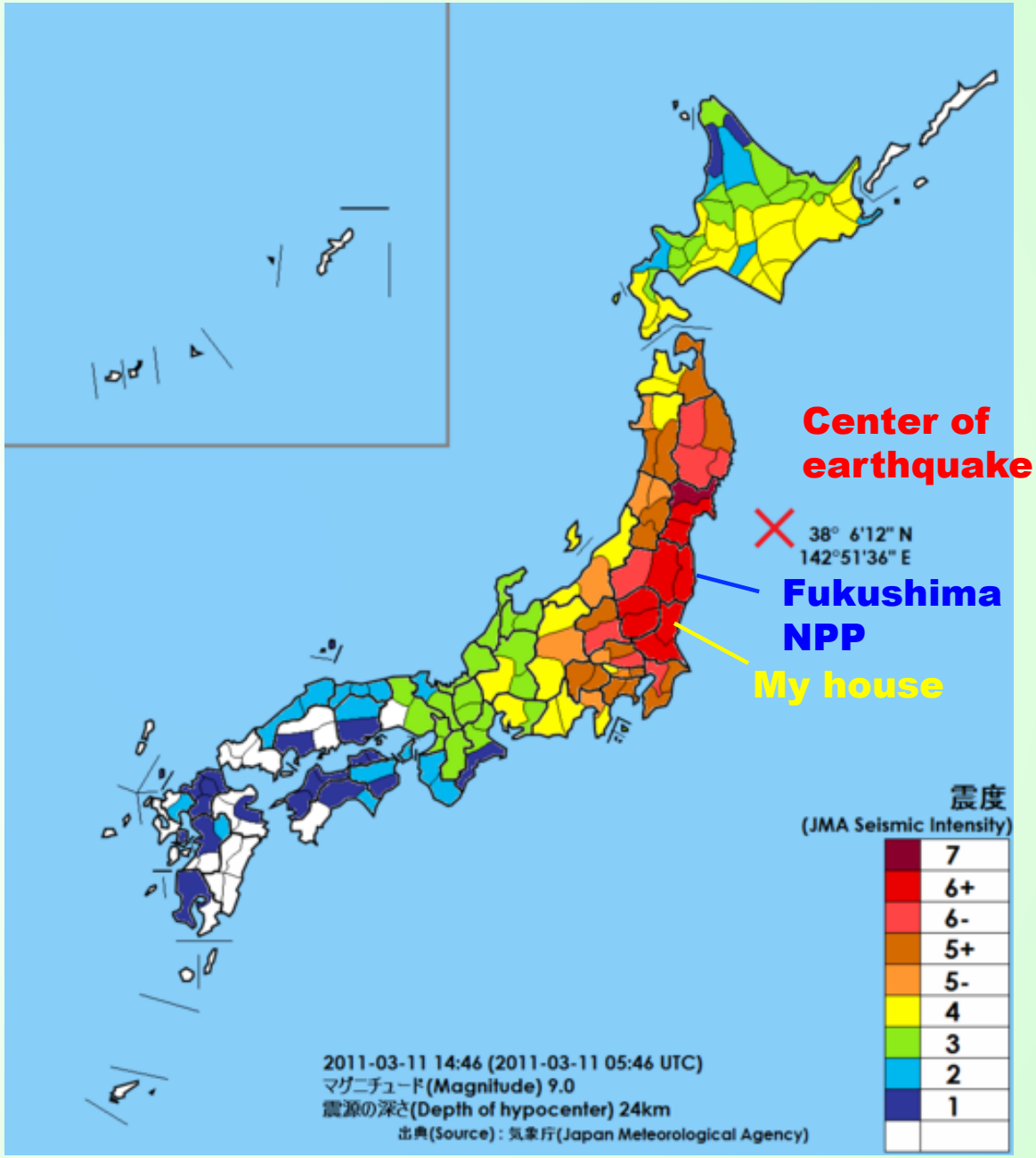


Industries in Fukushima Prefecture

1. Primary industries
   a) Agriculture: rice (5th in Japan), fruits (peach, apple, cherry, peer, strawberry, persimmon), vegetables
   b) Stock raising: beef, pork, egg, milk
   c) Fisheries: bonito, carp, shell fish
2. Secondary and tertiary industries
   a) Power generation: nuclear, water, thermal, geothermal, wind
   b) Manufacturing: information and communication apparatus, electronic components, transport equipments
   c) Commerce: large shopping malls

Intensity map of the Tohoku earthquake

- March 11, 2011 14:46
- Magnitude 9
- Tsunami >30 m
- Nuclear accident



Estimated radioactive releases into the atmosphere from the Fukushima accident (Bq)

Nuclide	Half life	Reactor 1	Reactor 2	Reactor 3	Total
Xe-133	5.2 d	3.4×10^{18}	3.5×10^{18}	4.4×10^{18}	1.1×10^{19}
Cs-134	2.1 y	7.1×10^{14}	1.6×10^{16}	8.2×10^{14}	1.8×10^{16}
Cs-137	30 y	5.9×10^{14}	1.4×10^{16}	7.1×10^{14}	1.5×10^{16}
Sr-89	50.5 d	8.2×10^{13}	6.8×10^{14}	1.2×10^{15}	2.0×10^{15}
Sr-90	29.1 y	6.1×10^{12}	4.8×10^{13}	8.5×10^{13}	1.4×10^{14}
Te-129m	33.6 d	7.2×10^{14}	2.4×10^{15}	2.1×10^{14}	3.3×10^{15}
Pu-238	87.7 y	5.8×10^{08}	1.8×10^{10}	2.5×10^{08}	1.9×10^{10}
Pu-239	24065 y	8.6×10^{07}	3.1×10^{09}	4.0×10^{07}	3.2×10^{09}
Pu-240	6537 y	8.8×10^{07}	3.0×10^{09}	4.0×10^{07}	3.2×10^{09}
Pu-241	14.4 y	3.5×10^{10}	1.2×10^{12}	1.6×10^{10}	1.2×10^{12}
I-131	8 d	1.2×10^{16}	1.4×10^{17}	7.0×10^{15}	1.6×10^{17}

Nuclear Industry Safety Agency（June 6, 2011）

Contamination mapping projects

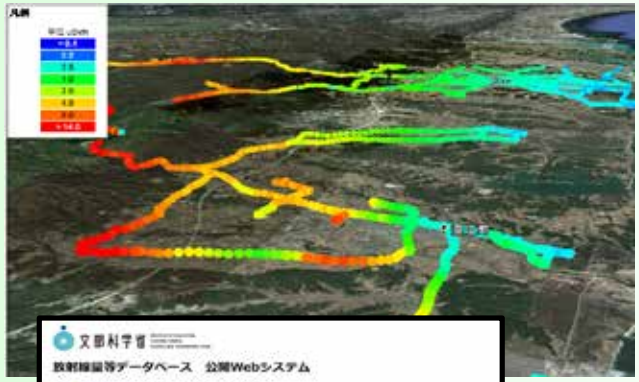
1. In order to estimate the impact of the Fukushima accident and take appropriate countermeasures, it has been necessary to obtain reliable precise information on the contamination conditions.
2. JAEA has implemented a series of the mapping projects in collaboration with many universities and research institutes commissioned by the Japanese Government.
   1) 2011/6 ～2011/11 (MEXT)
   2) 2011/12～2012/6 (MEXT)
   3) 2012/7 ～2013/3 (MEXT)
   4) 2013/4 ～2014/3 (NRA)
   5) 2014/4 ～2015/3 (NRA) ongoing

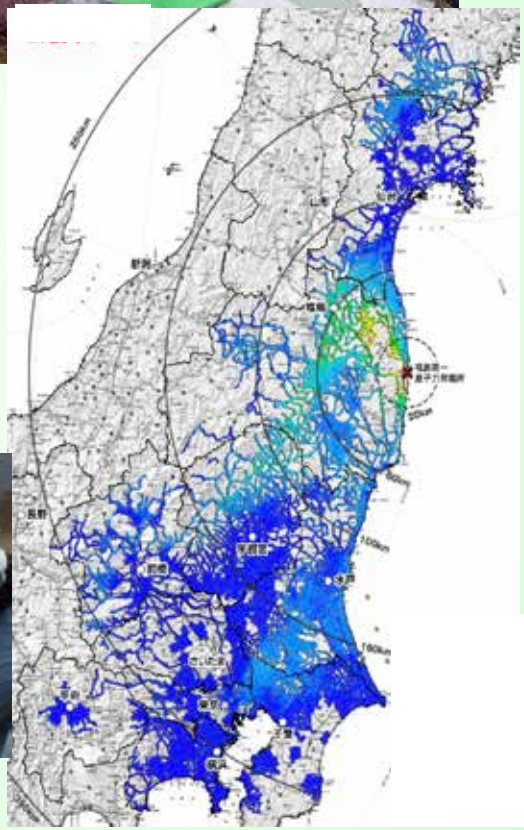
MEXT : Ministry of Education, Sports, Science and Technology
NRA: Nuclear Regulation Authority

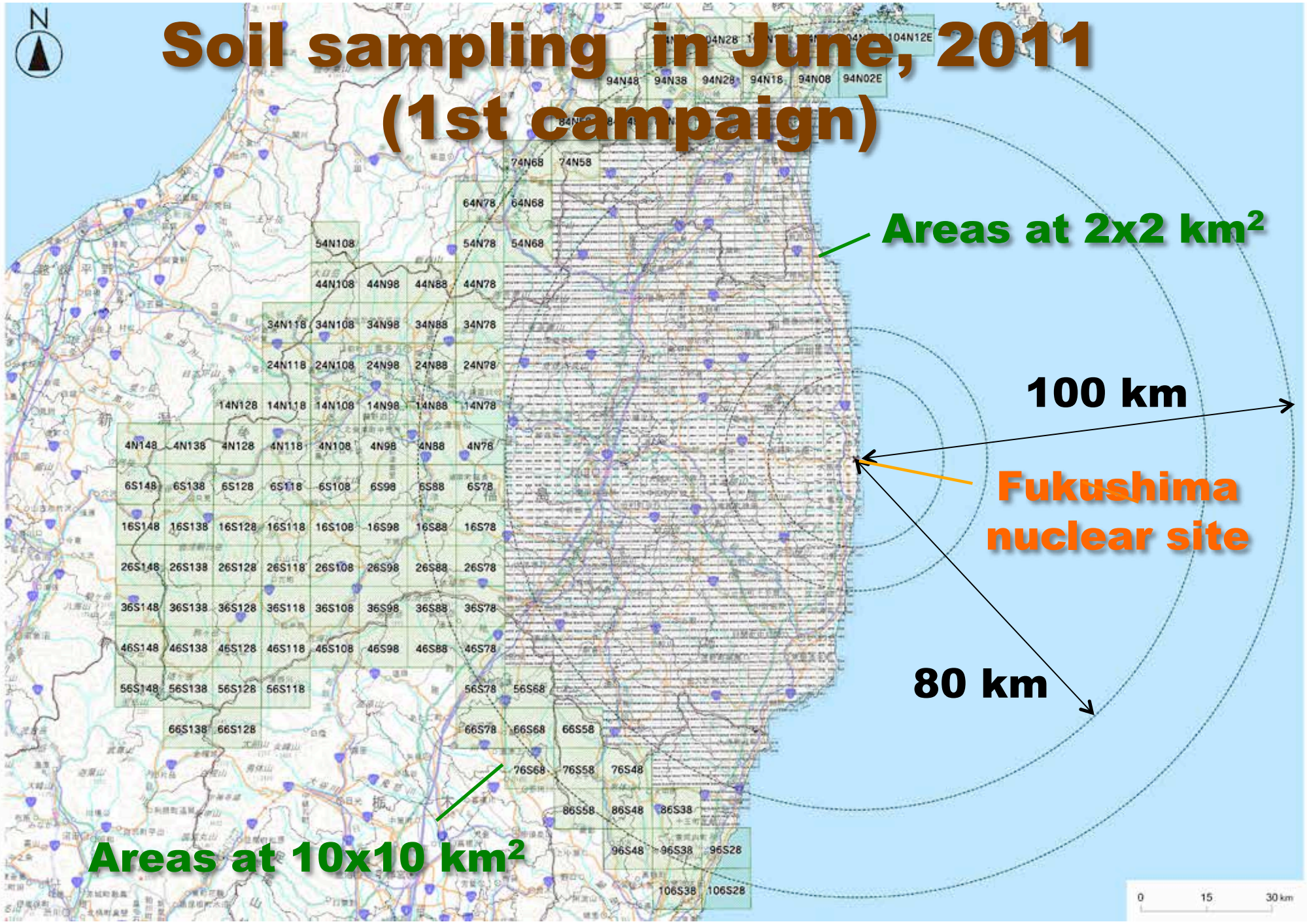
Tasks of mapping projects

1. Mapping of radionuclide deposition and dose rates in air
2. Studies on radionuclide migration in natural environment
3. Construction of a database
4. Prediction of contamination condition in future

Mapping projects






Soil sampling in June, 2011
(1st campaign)
Areas at 2x2 km²
100 km
Fukushima
nuclear site
80 km
Areas at 10x10 km²
N
0
15
30 km

Collection procedures of a soil sample

- Top 5 cm soil
- Sufficient mixing
- U8 plastic container
- 11,000 samples in 1st campaign
- Analyzed at 21 laboratories

In-situ measurement using a portable Ge detector

In-situ measurements have been used to determine deposition density of radionuclides since December 2011.

Radionuclide deposition maps

1. Gamma-ray emitting nuclides

- Cs-137 (30.2 y)　• Cs-134 (2.06 y)
- I-131 (8.02 d)
- Te-129m (33.6 d)　• Ag-110m (250 d)

2. Alpha-ray emitting nuclides

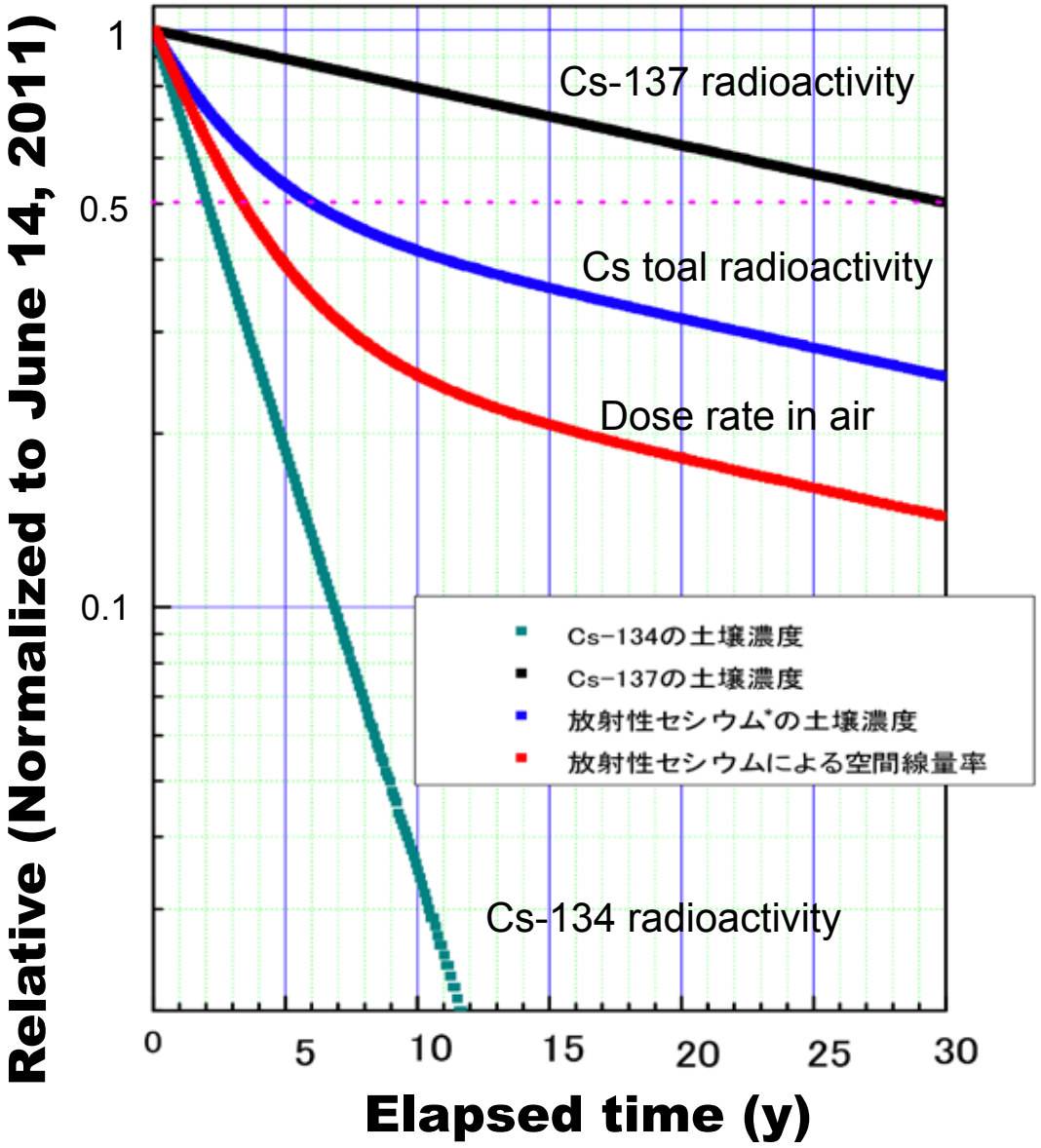
- Pu-238 (87.7 y)
- Pu-239 (24,100 y) + Pu-240 (6,564 y)

3. Beta-ray emitting nuclides

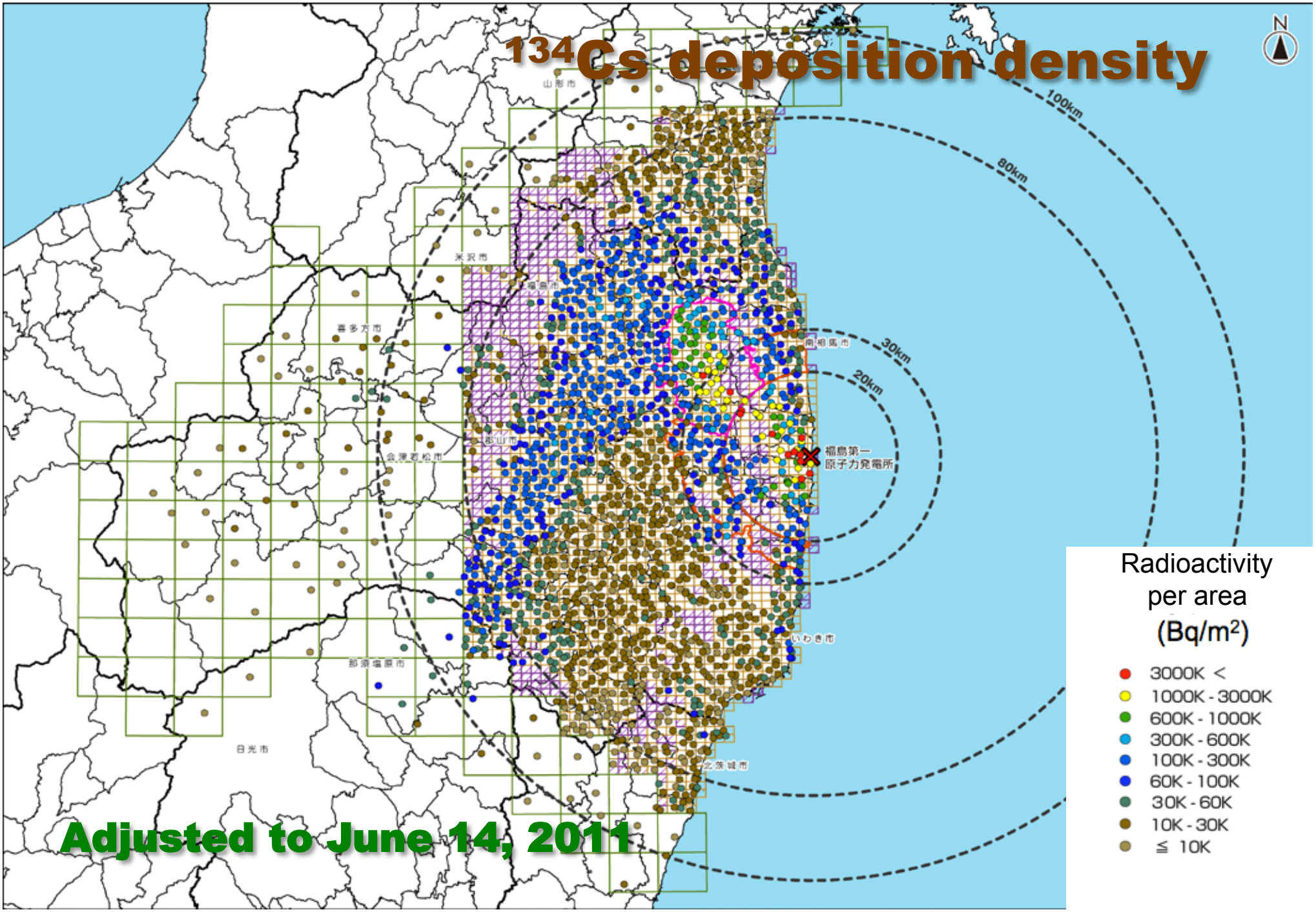
- Sr-89 (50.5 d)
- Sr-90 (28.8 y)

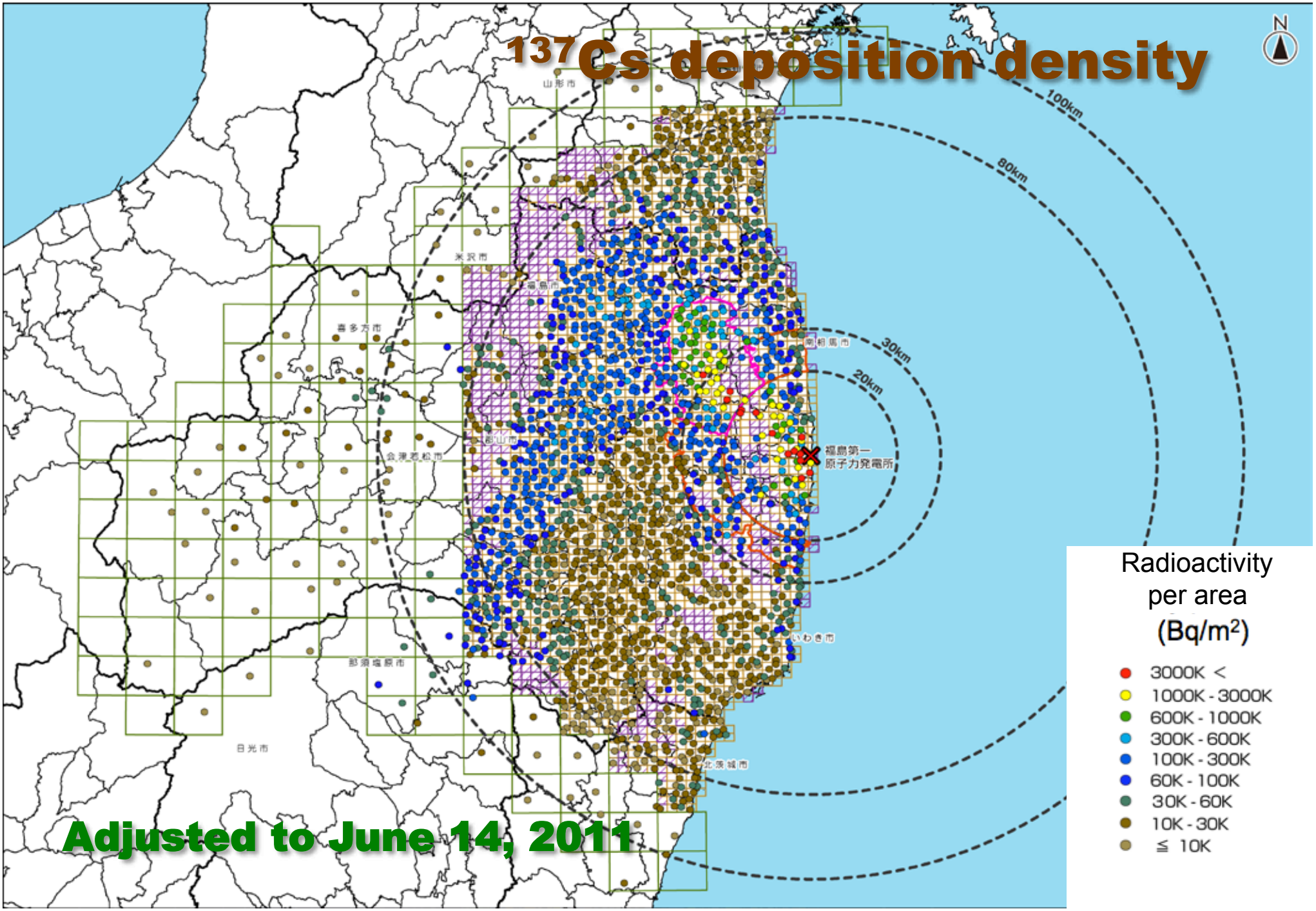
(half life)

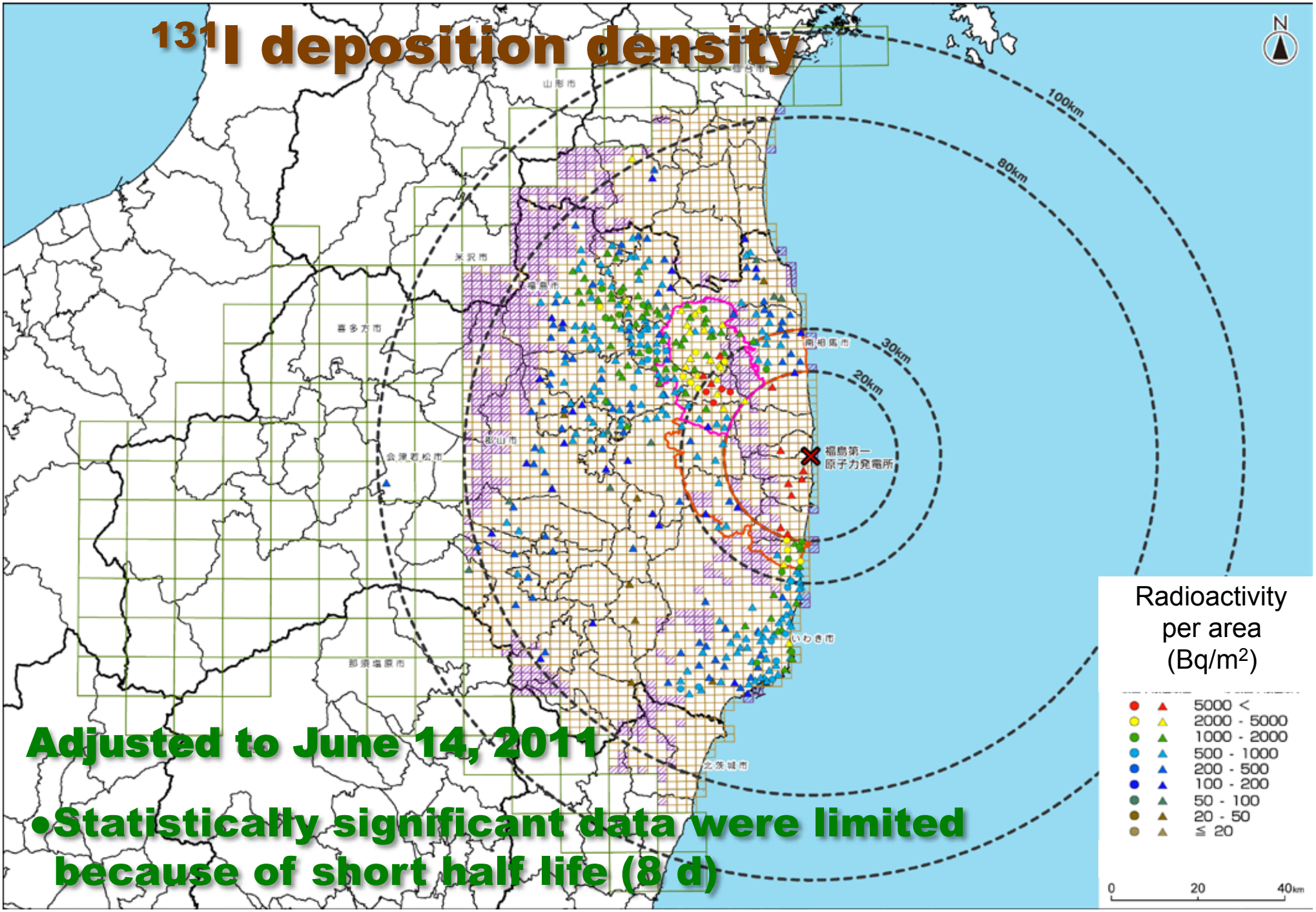
Decrease of environmental contamination due to physical decay



- **Dose rates in air are expected to decrease rather rapidly within several years according to physical decay of Cs-134.**
- **Weathering effects will accelerate the dose rate decrease.**


^{134}Cs deposition density
N
100km
80km
30km
20km
福島第一
原子力発電所
山形市
米沢市
福島市
喜多方市
南相馬市
郡山市
会津若松市
いわき市
那須塩原市
日光市
北茨城市
Radioactivity
per area
(Bq/m²)
3000K <
1000K - 3000K
600K - 1000K
300K - 600K
100K - 300K
60K - 100K
30K - 60K
10K - 30K
≦ 10K
Adjusted to June 14, 2011

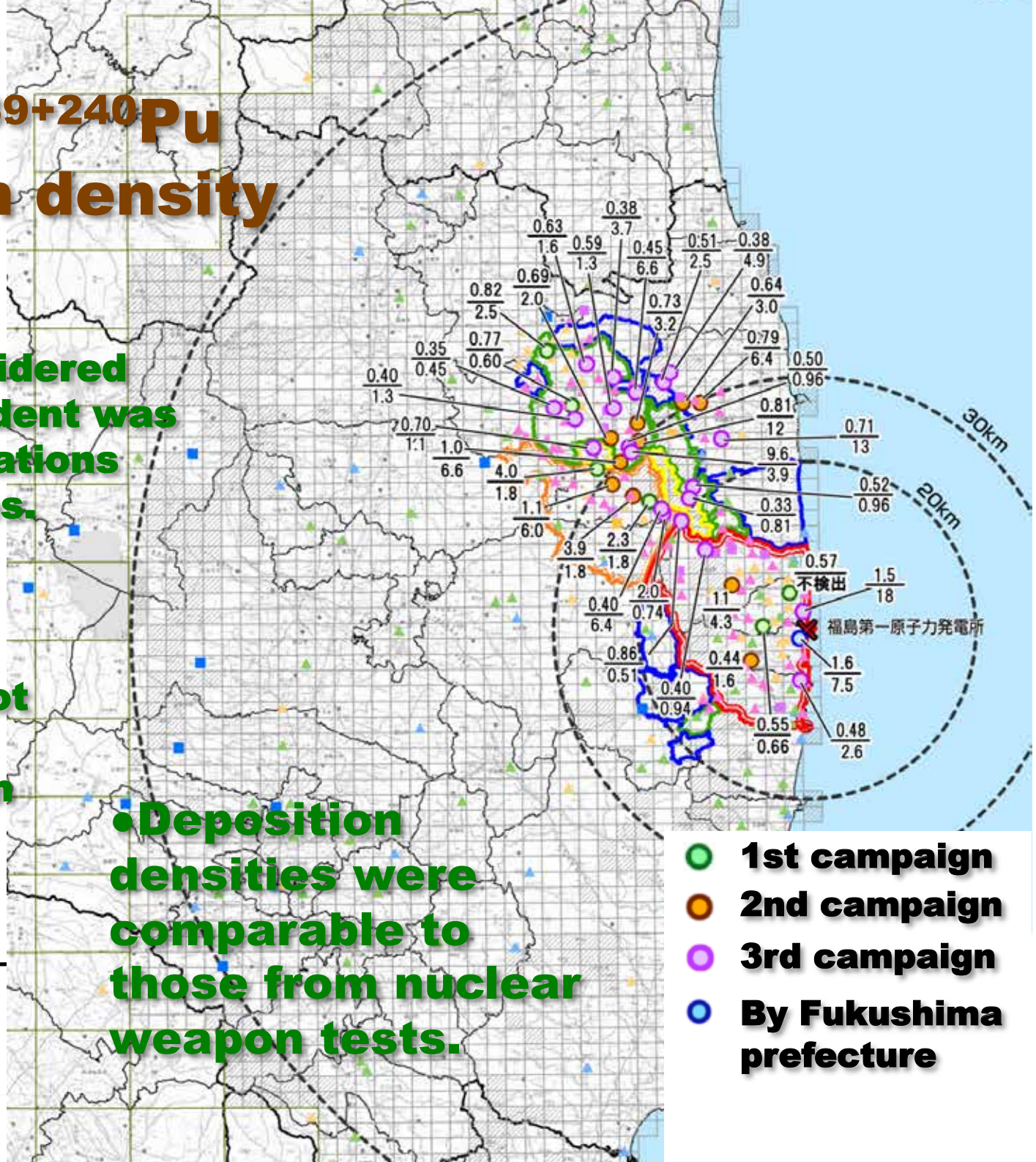

^{137}Cs deposition density
N
100km
80km
30km
20km
福島第一
原子力発電所
山形市
米沢市
福島市
喜多方市
相馬市
郡山市
会津若松市
いわき市
那須塩原市
日光市
北茨城市
Radioactivity
per area
(Bq/m²)
3000K <
1000K - 3000K
600K - 1000K
300K - 600K
100K - 300K
60K - 100K
30K - 60K
10K - 30K
≦ 10K
Adjusted to June 14, 2011


131I deposition density
100km
80km
30km
20km
福島第一
原子力発電所
山形市
米沢市
福島市
喜多方市
南相馬市
郡山市
会津若松市
いわき市
郡須塩原市
北茨城市
N
Radioactivity
per area
(Bq/m2)
5000 <
2000 - 5000
1000 - 2000
500 - 1000
200 - 500
100 - 200
50 - 100
20 - 50
≤ 20
0
20
40km
Adjusted to June 14, 2011
•Statistically significant data were limited
because of short half life (8 d)

^{238}Pu, $^{239+240}Pu$ deposition density

- Plutonium considered due to the accident was detected at locations shown by circles.
- Plutonium was detected but not identified as originating from the accident.

$$\frac{^{238}Pu\ (Bq/m^2)}{^{239+240}Pu\ (Bq/m^2)}$$



- Deposition densities were comparable to those from nuclear weapon tests.

- 1st campaign
- 2nd campaign
- 3rd campaign
- By Fukushima prefecture

Evaluation of accumulated effective doses for 50 years

- Maximum nuclide deposition densities (Bq/m^2) were used.
- External exposures and inhalation due to re-suspension were evaluated.

Nuclide	Half life	Maximum concentration (Bq/m2)	Effective dose for 50 years	
			Conversion coef. ($\mu Sv/(Bq/m^2)$)	Dose (mSv)
Cs-134	2.065 y	1.4×10^{7}	5.1×10^{-2}	710
Cs-137	30.167 y	1.5×10^{7}	1.3×10^{-1}	2000(2.0Sv)
I-131	8.02 d	5.5×10^{4}	2.7×10^{-4}	0.015
Sr-89	50.53 d	2.2×10^{4}	2.8×10^{-5}	0.00061 (0.61 μSv)
Sr-90	28.79 y	5.7×10^{3}	2.1×10^{-2}	0.12
Pu-238	87.7 y	4	6.6	0.027
Pu-239+240	2.411×10^{4} y	15	8.5	0.12
Ag-110m	249.95 d	8.3×10^{4}	3.9×10^{-2}	3.2
Te-129m	33.6 d	2.7×10^{6}	2.2×10^{-4}	0.6

(Dose coefficients from TECDOC-1162)

Measurements of air dose rates

1. Monitoring above flat fields

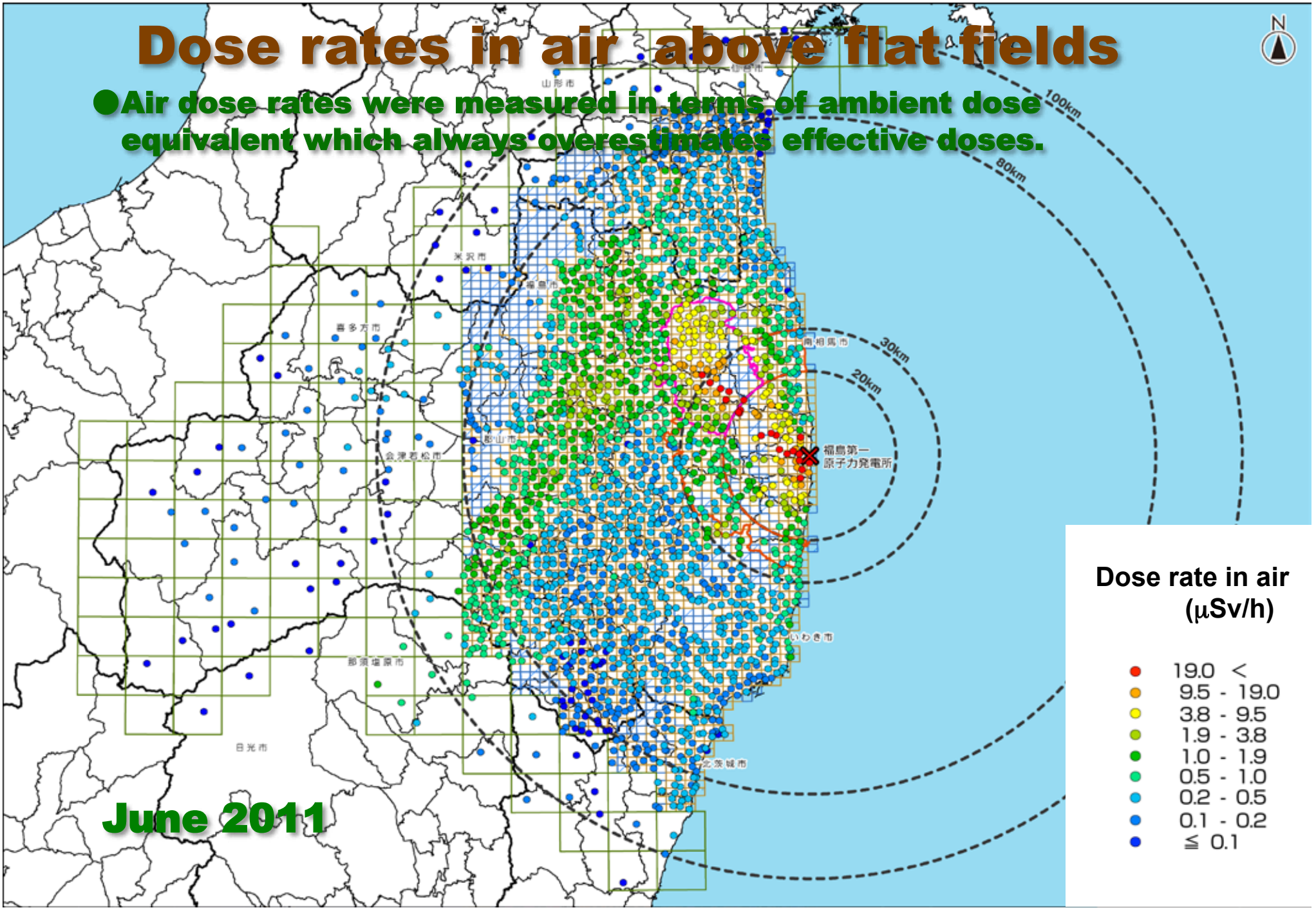
- undisturbed flat fields
- several thousand points in the 80 km zone
- mapping based on GPS data

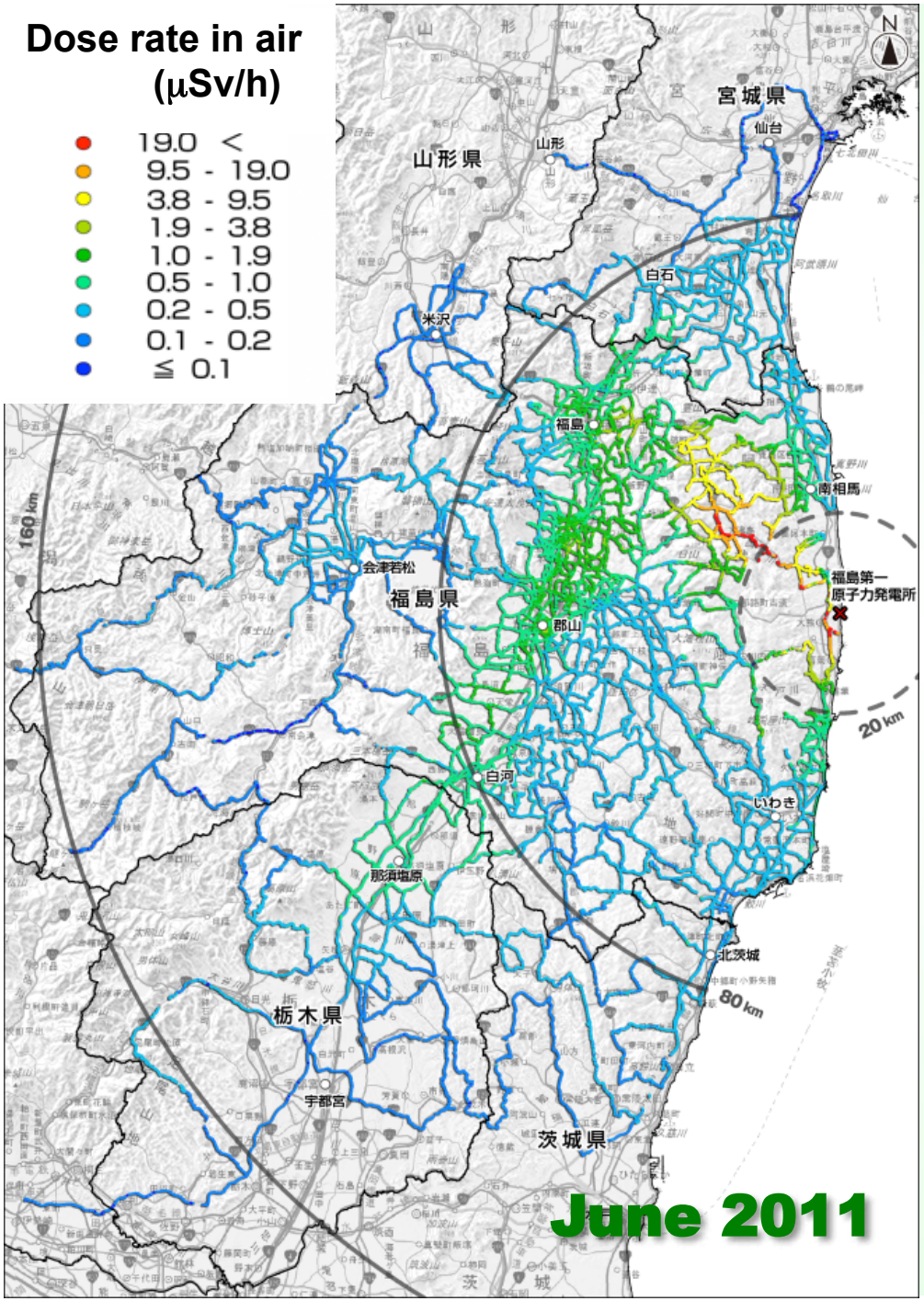
2. Car-borne survey

- continuous measurements on roads
- every 3 sec
- mapping based on GPS data
- run in various environments

Survey meter with a good energy response

KURAMA-II system developed at Kyoto University

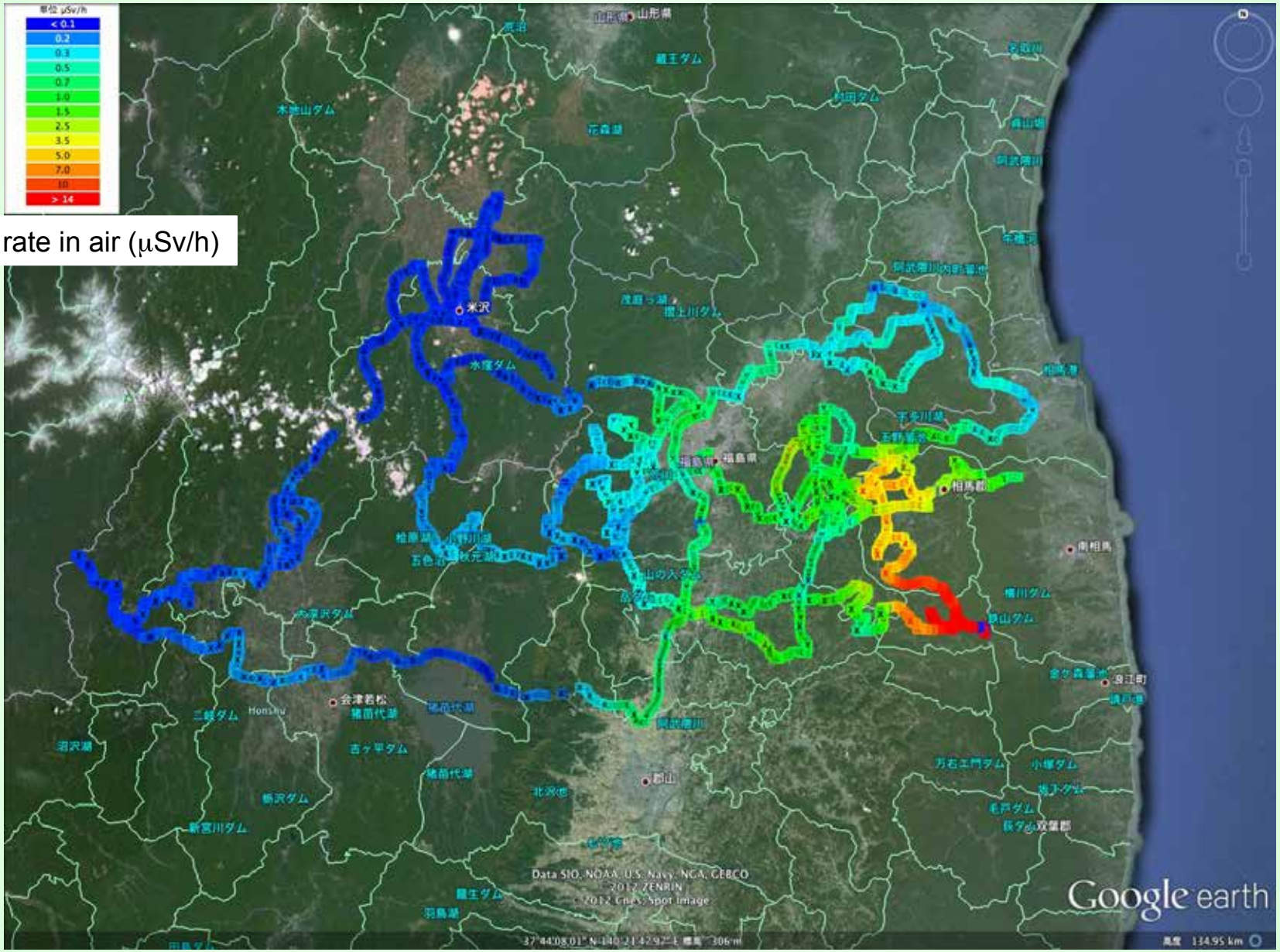

Dose rates in air above flat fields
●Air dose rates were measured in terms of ambient dose equivalent which always overestimates effective doses.
June 2011
N
100km
80km
30km
20km
福島第一
原子力発電所
山形市
米沢市
福島市
喜多方市
南相馬市
郡山市
会津若松市
いわき市
郡須塩原市
日光市
北茨城市
Dose rate in air
(μSv/h)
19.0 <
9.5 - 19.0
3.8 - 9.5
1.9 - 3.8
1.0 - 1.9
0.5 - 1.0
0.2 - 0.5
0.1 - 0.2
≦ 0.1



Dose rates in air above roads by car-borne survey

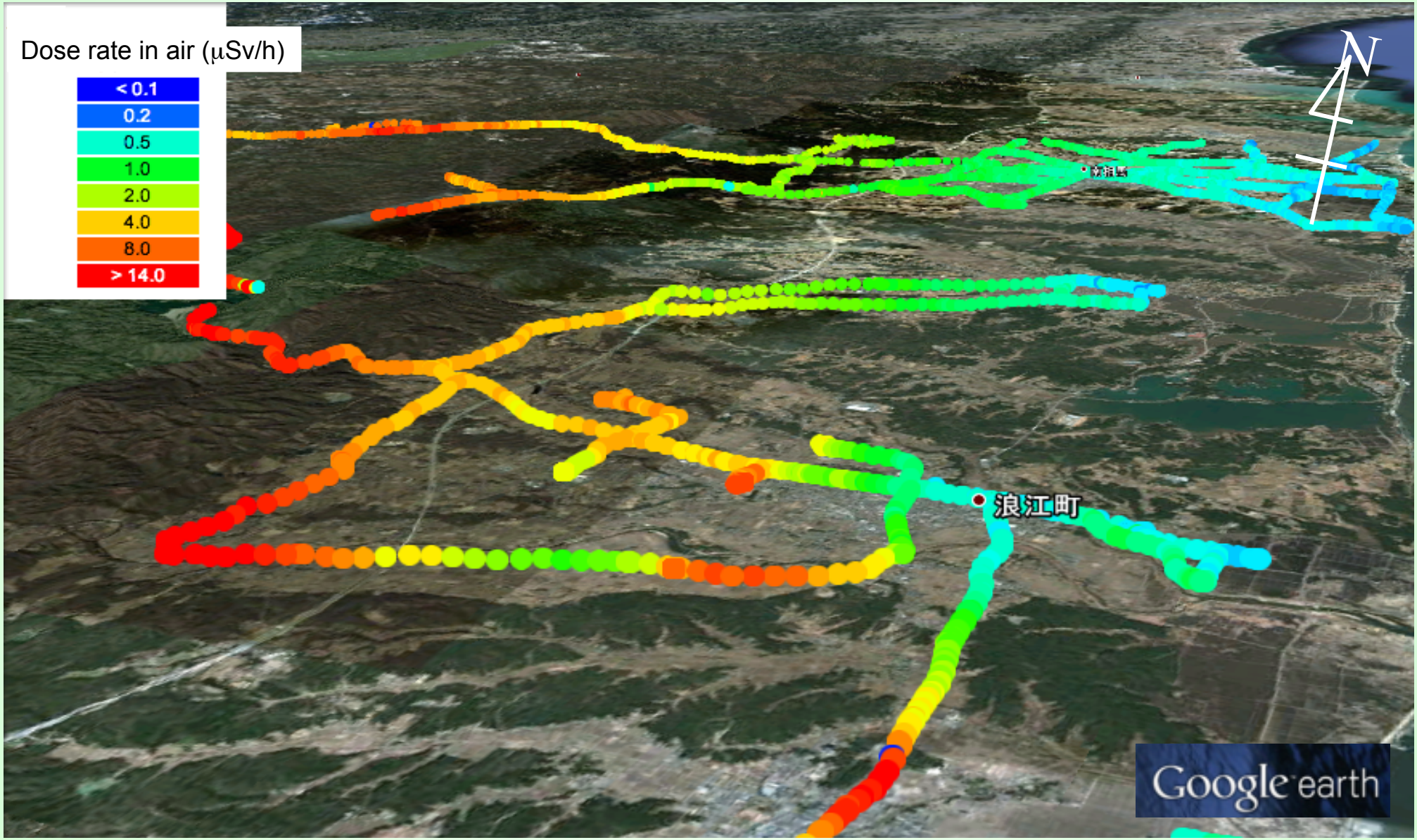
- Immediate data transfer through a cellular phone network
- Conversion of dose rates inside a car to those outside the car

Real-time display of car-borne survey data



Dose rate in air (μSv/h)

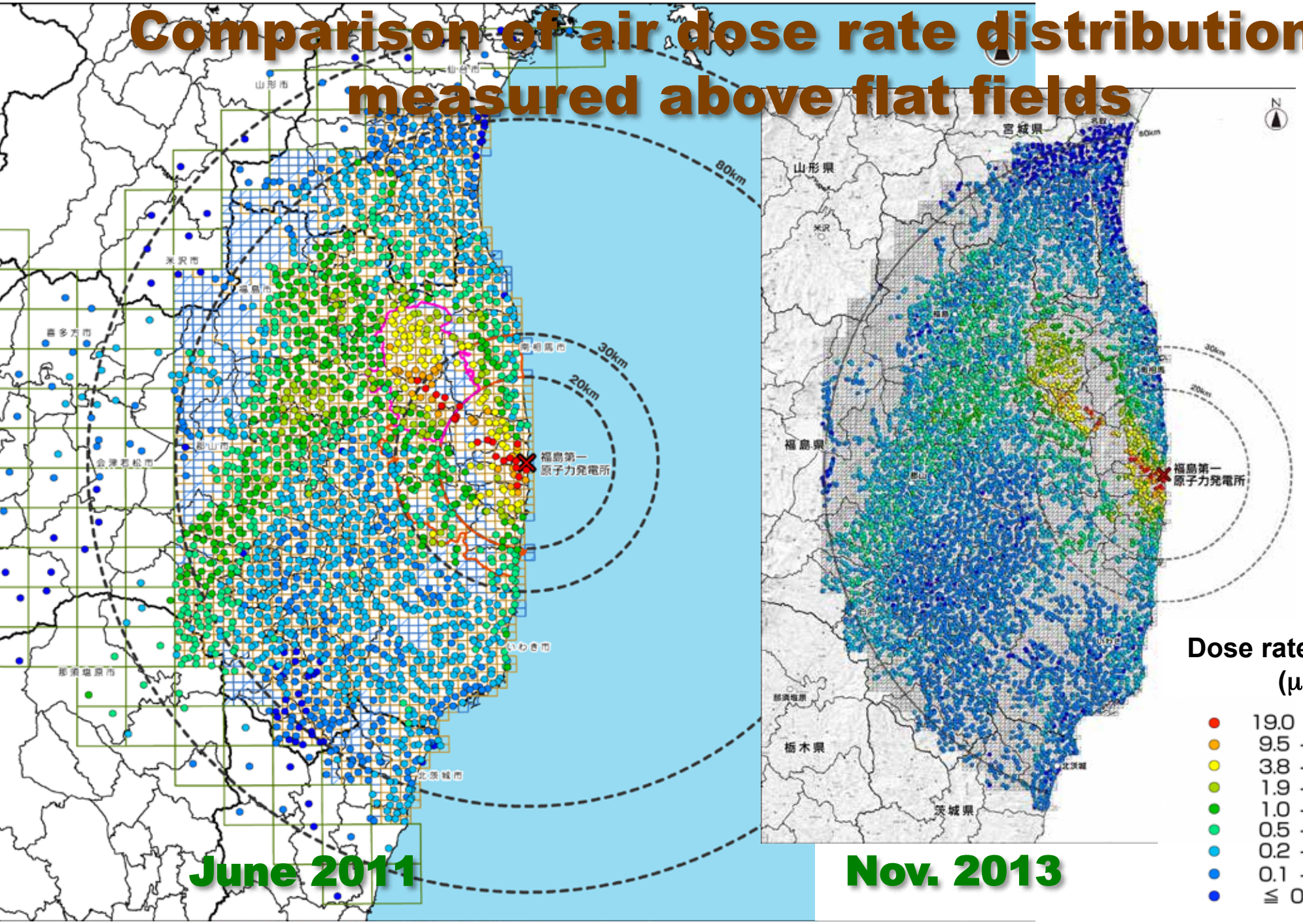
3D picture near the Fukushima site



Summary on initial contamination conditions

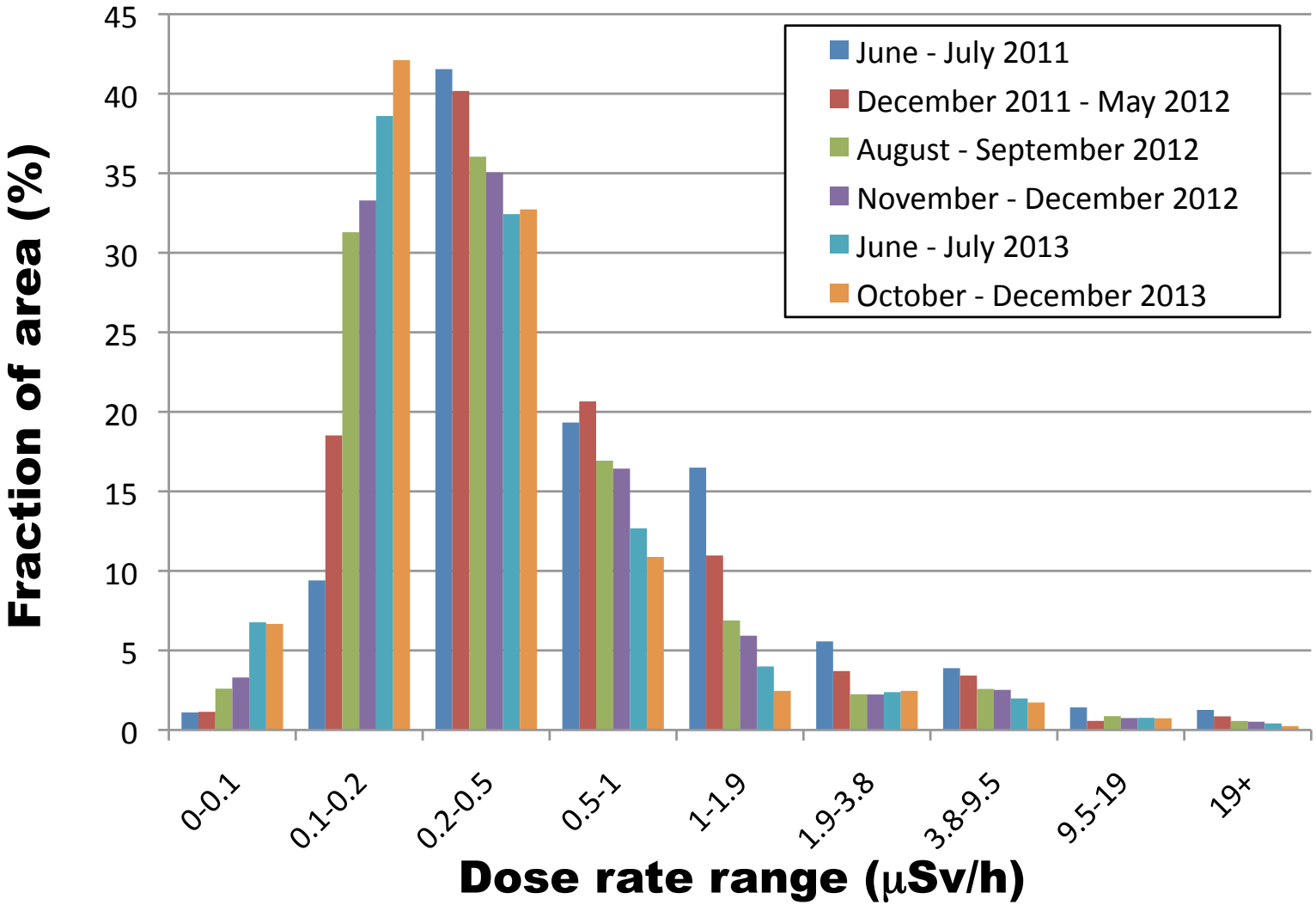
1. Region north-west of the Fukushima NPP was highly contaminated.
2. Cesium is far more important than other nuclides from a viewpoint of exposure doses in future.
3. Plutonium and Strontium originating from the accident were detected; the deposition densities are quite small.

Comparison of air dose rate distributions measured above flat fields

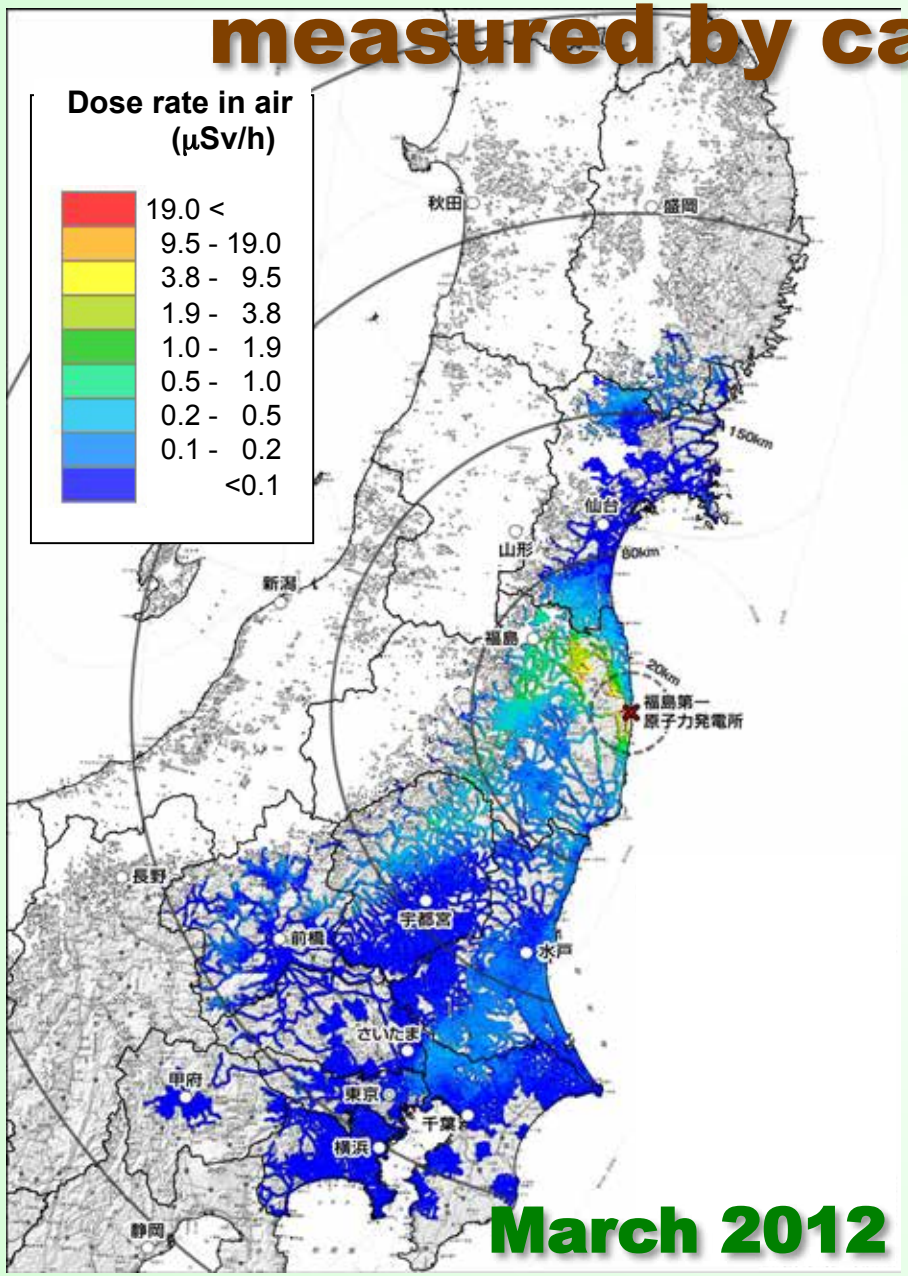


Distribution of areas having different air dose rates within the 80 km zone

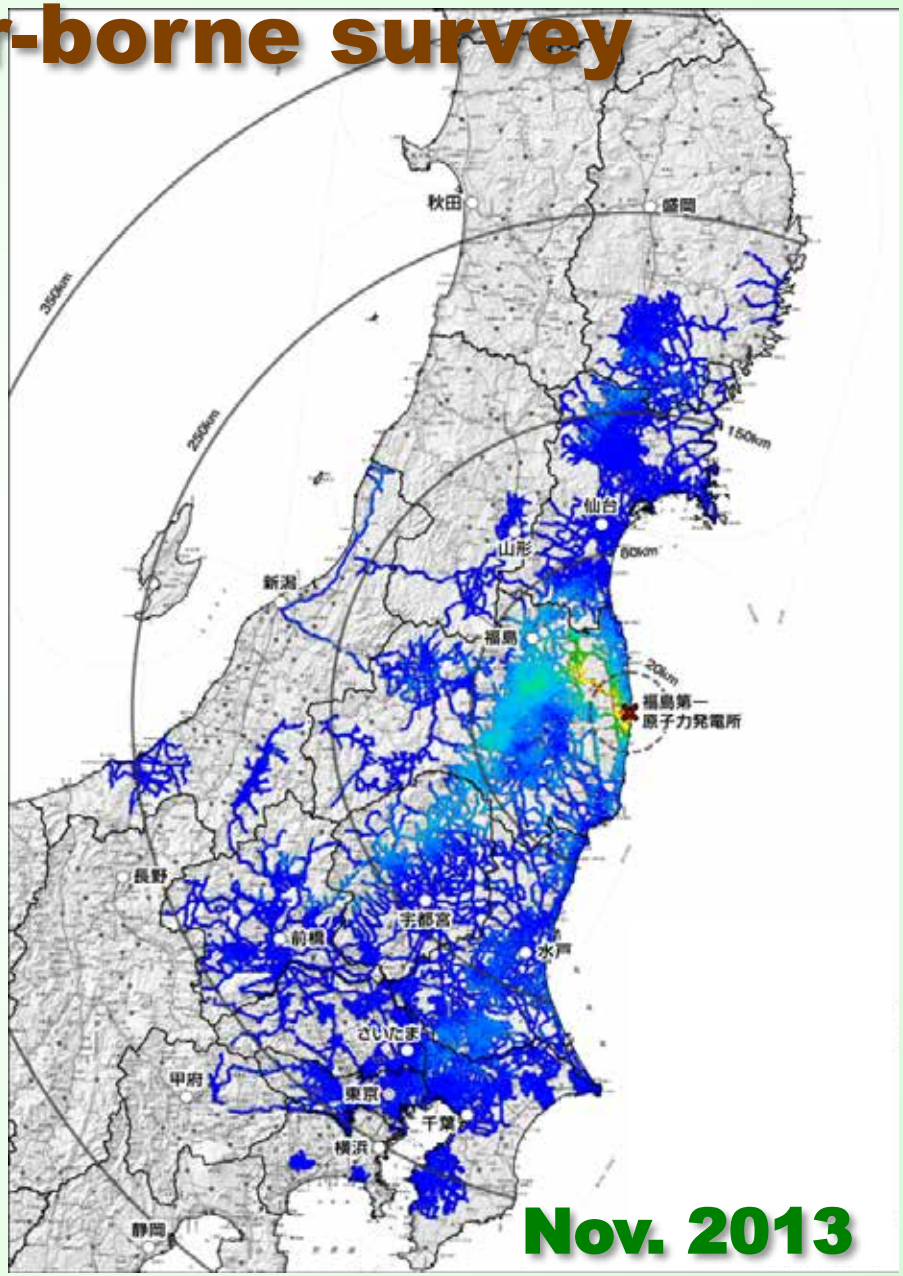
- Areas more than 0.2 μSv/h are decreasing, less than 0.2 μSv/h increasing.
- Nearly 80% of the total area has dose rates below 0.5 μSv/h.



Comparison of air dose rate distributions measured by car-borne survey

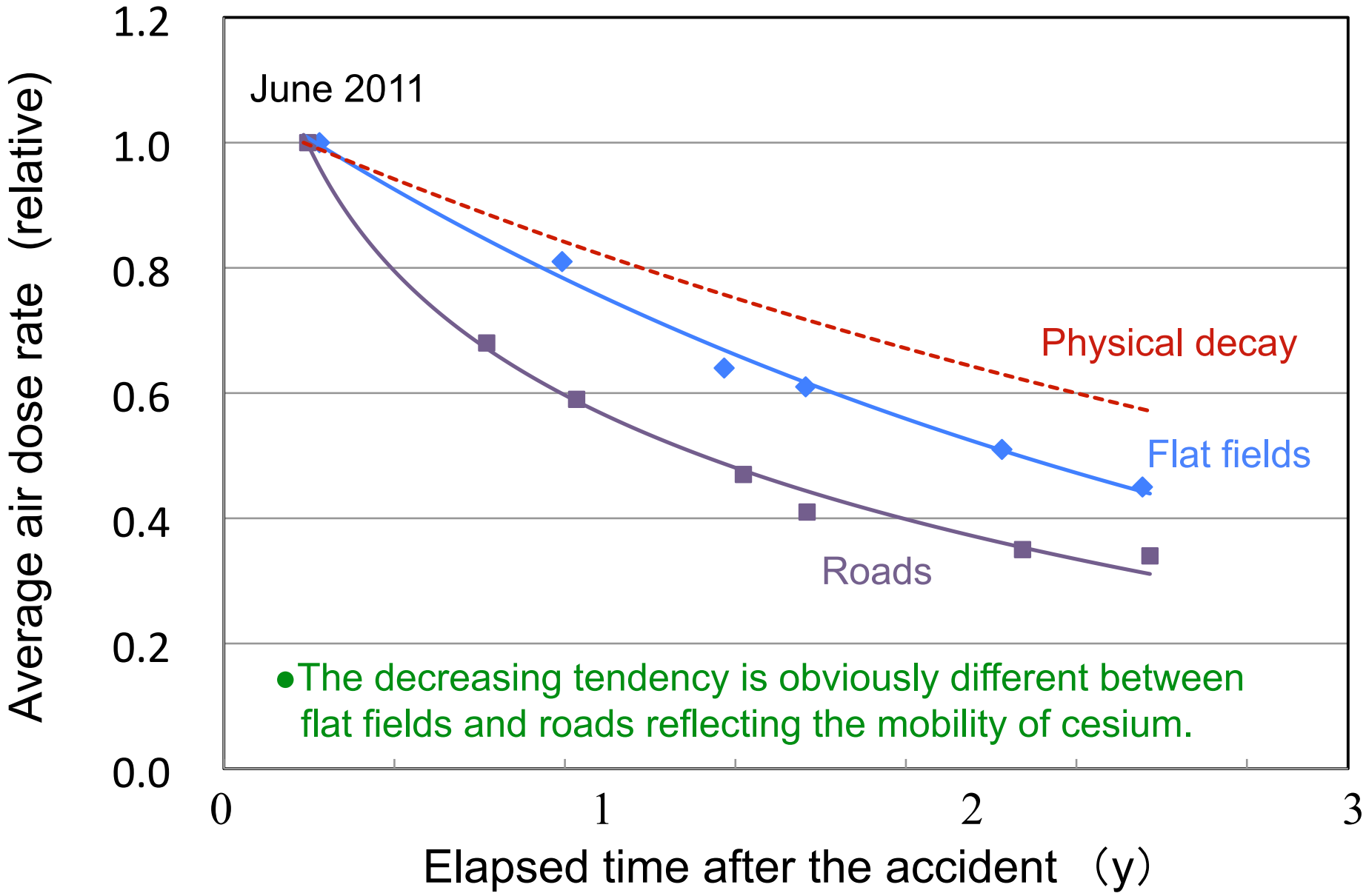


March 2012



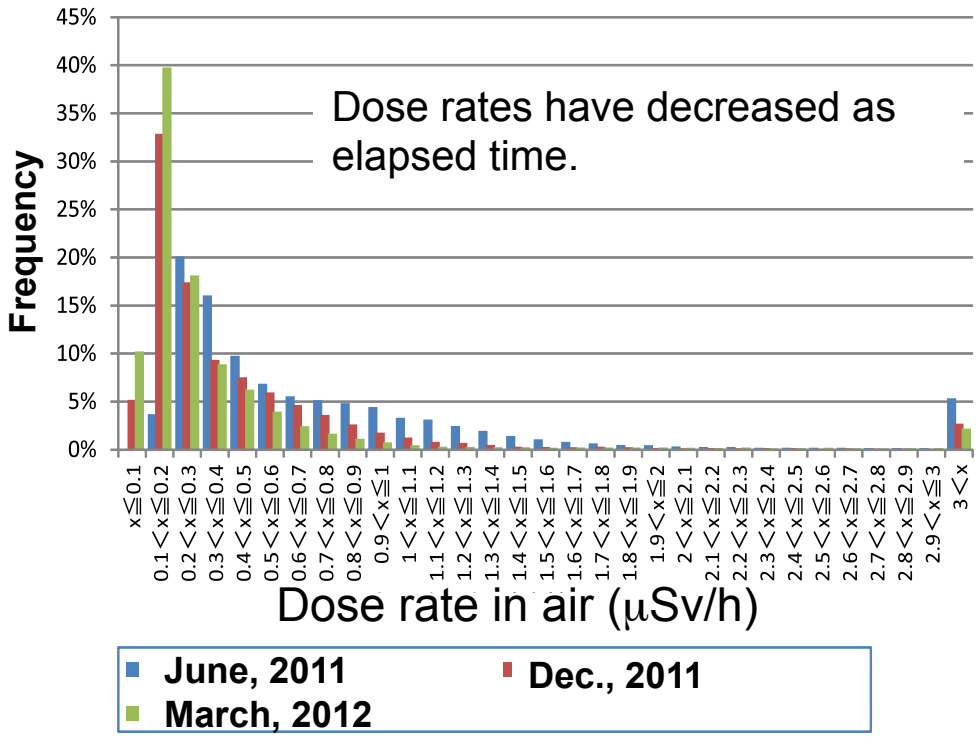
Nov. 2013

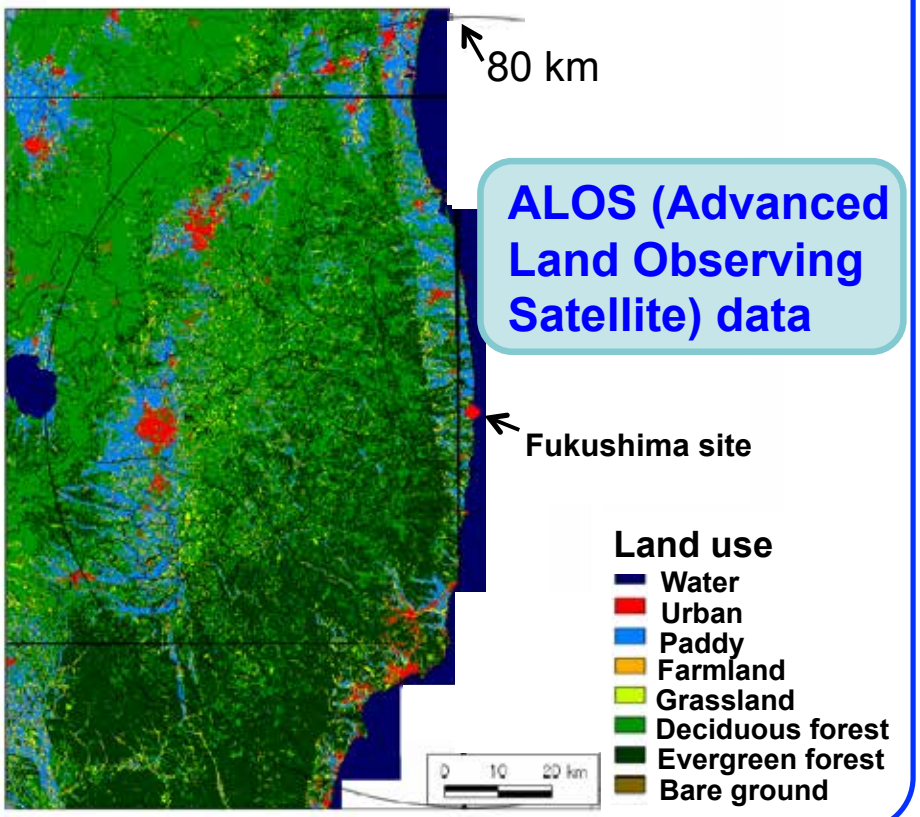
Temporal change in average air dose rate



Analyses based on land uses

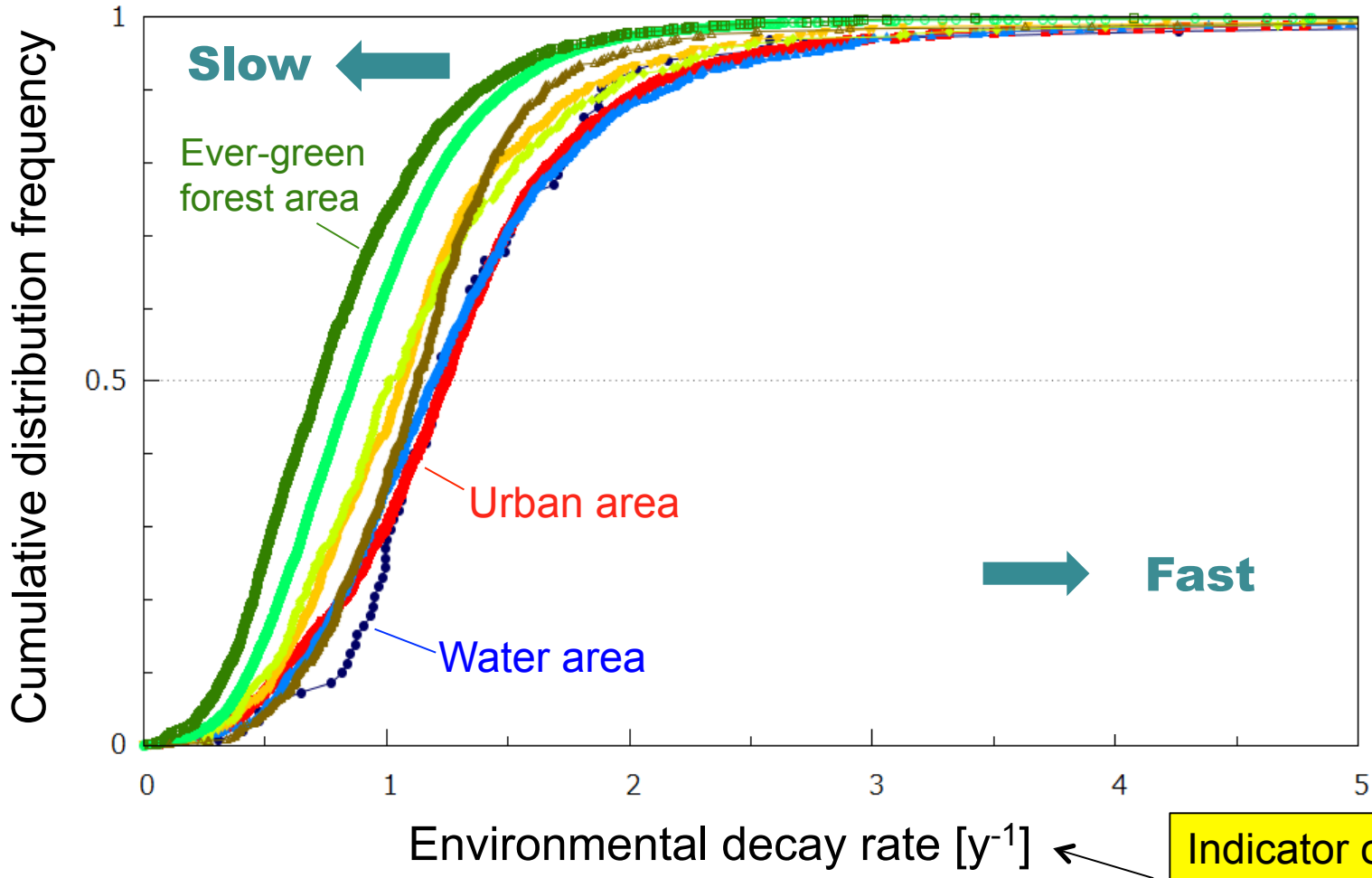
Car-bone survey data





- **Dose rate reduction tendency was analyzed in connection with different land uses**

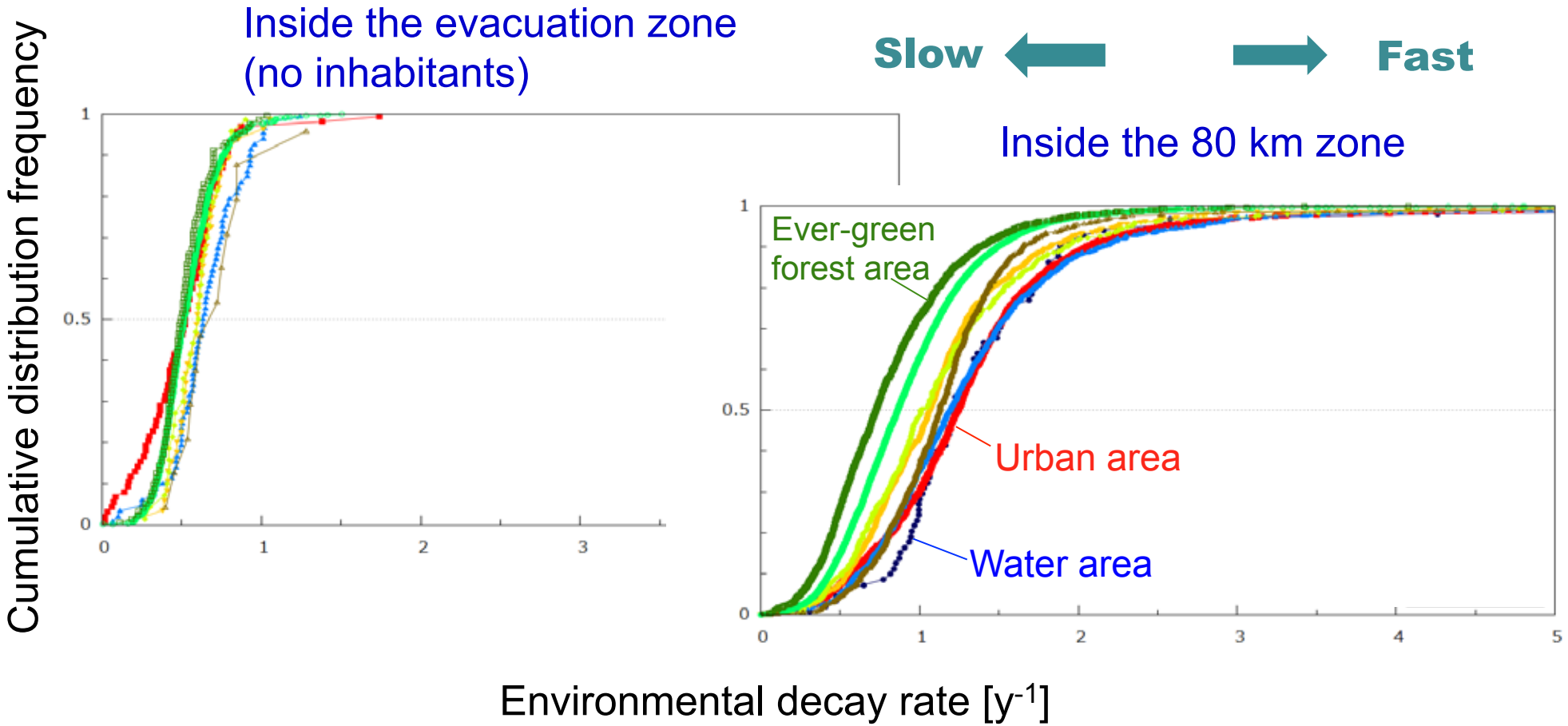
Dose rate reduction tendency for different land uses



Indicator of temporal dose rate reduction

- **Fast in urban and water areas**
- **Slow in ever-green forest area**

Dose rate reduction tendency for evacuation zone

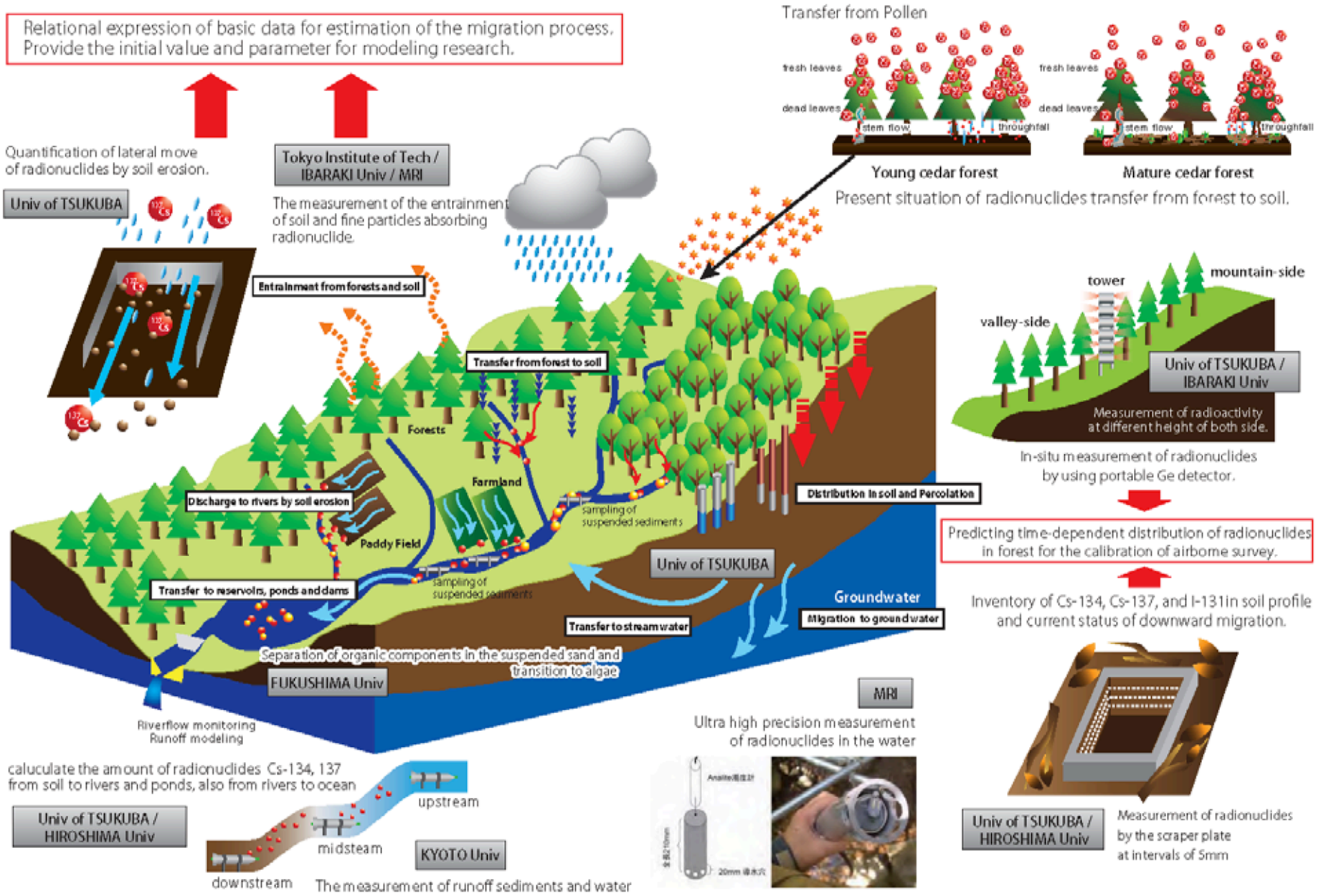


- **Slow in the evacuation zone as a whole**
- **Dose rate reduction is related to human activity**

Summary on temporal change in contamination conditions

1. Dose rates in air above roads have decreased much faster than those at undisturbed flat fields.
2. Dose-rate reduction tendency has land-use dependency: fast in urban area and slow in forest area.
3. Human activities accelerate dose rate reduction: decontamination, car driving, cultivation, cleaning, weeding, etc.

Field studies on radionuclide migration



Radionuclide distribution and migration in the forest

●Clarify the actual condition of radionuclide migration from forest to soil

Radiation measurements using a portable Ge detector at forest tower

Monitoring of the forest floor

Measurements of stemflow, throughfall, and litter

Broad-leaved mixed forest

Mature cedar forest

Young cedar forest

Soil sample collection

University of Tsukuba 筑波大学

CRiED Center for Research in Isotopes and Environmental Dynamics

Migration of cesium by soil erosion

Bare land

Cultivated (gentle)

Grass land

Cultivated (Steep)

Forest (young ceder)

Pasture A

Pasture B

Soil Erosion Plots

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Evaluation of radiocaesium wash-off by soil erosion from various land uses using USLE plots

Kazuya Yoshimura*, Yuichi Onda, Hiroaki Kato

Center for Research in Isotopes and Environmental Dynamics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572, Japan

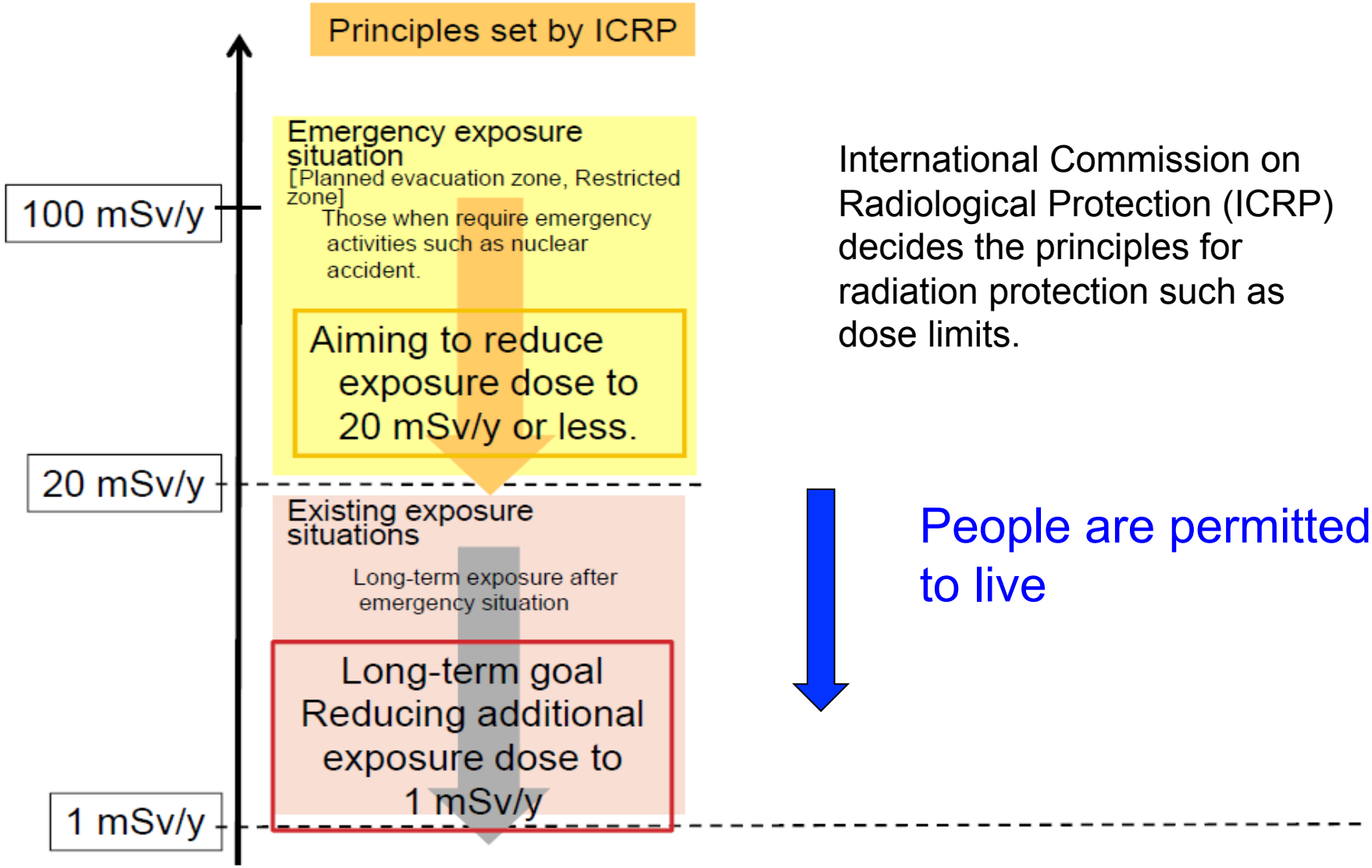
Sampling of water and suspended sediment in rivers

Air sampling

Summary on cesium movement in various environment

1. In forest, movement of radiocesium is quite slow; cesium captured by canopies has fell down to the ground level with time.
2. In soil, generally cesium movement in horizontal direction is slow; cesium has been penetrating into deeper part of the ground.
3. Rivers play an important role in long-distance migration of cesium; cesium concentration in river water has been decreased.
4. Cesium concentration in air is very low.

Targets for radiation protection were set in accordance with ICRP principle



International Commission on Radiological Protection (ICRP) decides the principles for radiation protection such as dose limits.

People are permitted to live

http://www.nsr.go.jp/archive/nisa/shingikai/700/14/240723/BM-1-2.pdf

(provided by MOE)

Rearrangement of restricted zone and planned evacuation zone

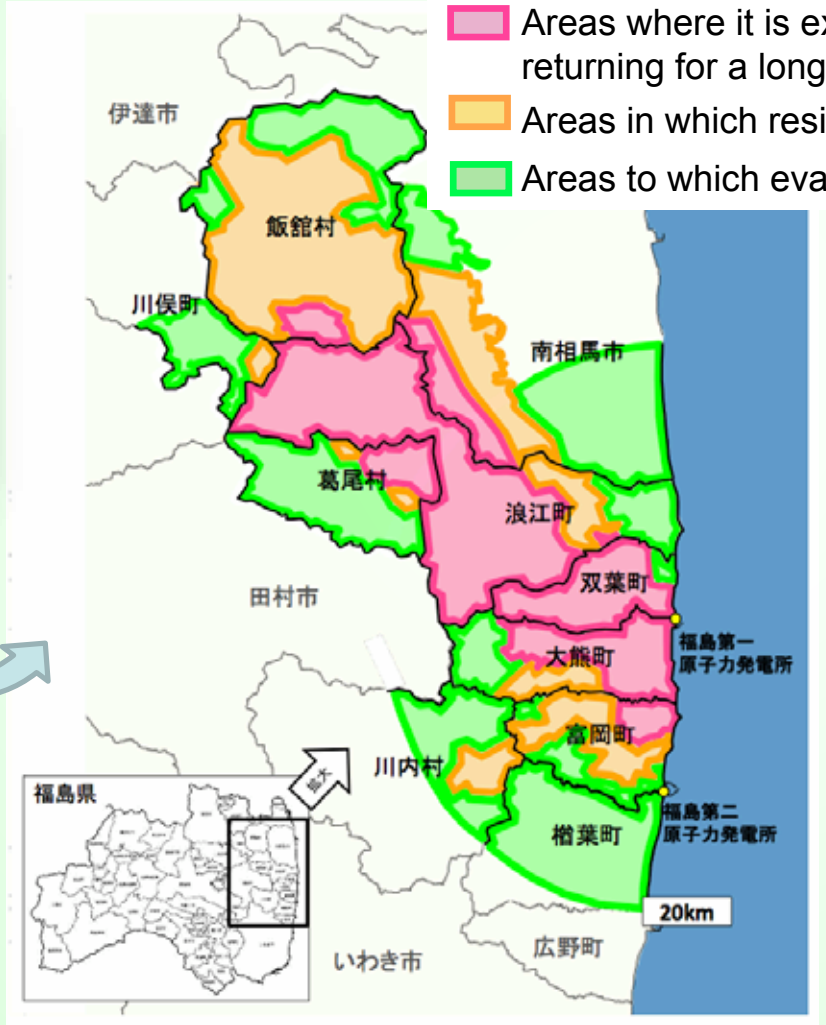
- Restricted zone and planed evacuation zone have been rearranged into 3 areas responding to the annual doses.

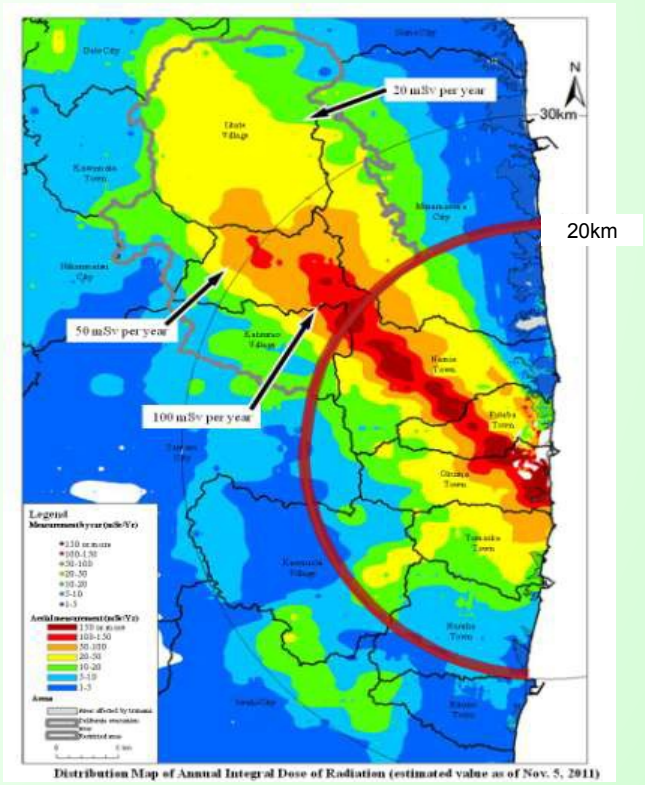
Until 31st March 2012

Areas where it is expected that residents will face difficulties in returning for a long time (> 50 mSv/y)

Areas in which residents are not permitted to live (20 – 50 mSv/y)

Areas to which evacuation orders are ready to be lifted (< 20 mSv/y)





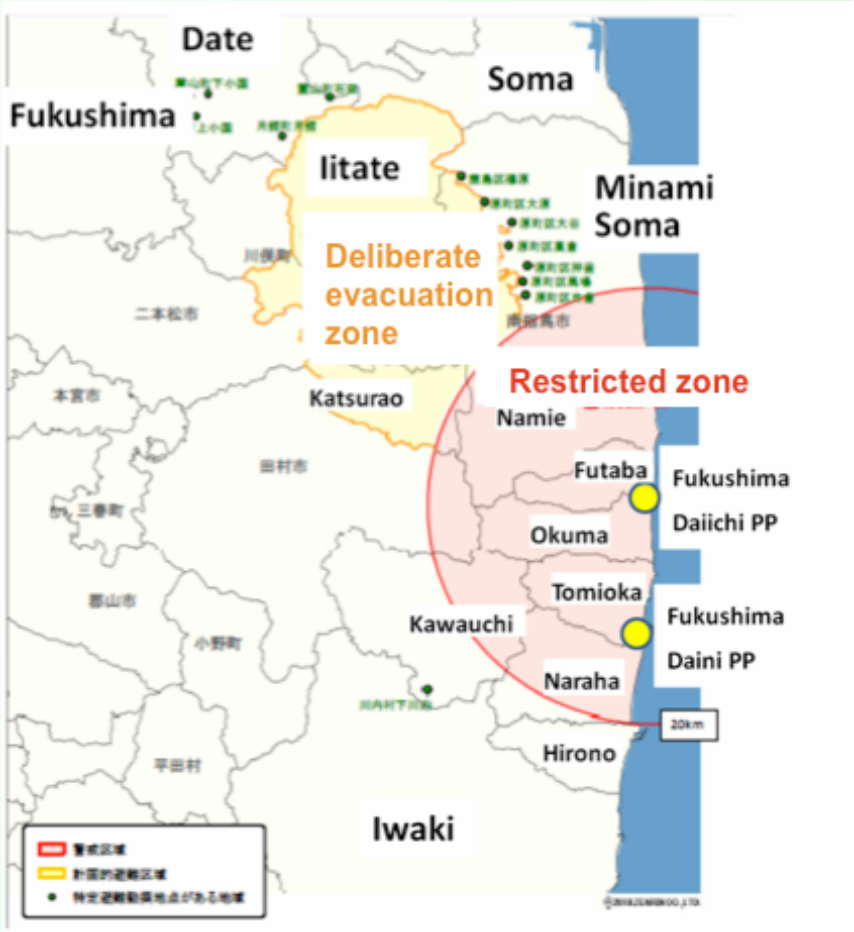
(April 2014)

Decontamination Pilot Project by JAEA

Demonstration of decontamination

- **The model areas were selected for;**
  - ✓**various components such as forest, farmland, building, road and playground**
  - ✓**various dose rate levels; high (> 100 mSv/y), intermediate (20 – 100), and low (5 – 20)**
- **Evaluation of efficiency, production of wastes, cost, safety.**

Based on the knowledge obtained in the pilot projects, full-scale decontamination has been performed.



Decontamination Pilot Project

Decontamination Techniques for Pavement

◆ high pressure water washing

◆ surface stripping

◆ blasting

Iron shot blasting

Dry ice blasting

Decontamination Pilot Project

Decontamination Techniques for Buildings

- high pressure water washing

- removal of dirt, sludge, fallen leaves, etc. in roof gutters and street gutters

- removal with peeling agent

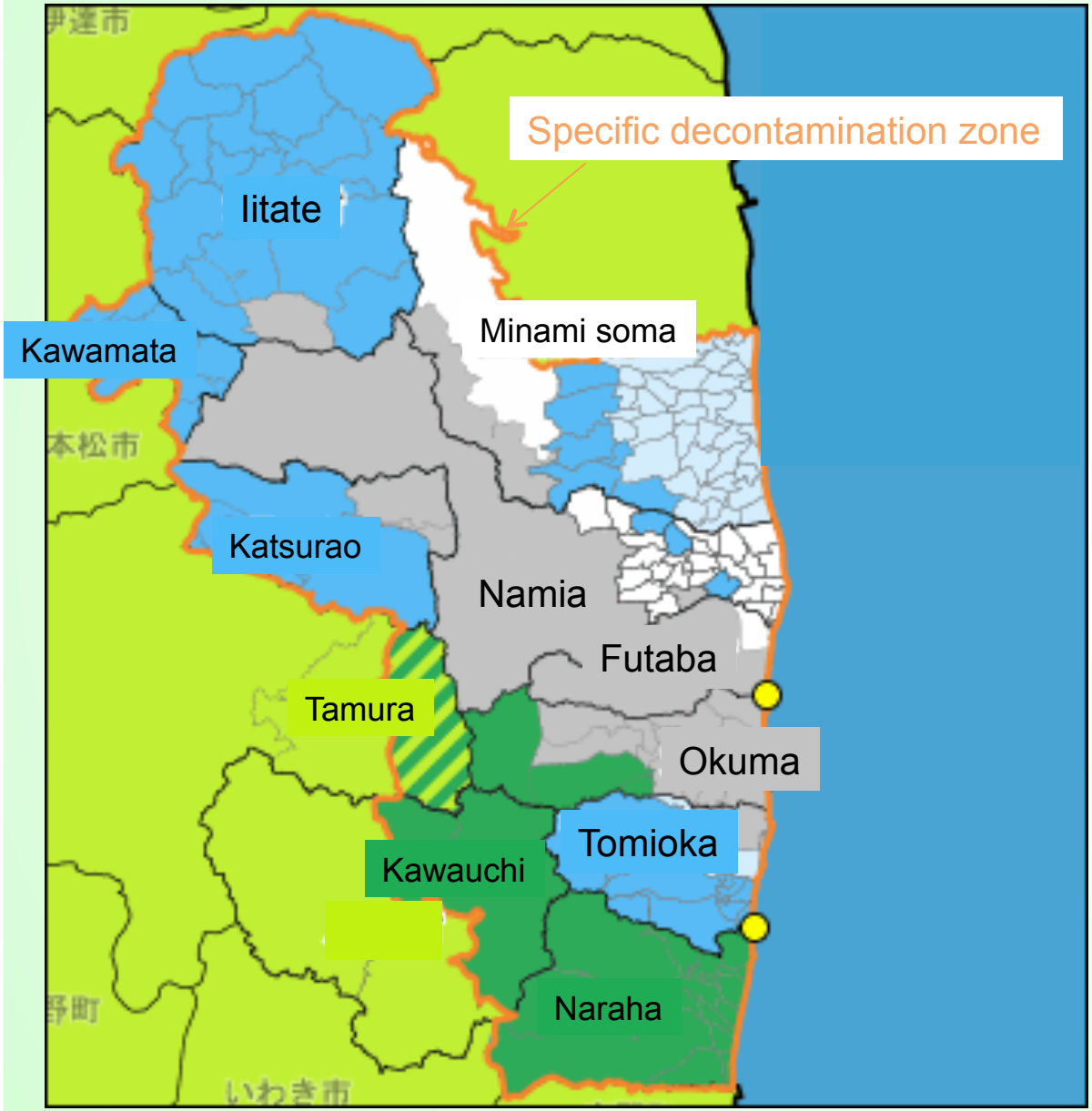
Decontamination Pilot Project: Farmland

- plow

- turf stripping

- topsoil removal

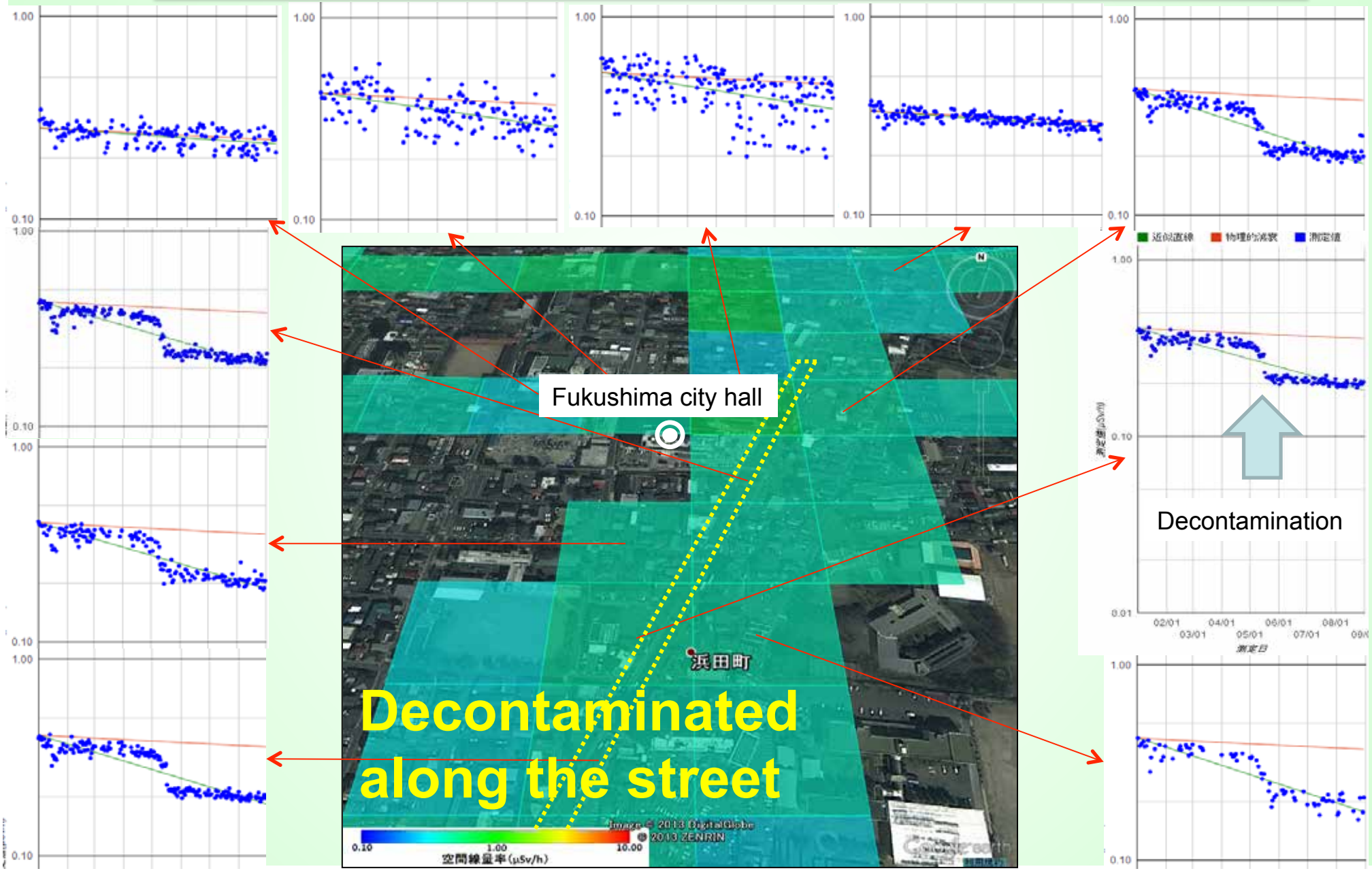
Situation of full-scale decontamination



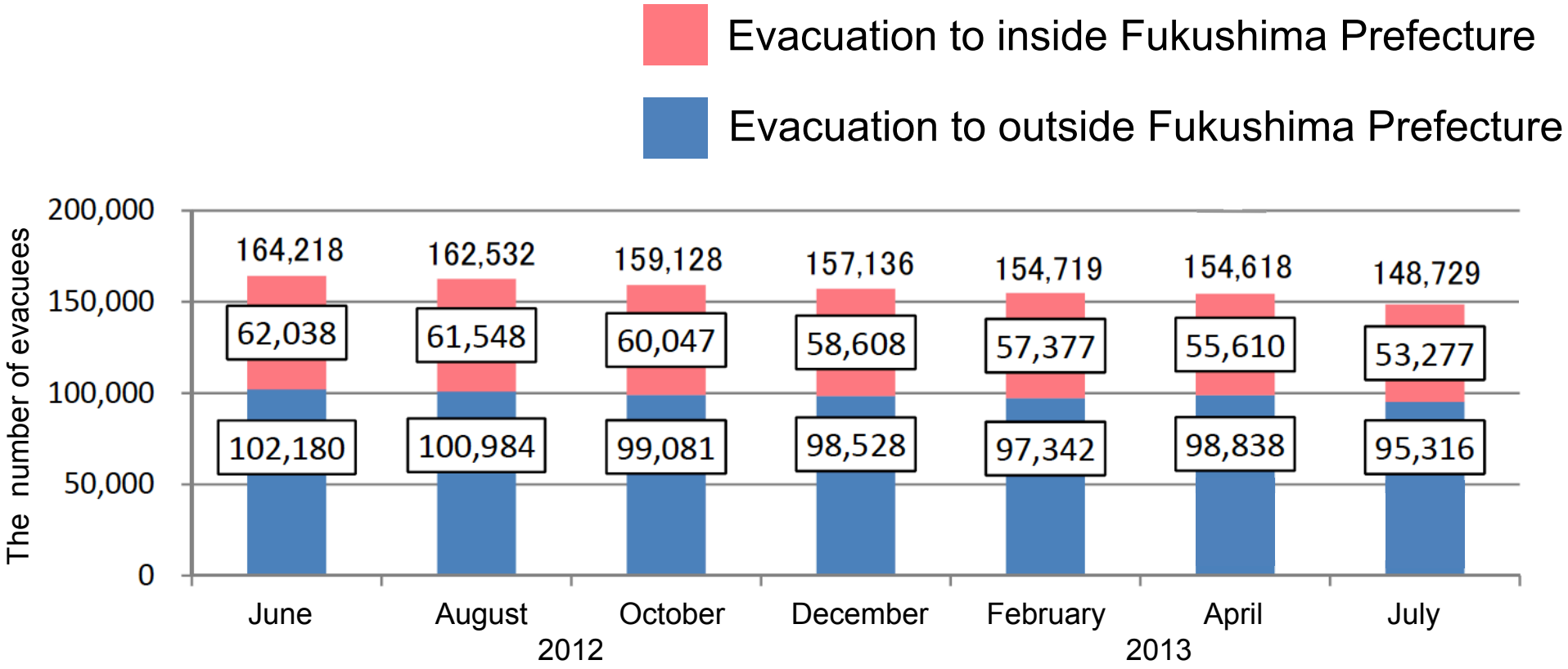
Full-scale decontamination work has been conducted by the National Government for the specific decontamination zone.

- Decontamination finished
- Started
- Ordered
- Not yet ordered
- Difficult-to-return zone

Example of effect of decontamination



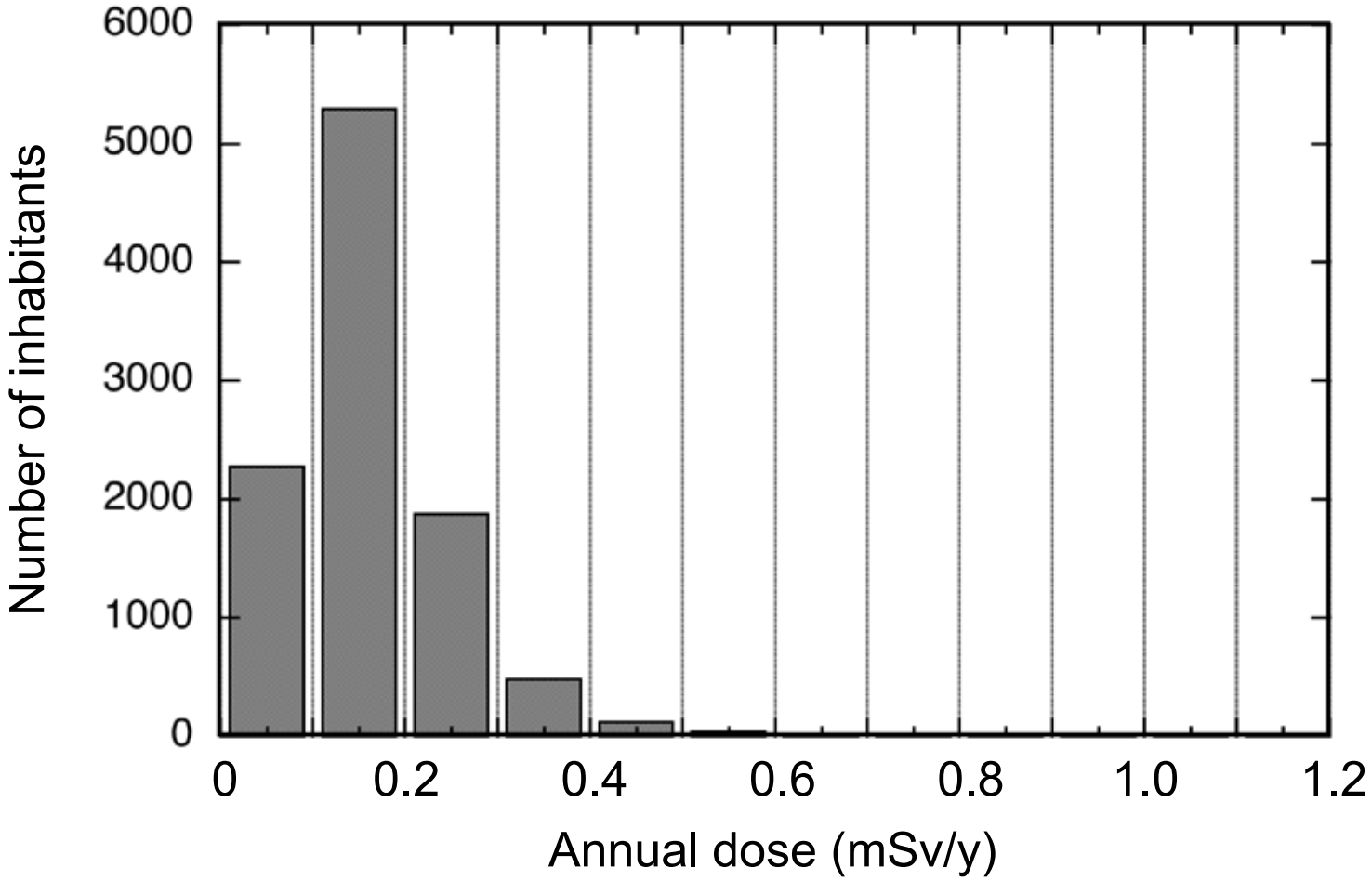
Statistics on the number of evacuees



- **A great number of inhabitants have evacuated.**
- **Inhabitants are gradually returning.**

Annual personal doses in Fukushima City

(2013)



- **Many people are wearing personal dosimeters to estimate external exposure doses**

Check of foodstuffs produced in Fukushima

Statistics on food inspection

April 2012 – June 2013

	Rice	Vegetable, fruit	Meat, milk	Mushroom, etc.	Fish
Inspection No.	Checked whole 10,331,405	8,857	8,381	1,910	9,019
Exceeding the limit	71	7	0	166	993
Rejected rate	0.0007%	0.08%	0.00%	8.69%	11.01%

- **Cesium concentration in many foodstuffs has been monitored.**
- **Most of monitored foodstuffs have concentrations below the limit (100 Bq/kg).**

Summary on recovery

1. Evacuation zones were rearranged according to the current contamination conditions.
2. Full-scale decontamination work has been done step by step.
3. Evacuees are returning to their native towns.
4. It will take a long time to entirely recover from the accident.
5. People in Fukushima are steadily moving forward.

Thank you for attention