Situation in Japan today, latest results of the radiological health effects assessments

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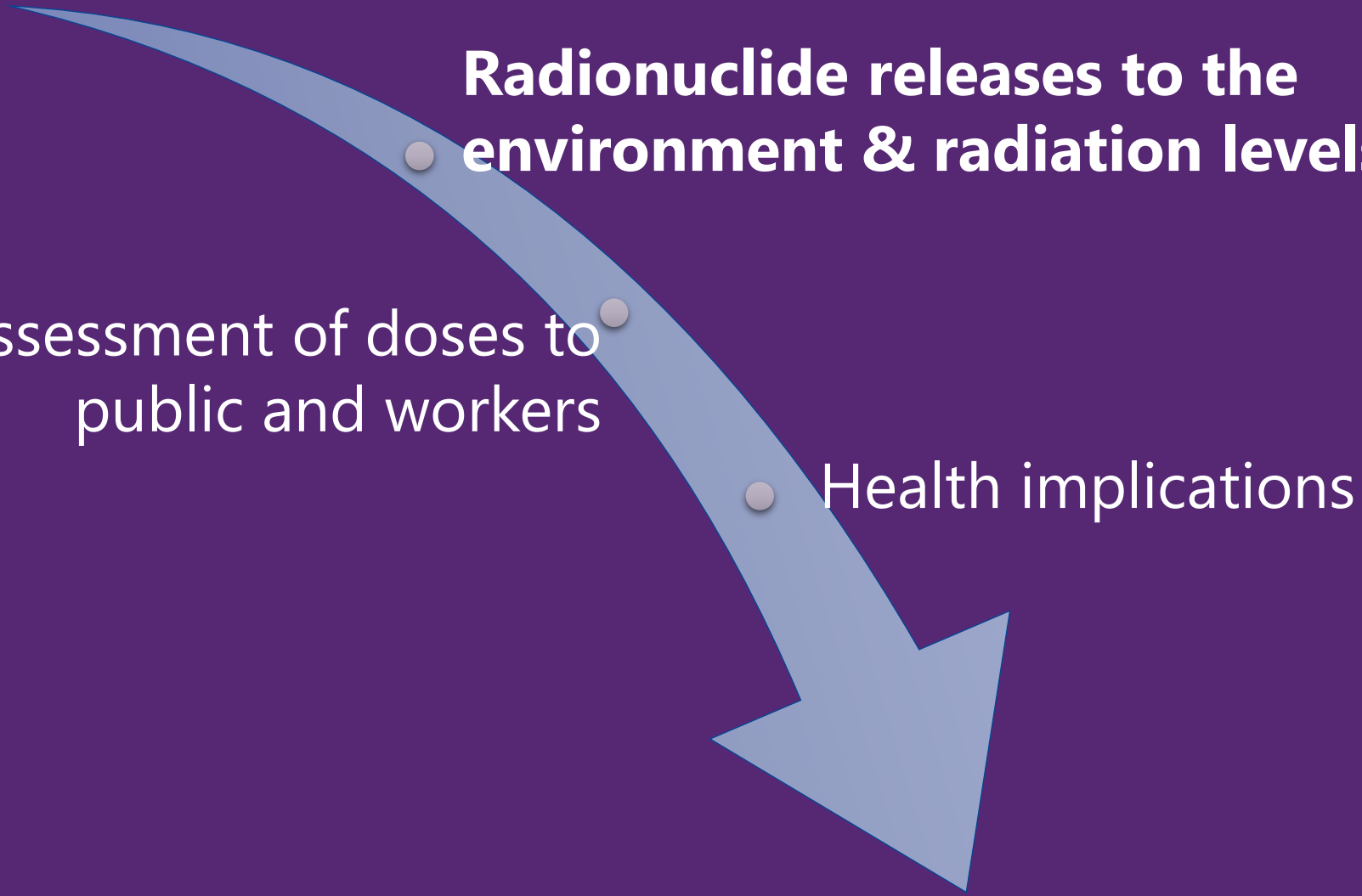
Testing a portal monitor during a nuclear emergency exercise

About me …

- PhD in Physics (Nuclear and Radiation Physics) – KULeuven
- Unit Head and Scientific Researcher at the Belgian Nuclear Research Centre (SCK CEN)
  - Nuclear and Radiological Emergency Preparedeness and Response (ATM, Monitoring, …)
  - Nuclear explosion monitoring for treaty verification
  - Impact assessments of planned, existing and emergency exposure situations
- Radiological expert in context of Belgian Federal Nuclear and Radiological Emergency Plan
- President of the R&D Committee of the European Platform for Nuclear and Radiological Emergency Preparedness, Response and Recovery (NERIS)
- Lecturer in several courses: Guest Professor at UHasselt (Radiation Physics)

Outline



Largely based on UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) evaluations.

Releases to the environment

- Atmospheric releases (main radionuclides are given, 1 PBq= 10^{15} Bq = 1000 TBq):

Radionuclide (half-life)	Fukushima (Units 1,2, 3)	Chernobyl (Unit 4)	Atmospheric Nuclear testing
Xe-133 (5.25 d)	**7300 PBq (61%)**	6500 PBq (100%)	
I-131 (8.02 d)	**121 (100-500) PBq (2%)**	1760 (60 %)	675 000 PBq
Cs-137 (30.08 y)	**10 (6-20) PBq (1.3%)**	85 PBq (30%)	948 PBq
Cs-134 (2.065 y)	**10 (6-20) PBq (1.3%)**	47 PBq (30%)	
Sr-90 (28.90 y)	**<0.01 PBq (<0.001%)**	10 PBq (4%)	622 PBq
Pu-239 (24 110 y)	**very small**	0.013 PBq (1.5%)	6.52 PBq

- 20% released over land (Japan), 80% released over the Pacific Ocean
- Effective dose and thyroid dose mainly due to Cs-137/Cs-134 (external dose from deposition) and I-131 (inhalation)
- Iodine fractions: large variations reported,
  UNSCEAR: 20% $^{131}I_{elemental}$, 30% $^{131}I_{organic}$, 50% $^{131}I_{particulate}$

Releases to the environment

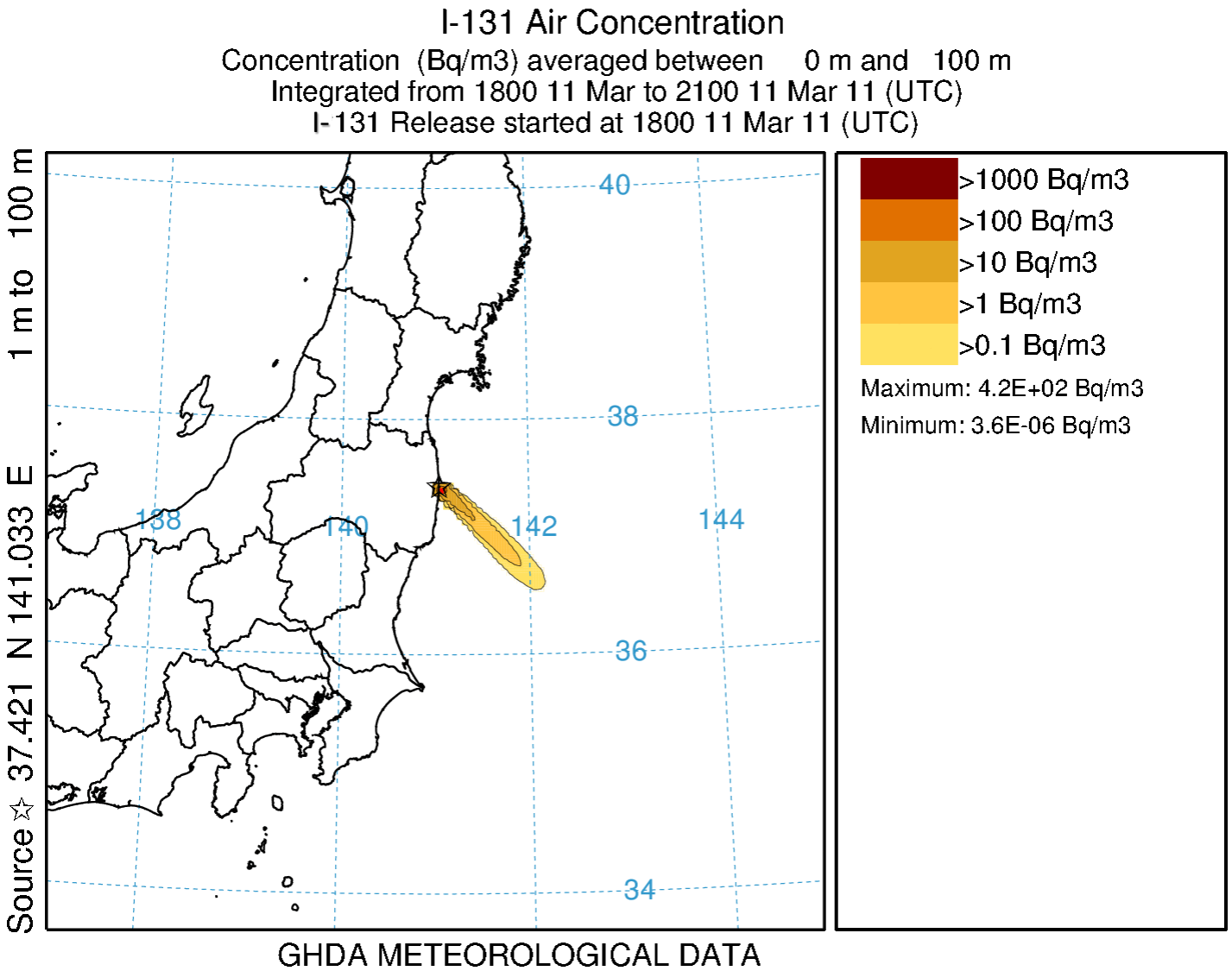
- Releases into the Pacific Ocean:

Radionuclide	Direct releases*	Indirect via deposition
H-3 (tritium)	0.3-0.7 PBq	
I-131	11-18 PBq (0.2%)	57-100 PBq
Cs-137	3.5-5.6 (0.6%)	5-8 PBq
Cs-134	3.5-5.6 (0.6%)	5-8 PBq
Sr-90	0.04-1	

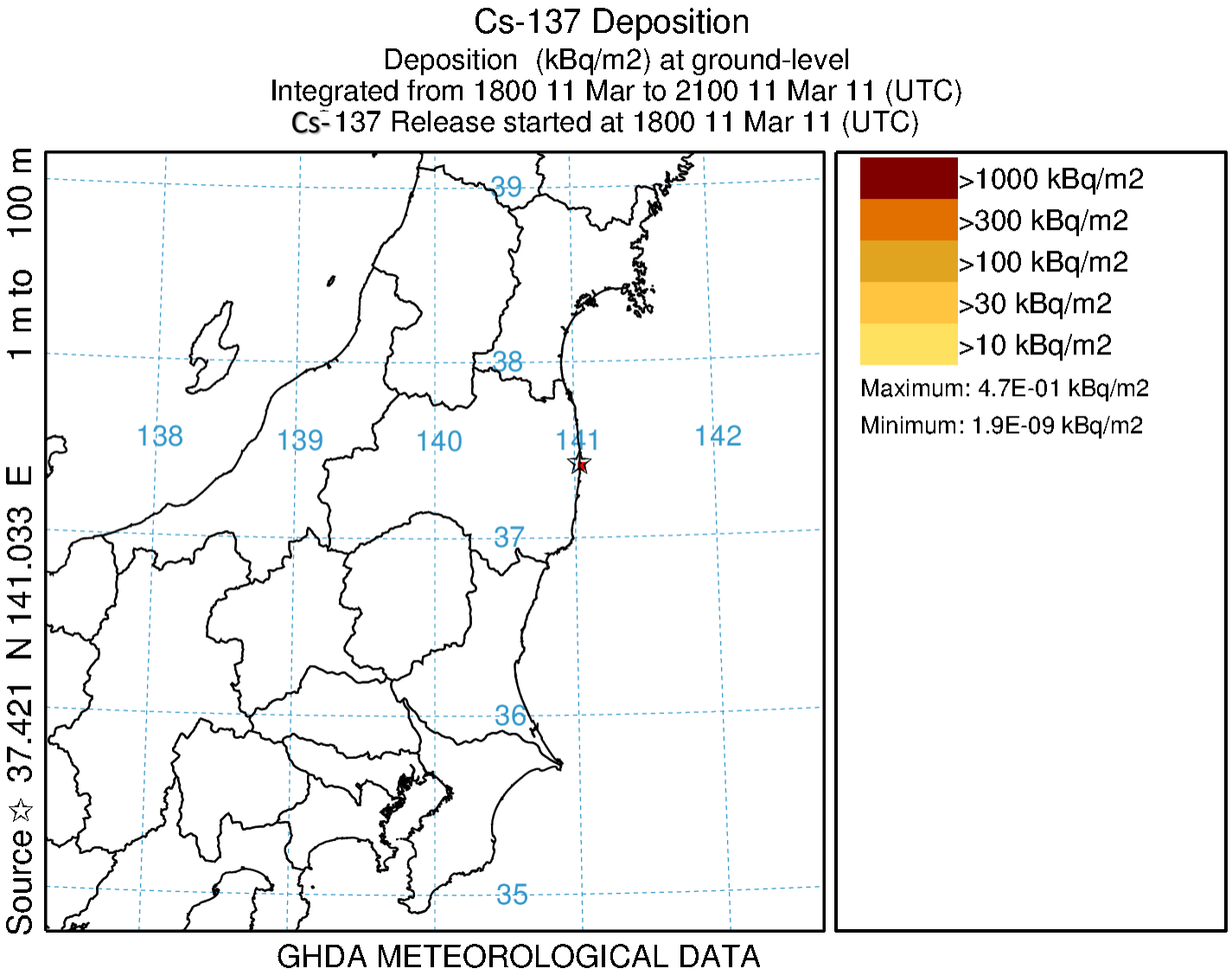
*Direct releases mainly in period March-May 2011

- Limited marine releases afterwards (Cs-137):
  - June 2014 - October 2015: 59 TBq, after October 2015: 0.5 TBq/y
  - From rivers: 5 - 10 TBq/y

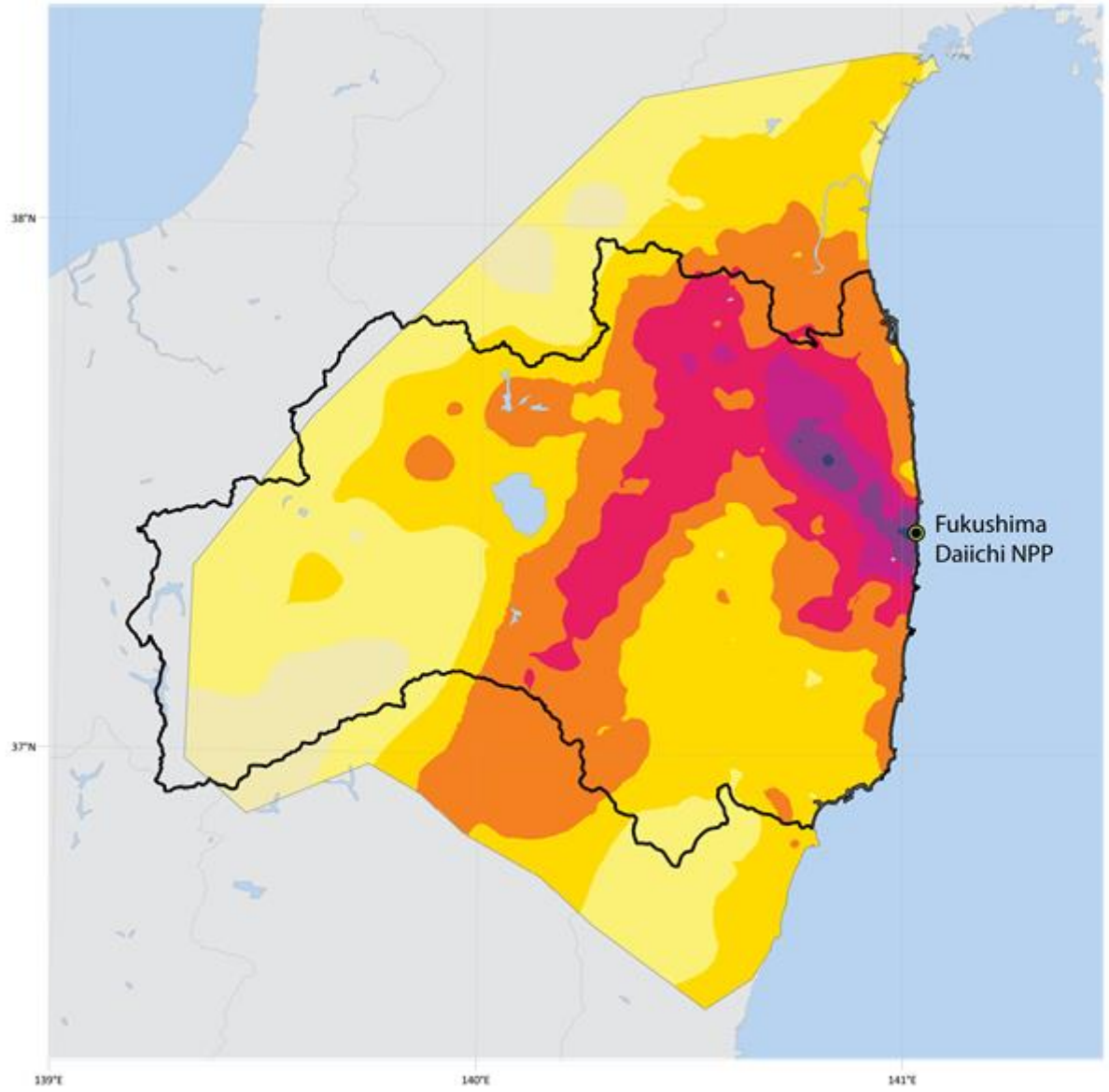
Animation of ^{131}I dispersion in atmosphere



Animation of ^{137}Cs deposition on ground/sea surface



^{137}Cs deposition on the ground (situation on June 14, 2011)



Fukushima Prefecture

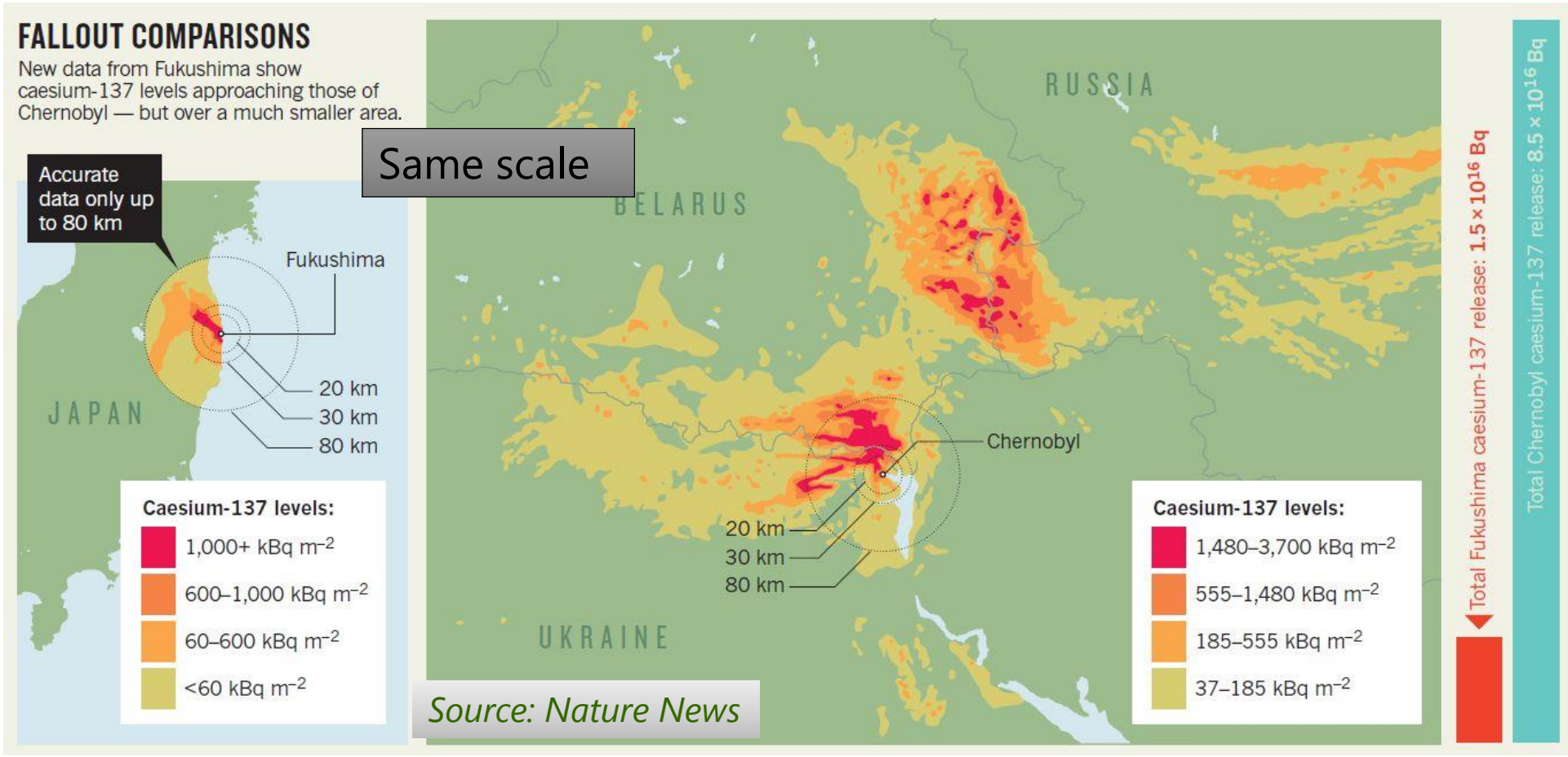
- Area: 13 783 km²
- Population: 1.85 million

Flanders

- Area: 13 522 km²
- Population: 6.59 million

The highest measurements exceeded 5 MBq/m²

Comparison Fukushima – Chernobyl – Cesium-137 soil contamination

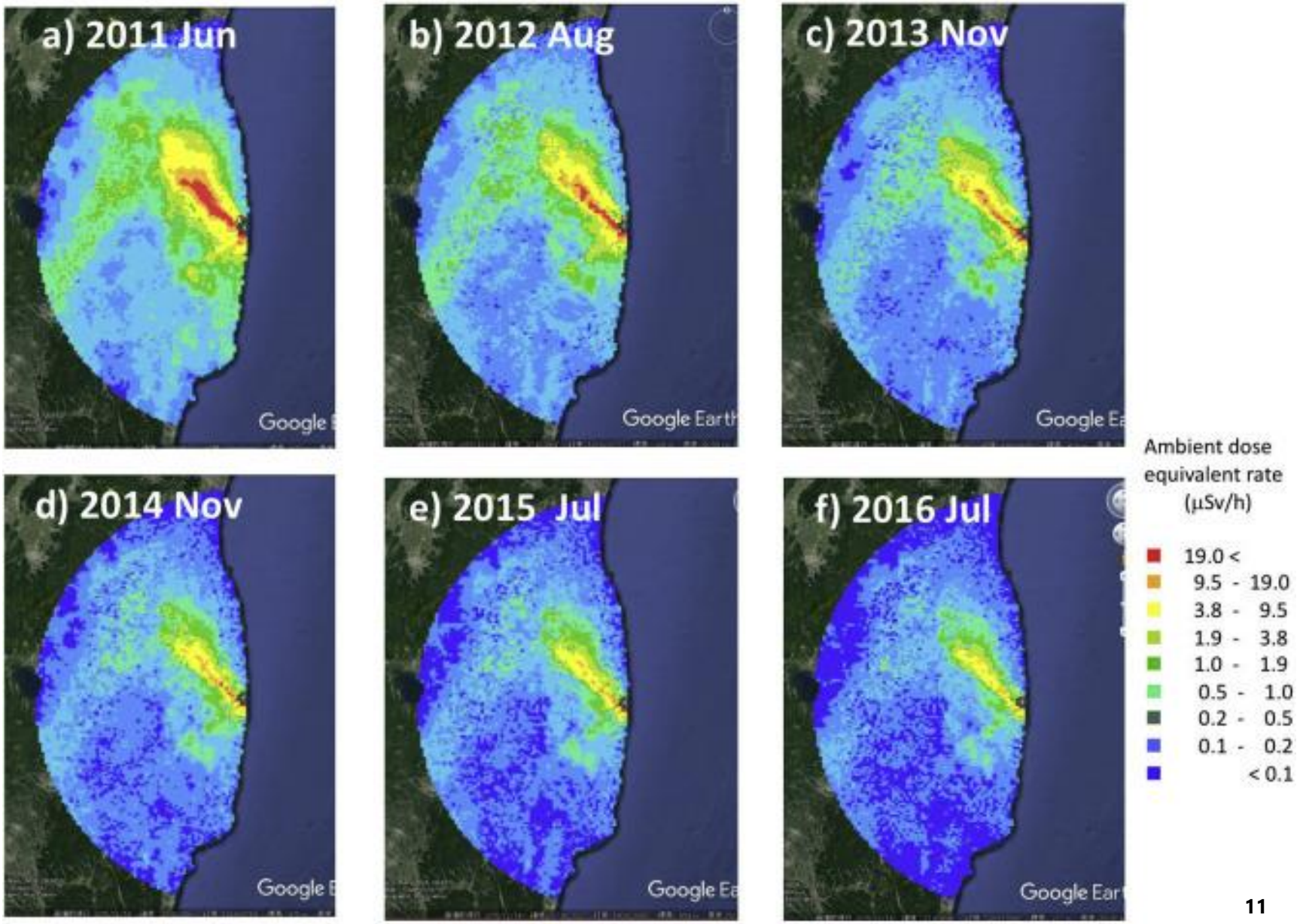


Comparable contamination levels in Fukushima but over a much smaller area

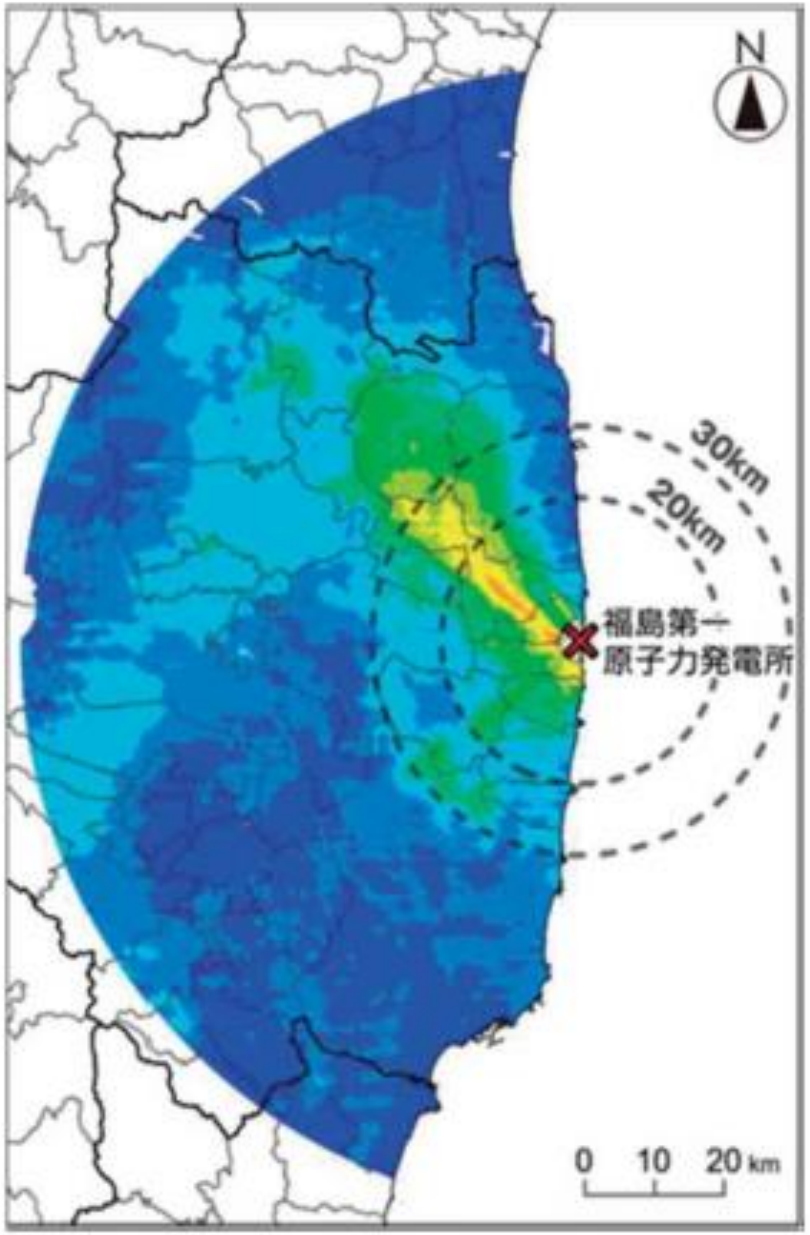
- The releases and fallout in sea are not included in the Fukushima figures

Evolution ambient dose equivalent rate

Effective dose from external radiation (Cs) Protection quantity	Corresponding ambient dose rate equivalent Operational quantity
mSv/y	μSv/h
100	19
20	3.8
1	0.19



Effective dose from external radiation (Cs) Protection quantity	Corresponding ambient dose rate equivalent Operational quantity
mSv/y	μSv/h
100	19
20	3.8
1	0.2



Legend

Air dose rate is measured from 1m above the ground (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
- No measurement result In the area

*In this map, the air dose rate includes that derives from natural nuclides

After 91 months from the accident (October 2018)

Decrease of dose rate

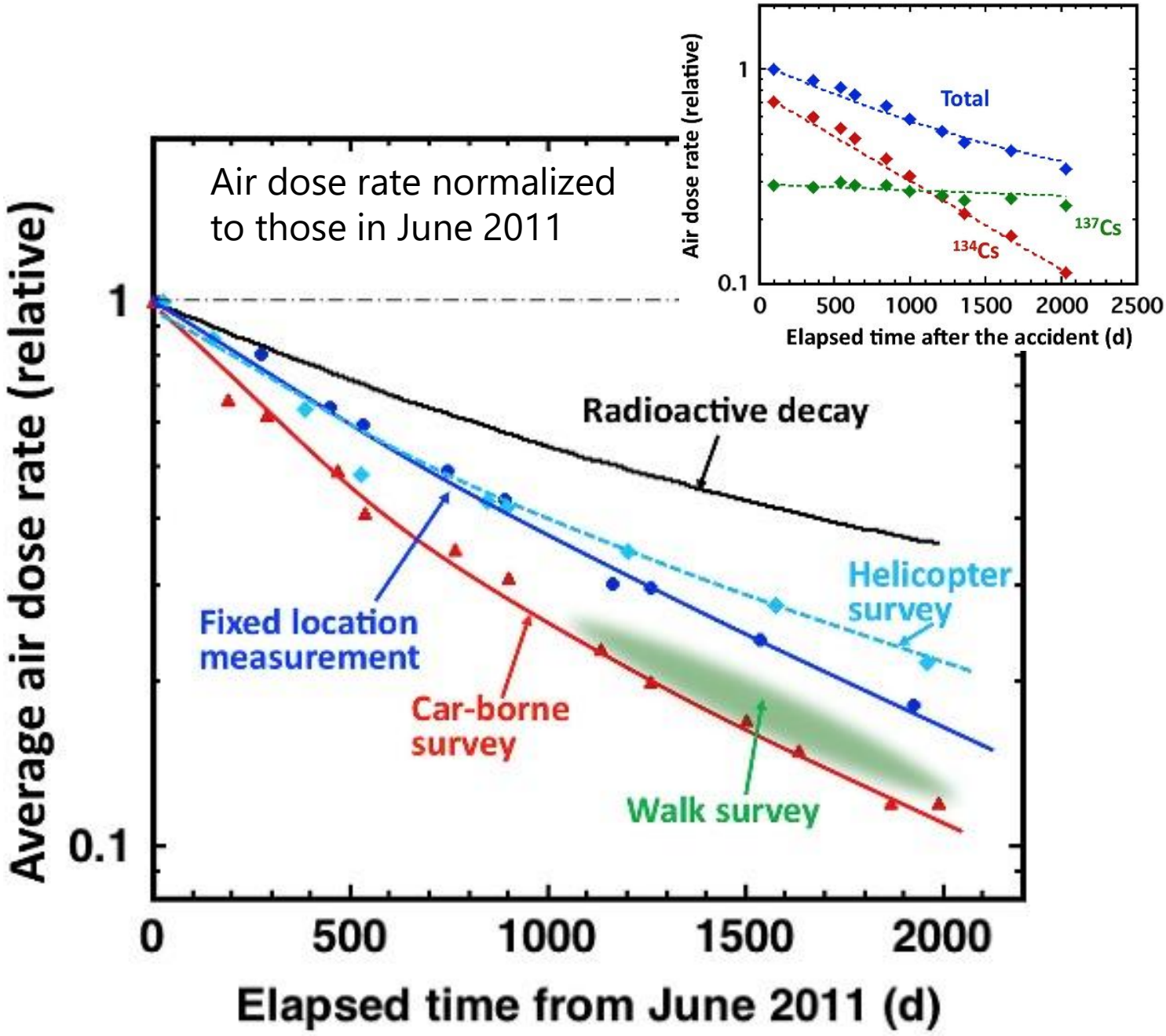
Deposited Cs-137 and Cs-134 fully dominate dose rate

- Still most in 10 cm upper soil layer

Dose rate reduced to (relative to June 2011):

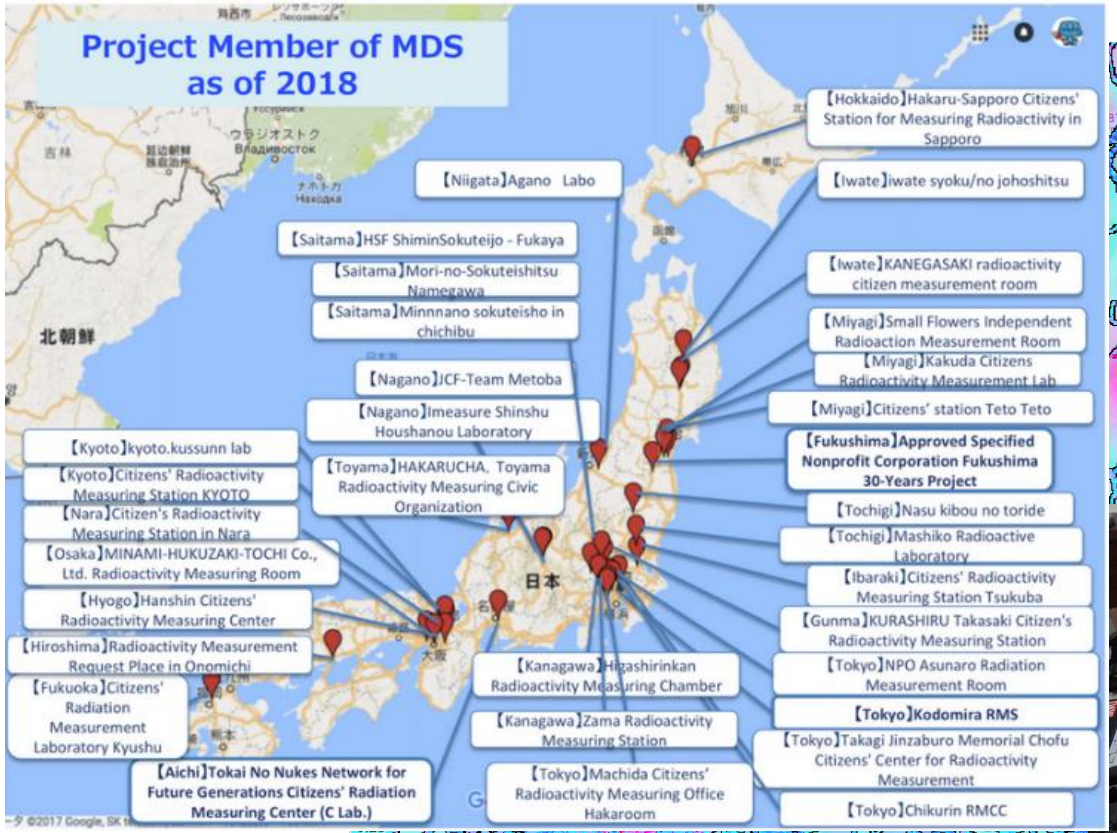
- Undisturbed areas: 18%
- Roads: 12 %
- Forests: 37 % (nearly half-life)

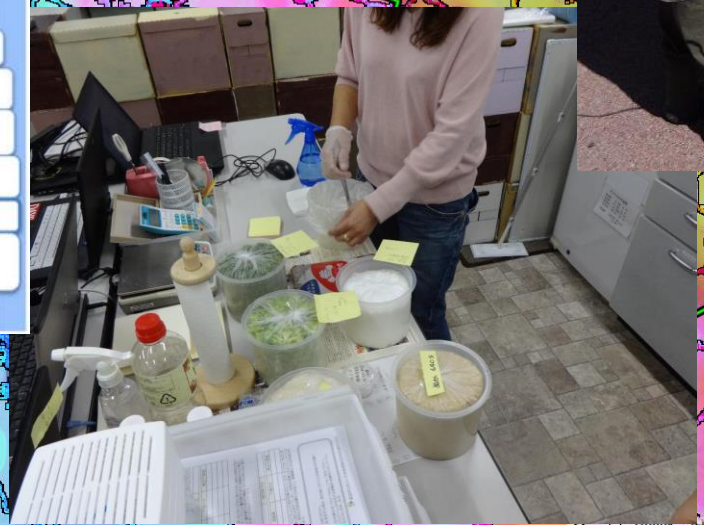
Dose reduction factor indoor ≈ 0.4

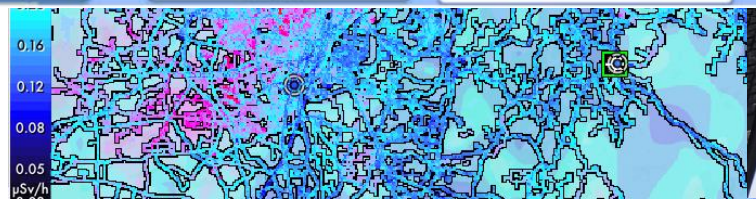


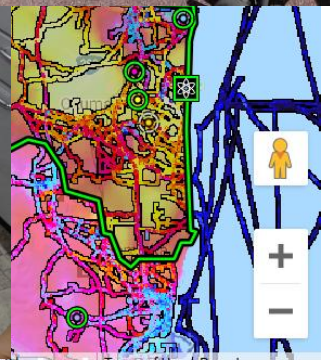
Citizen Science

Large number of Citizen initiatives to measure ambient radiation levels and radioactivity in samples (food)

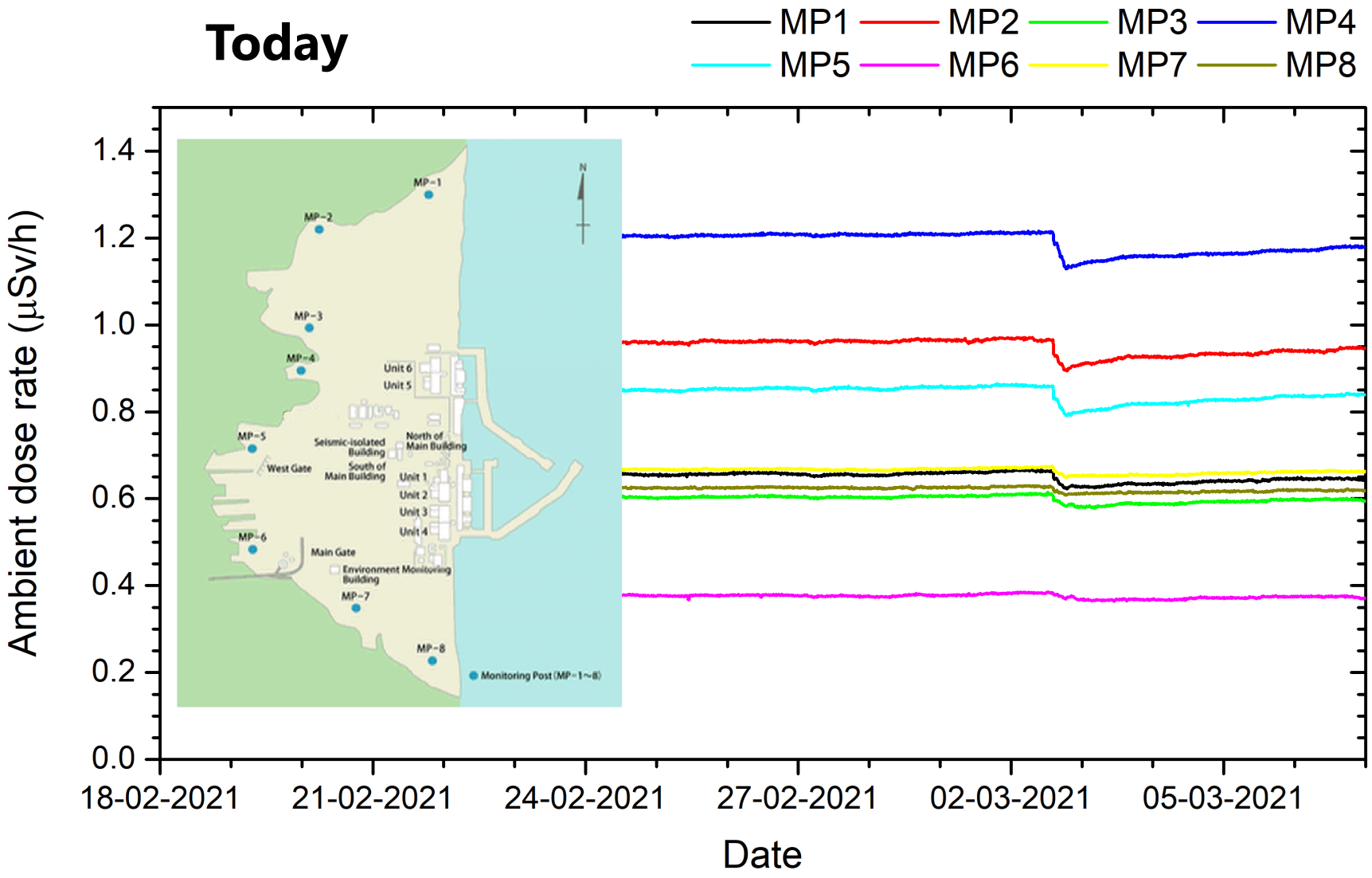




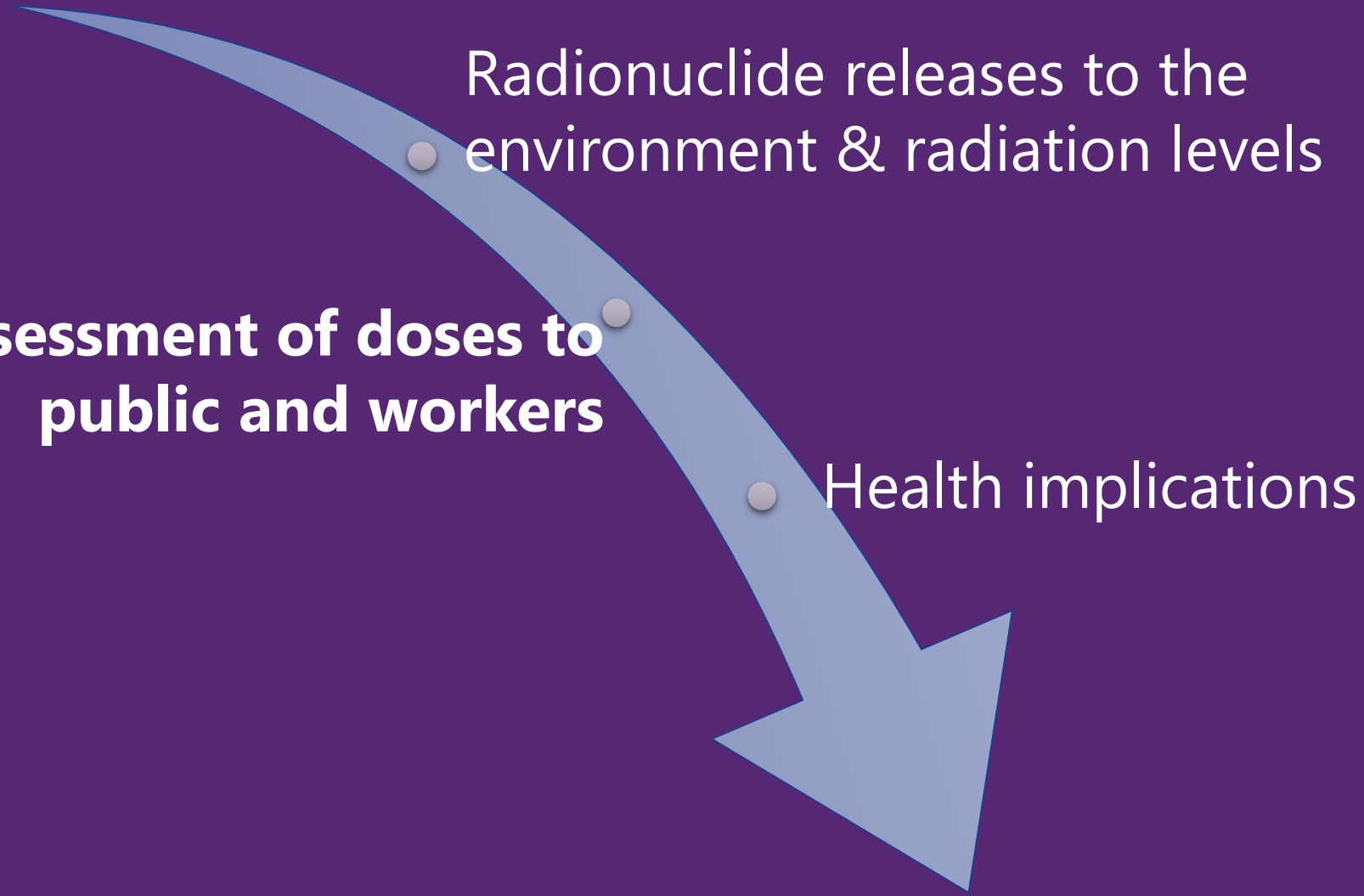




On-site specific radiation situation (direct radiation, debris, deposition, …)



Outline

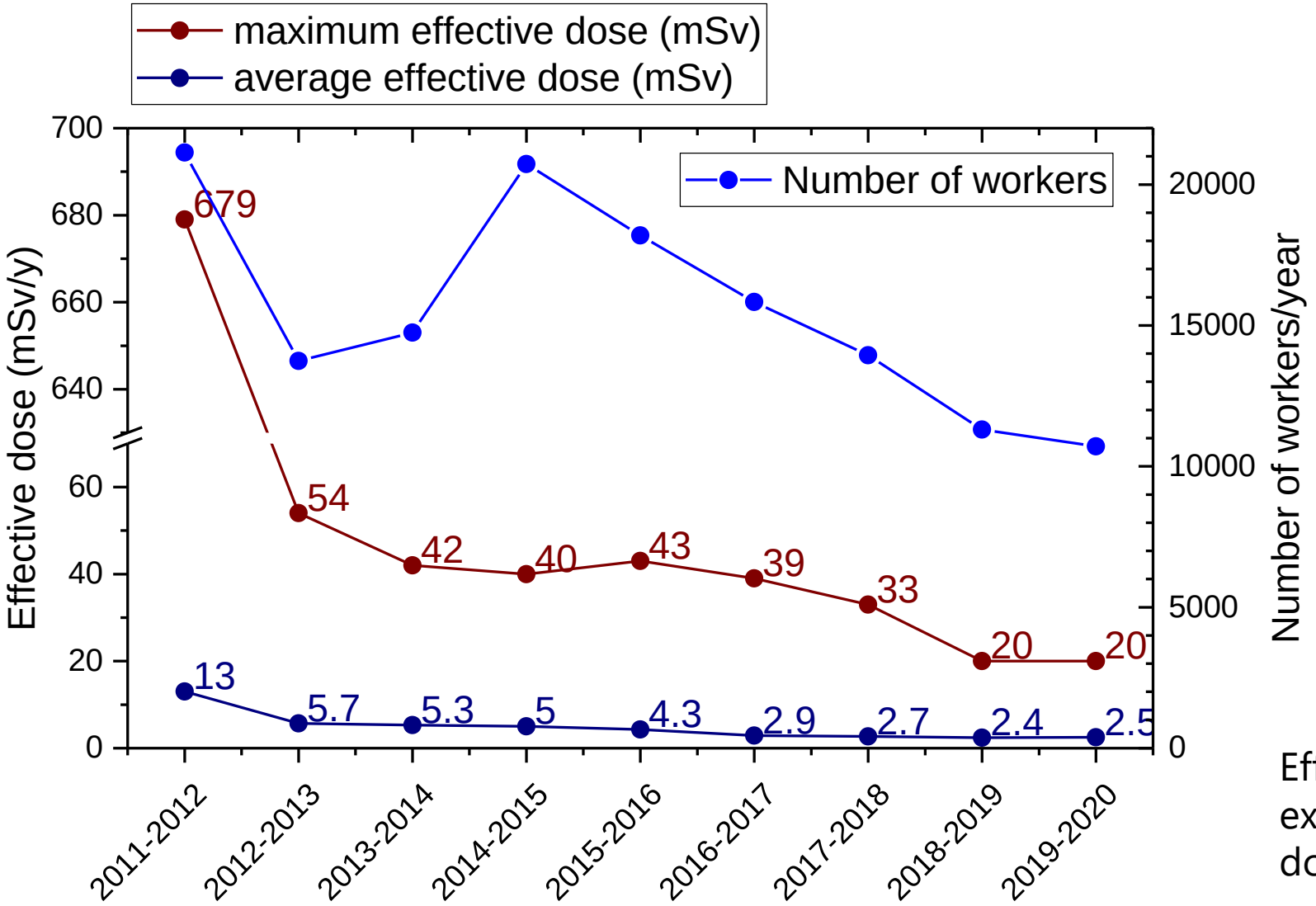


Largely based on UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) evaluations.

Doses to radiation workers not always well-determined

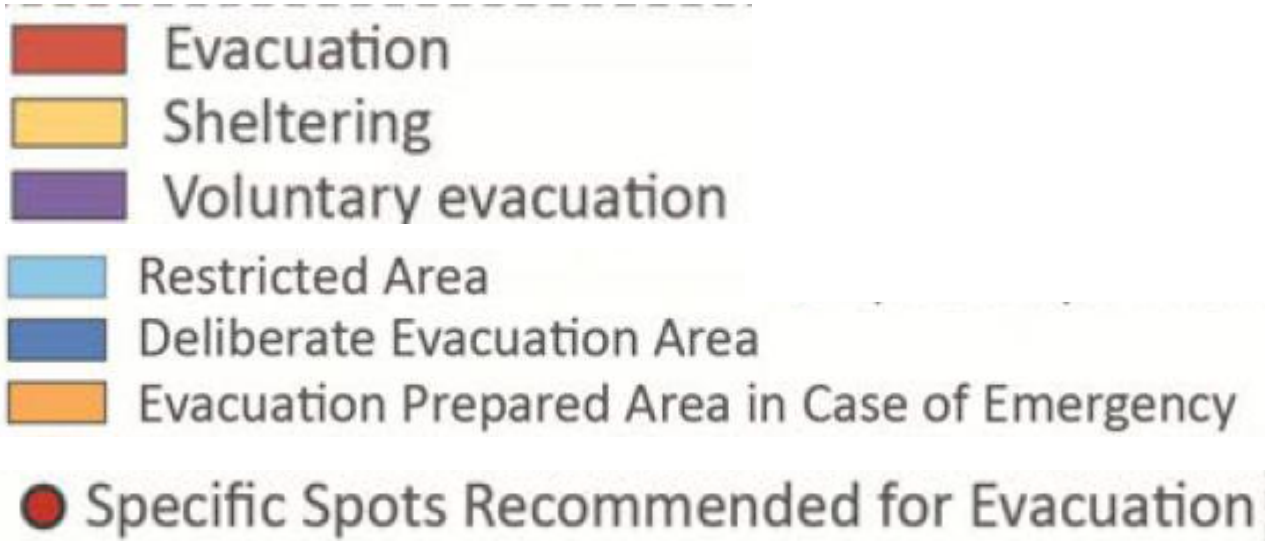
- 174 workers out of more than 21 000 received doses from 100 to 680 mSv in the first year
- Personal dosimeters were only provided after 1 April. Workers had to share dosimeters in March, with only one worker in a team wearing a dosimeter for many missions
- 13 workers received thyroid doses of 2 to 32 Gy. Thyroid monitoring of these workers started late (3 in mid-April and the others in mid- or late May). Contribution of ^{133}I and ^{132}Te could not be determined (assumed to be 20%). No urine monitoring to confirm the thyroid measurements
  - ➡ The detection limit for ^{131}I was quite high because the thyroid measurements were done late

Evolution of doses to radiation workers



Effective dose includes external and internal dose

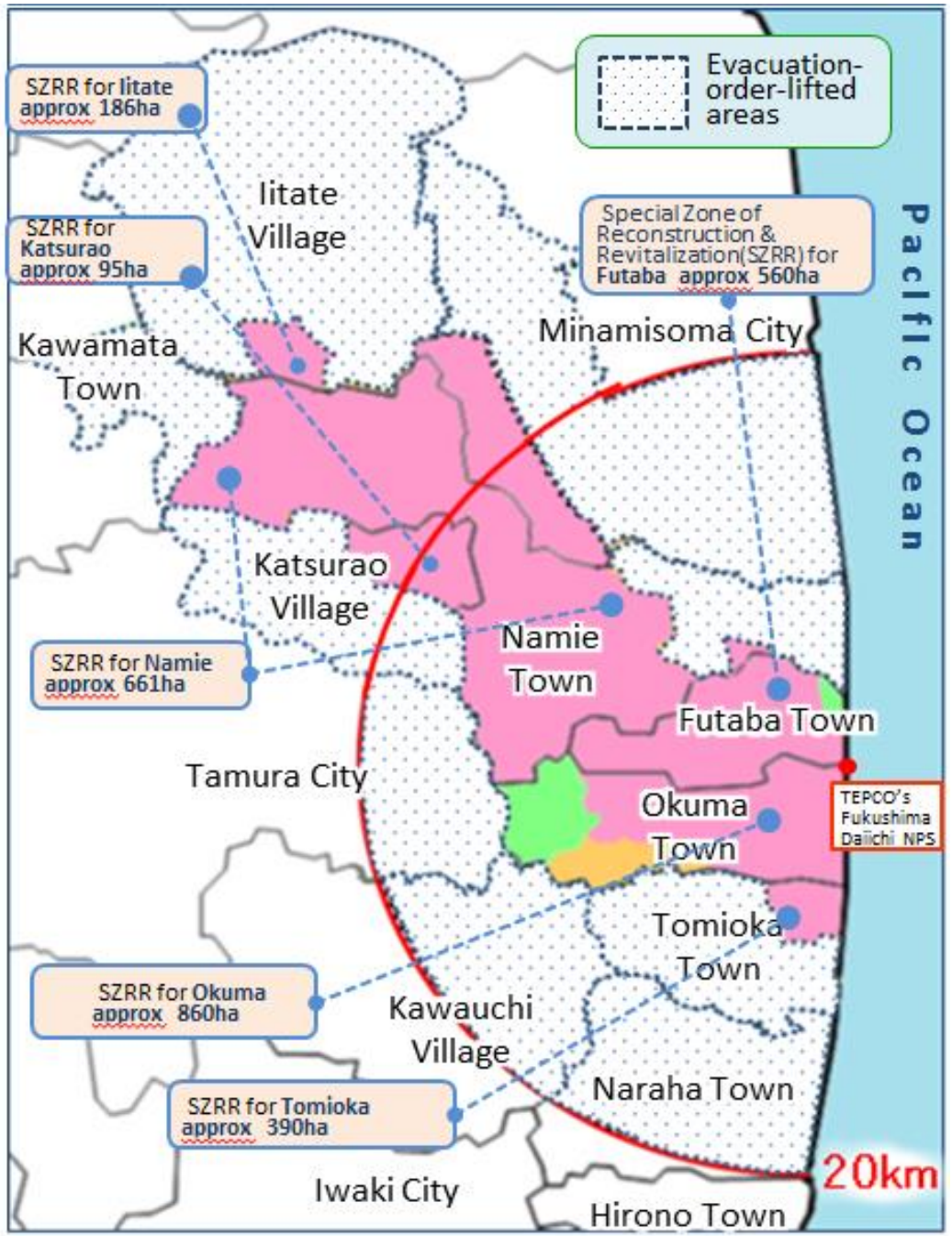
Doses to the public, different factors play:
Where were the people, at what time?



Dose to public

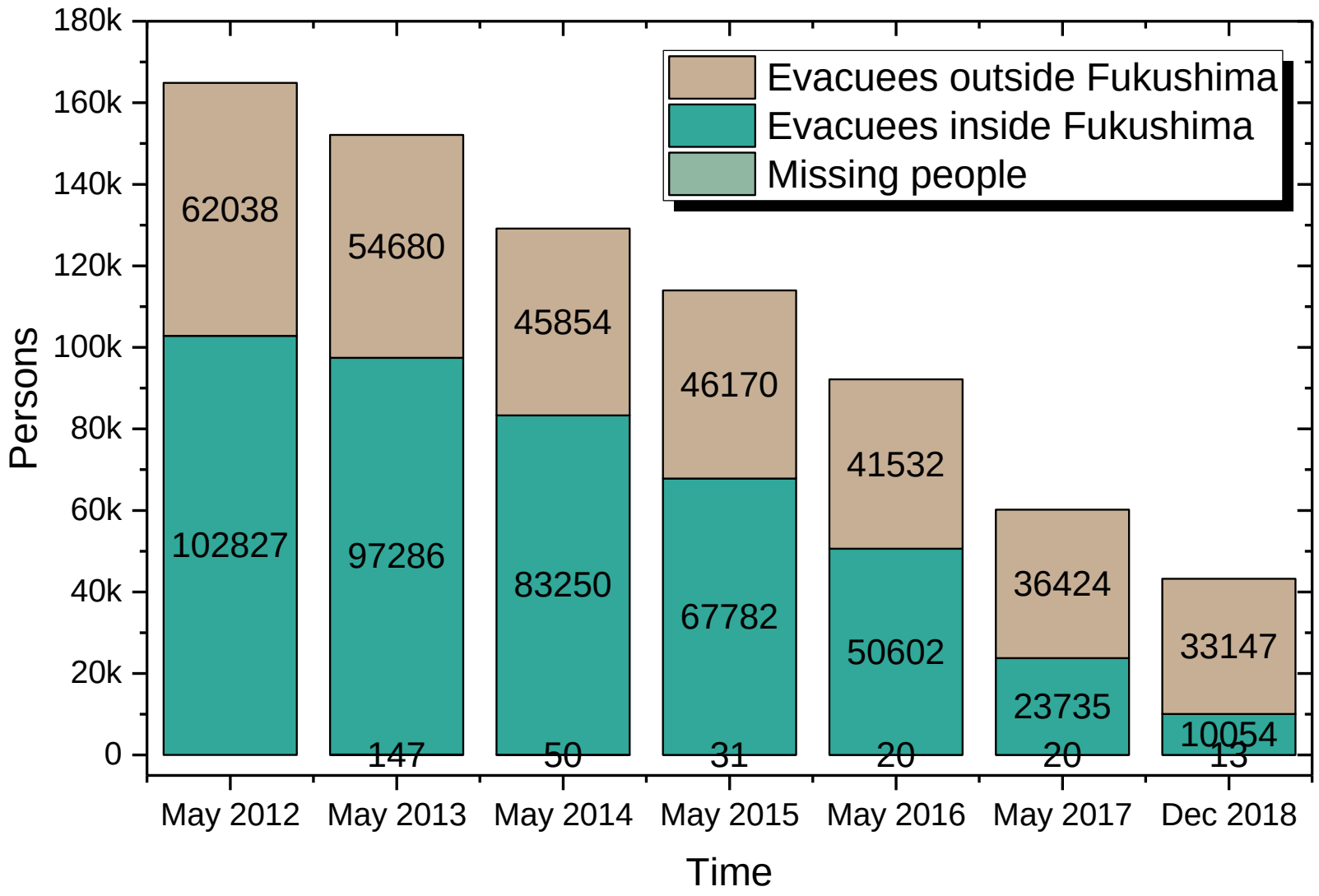
- Countermeasures:
  - Immediate evacuation
  - Sheltering
  - late (deliberative) evacuation
  - Restricting distribution and consumption of contaminated foodstuffs (milk, vegetables, grains, meat, fish) and drinking water
- Habits (fraction indoor/outdoor, diet, …)
- Remediation of affected areas (longer term doses)

Current situation:



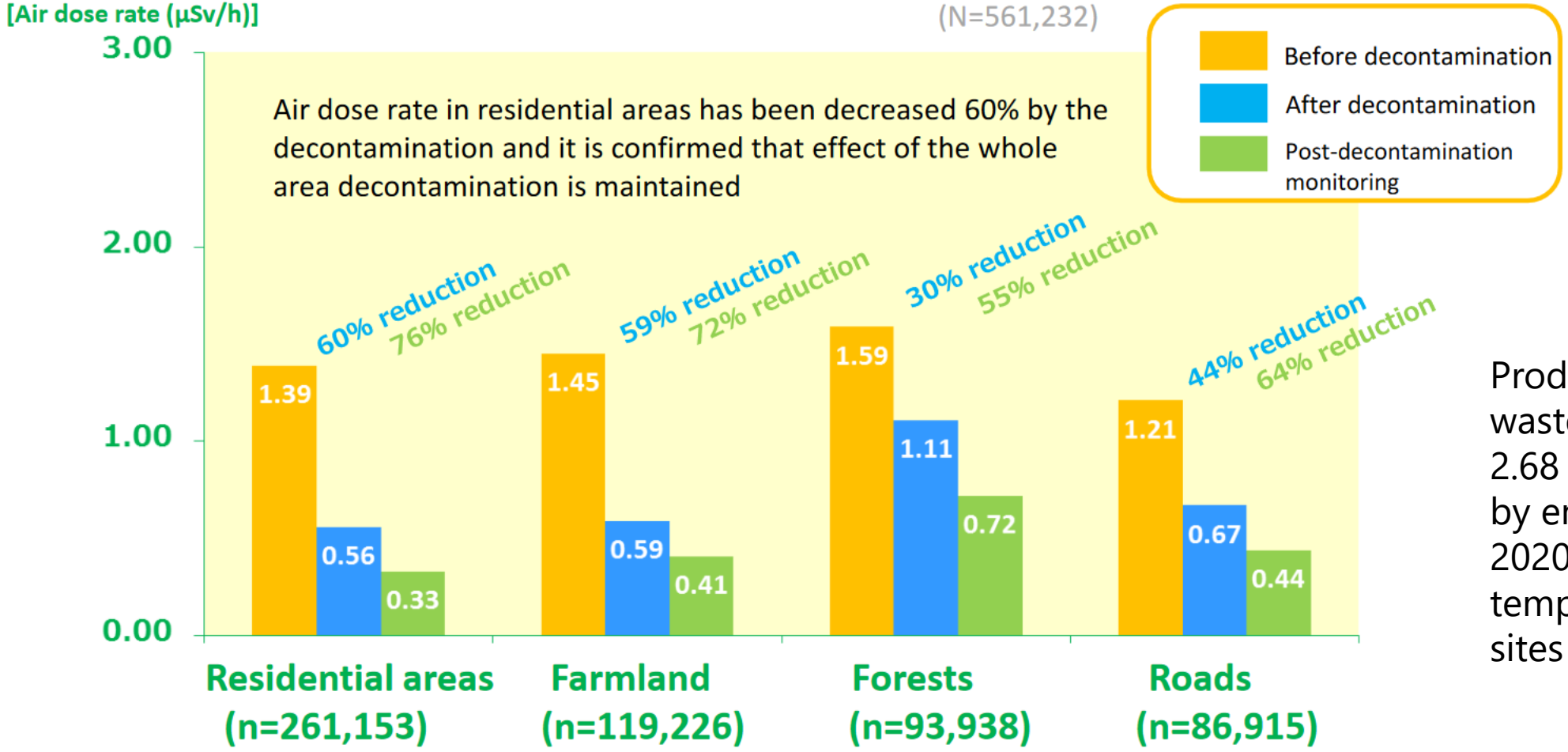
Evolution of evacuees

Around 2.3% of population of Fukushima are still under evacuation



Effectiveness of decontamination

<Air dose rate measured at the height of 1m from the ground / Transition according to land category>



Production of waste:
2.68 million tonnes by end of May 2020 stored at temporary storage sites

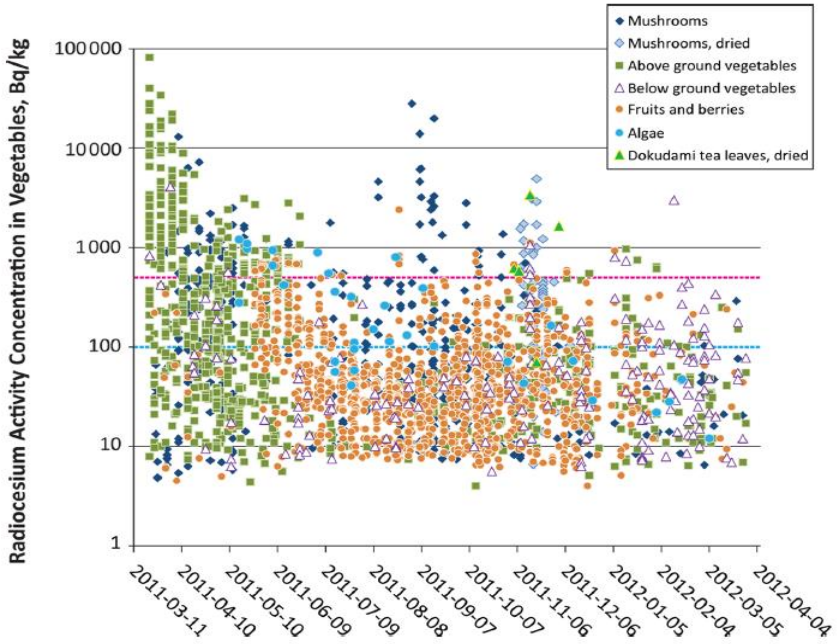
Consumers are reluctant to purchase (even slightly) contaminated food

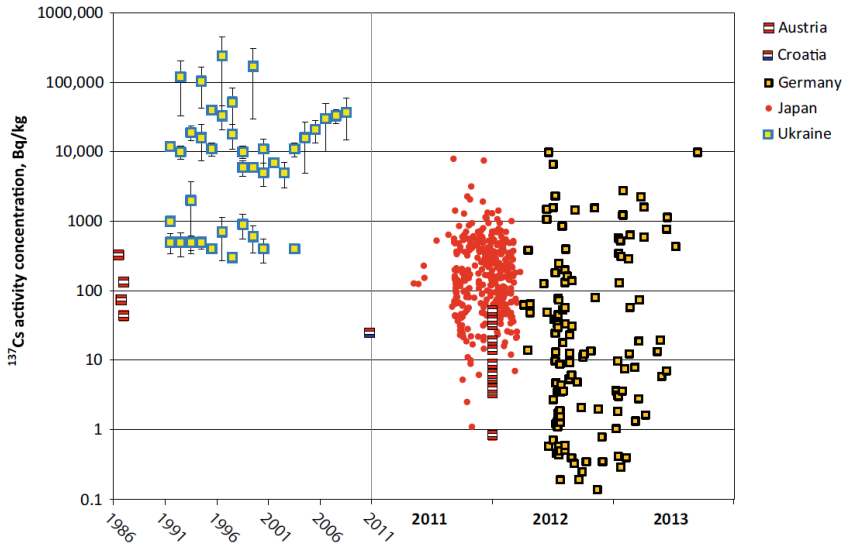
Provisional limit from March 2011		Standard limit from 1 April 2012	
Food category	**Standard limit (Bq/kg)**	**Food category**	**Standard limit (Bq/kg)**
Drinking water	200	Drinking water	10
Milk, dairy products	200	Milk	50
Vegetables Grains Meat, eggs, fish	500	General foods	100
		Food for infants	50

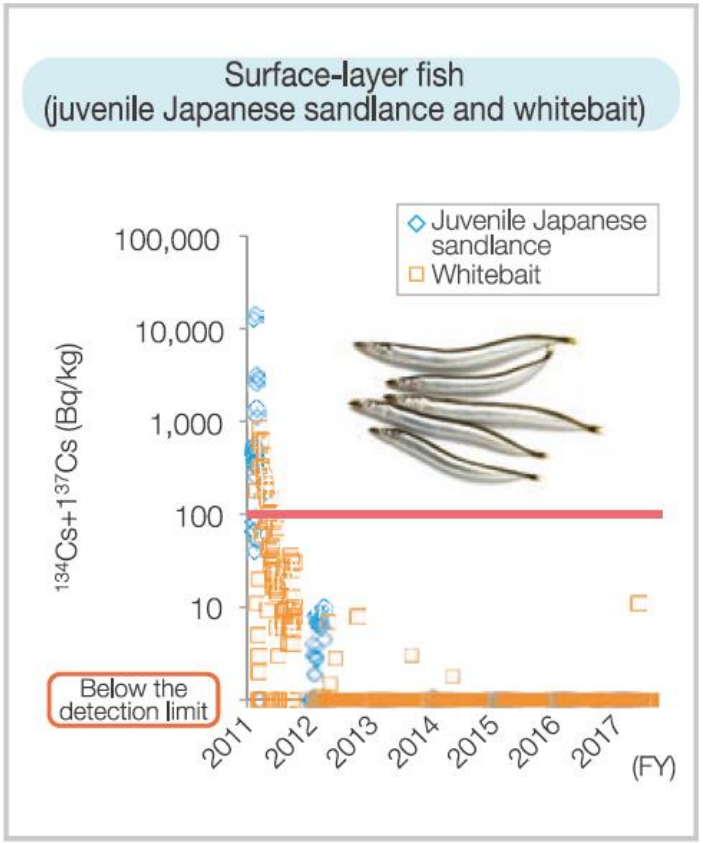
Limits correspond to concentrations of radiocaesium (Cs134 and Cs137) in foodstuff and drinking water

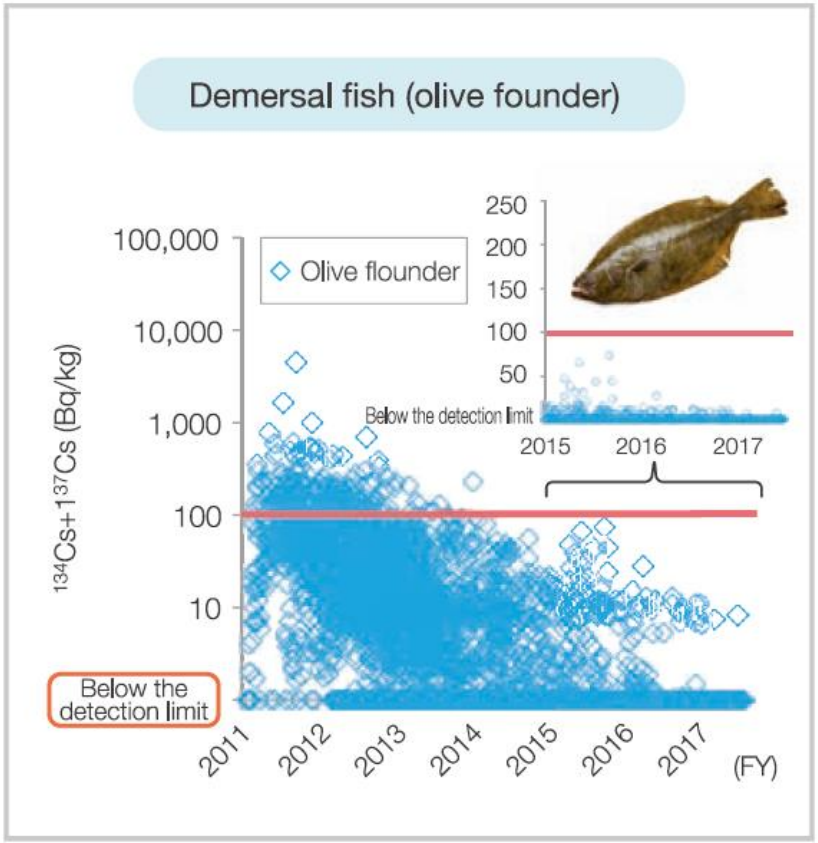
- ✓ Standard limit established order of magnitude lower than the levels recommended by the Codex Alimentarius for the purpose of international trade
- ✓ The dose from 100 kg food contaminated with Cs-137 at the current Japanese limit: **0.105 mSv for infants and 0.13 mSv for adults**
- ✓ The concentration of the natural K-40 in milk is 45 Bq/l

Some examples of food contamination









Vast majority of food consumed in Japan after accident below standard limit

First year doses to the general public

The fast evacuation and the effective restriction of contaminated food significantly reduced the effective doses for the evacuated people

- Different evacuation scenario's considered (dose from before & during evacuation + dose at destination)

→ Groups of evacuees: average effective dose ≤ 8 mSv, absorbed thyroid dose ≤30 mGy

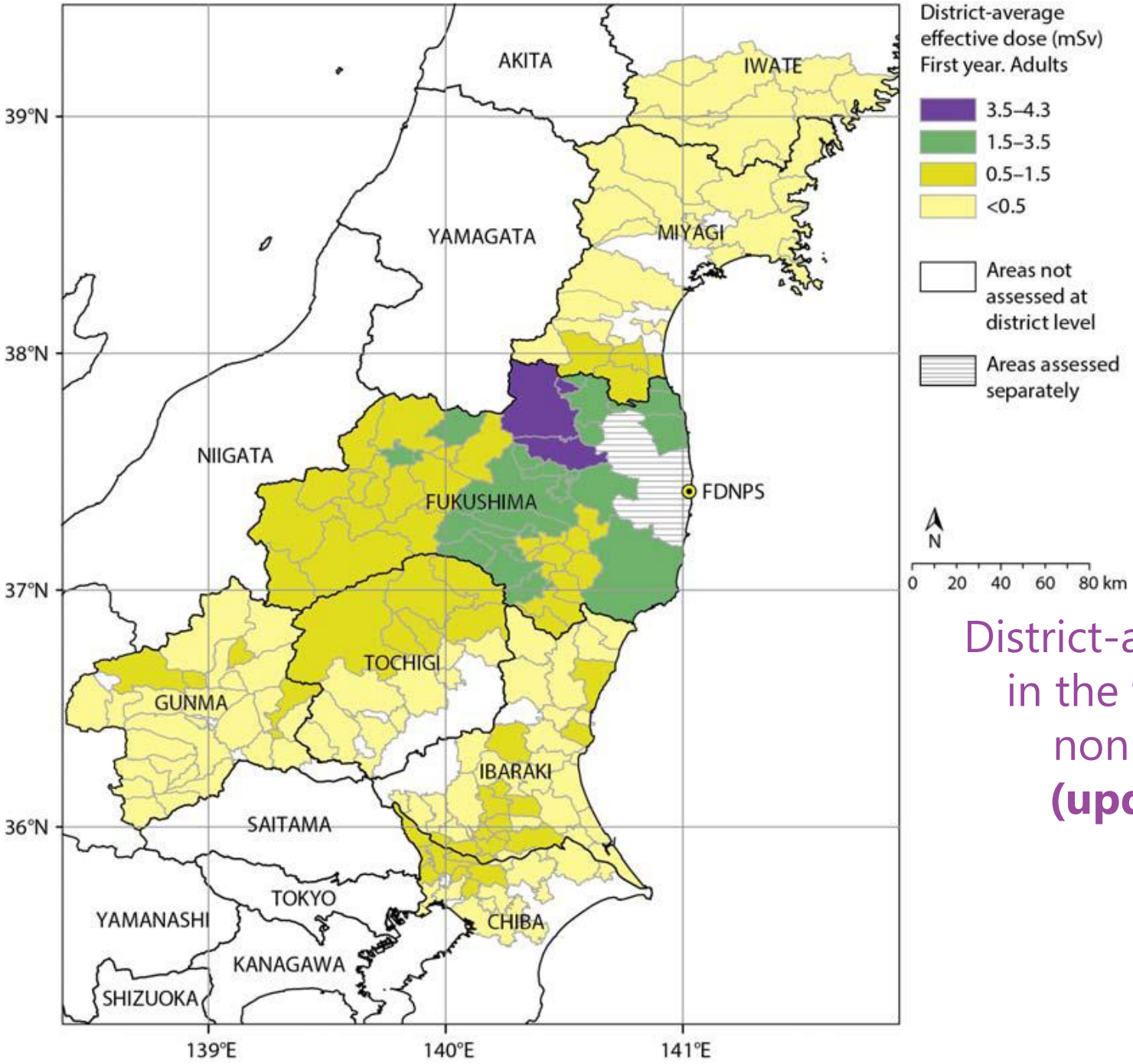
→ Doses or somewhat lower compared to UNSCEAR2013 report due to

Average effective doses in non-evacuated districts (Fukushima) were ≤ 5 mSv, absorbed thyroid dose: ≤20 mGy first year.

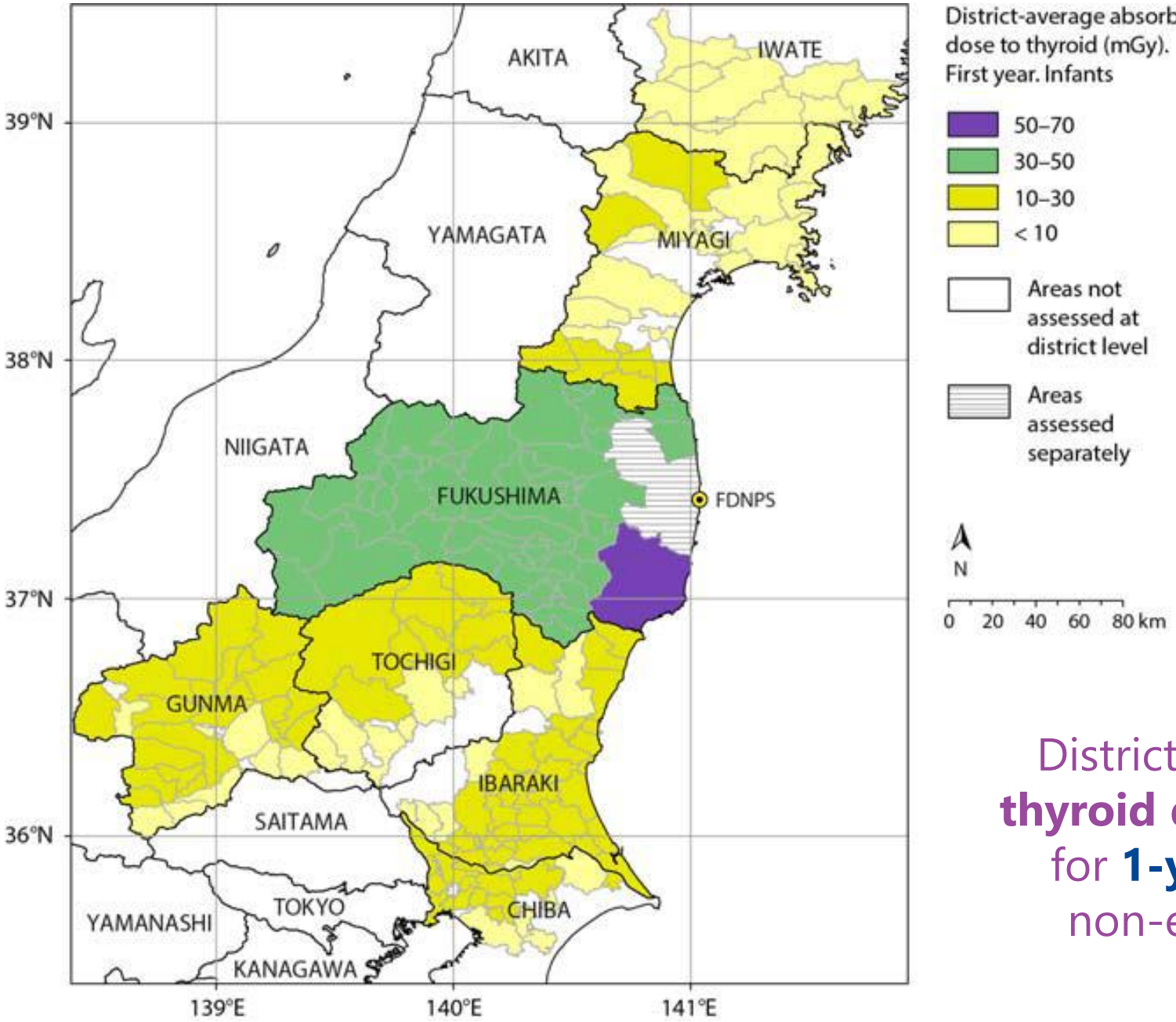
Non-evacuated neighboring prefectures: ≤1 mSv, thyroid absorbed dose ≤ 6 mGy

➡ Average values over large population groups (90% typical within factor 3)

➡ Considerable uncertainty on the inhalation dose of ^{131}I

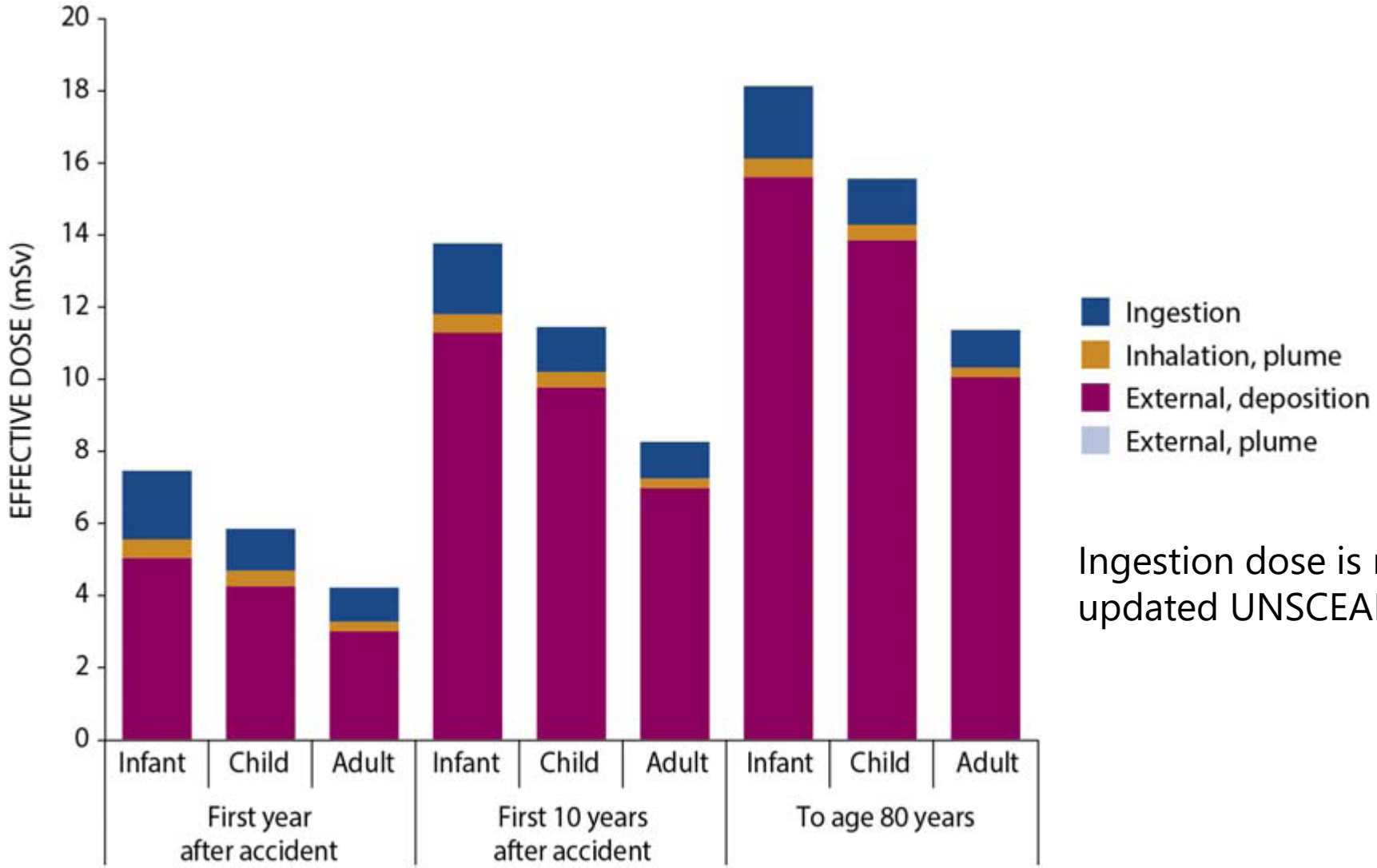


District-average **effective doses** in the first year for **adults** in non-evacuated districts **(updated maps will be published in**



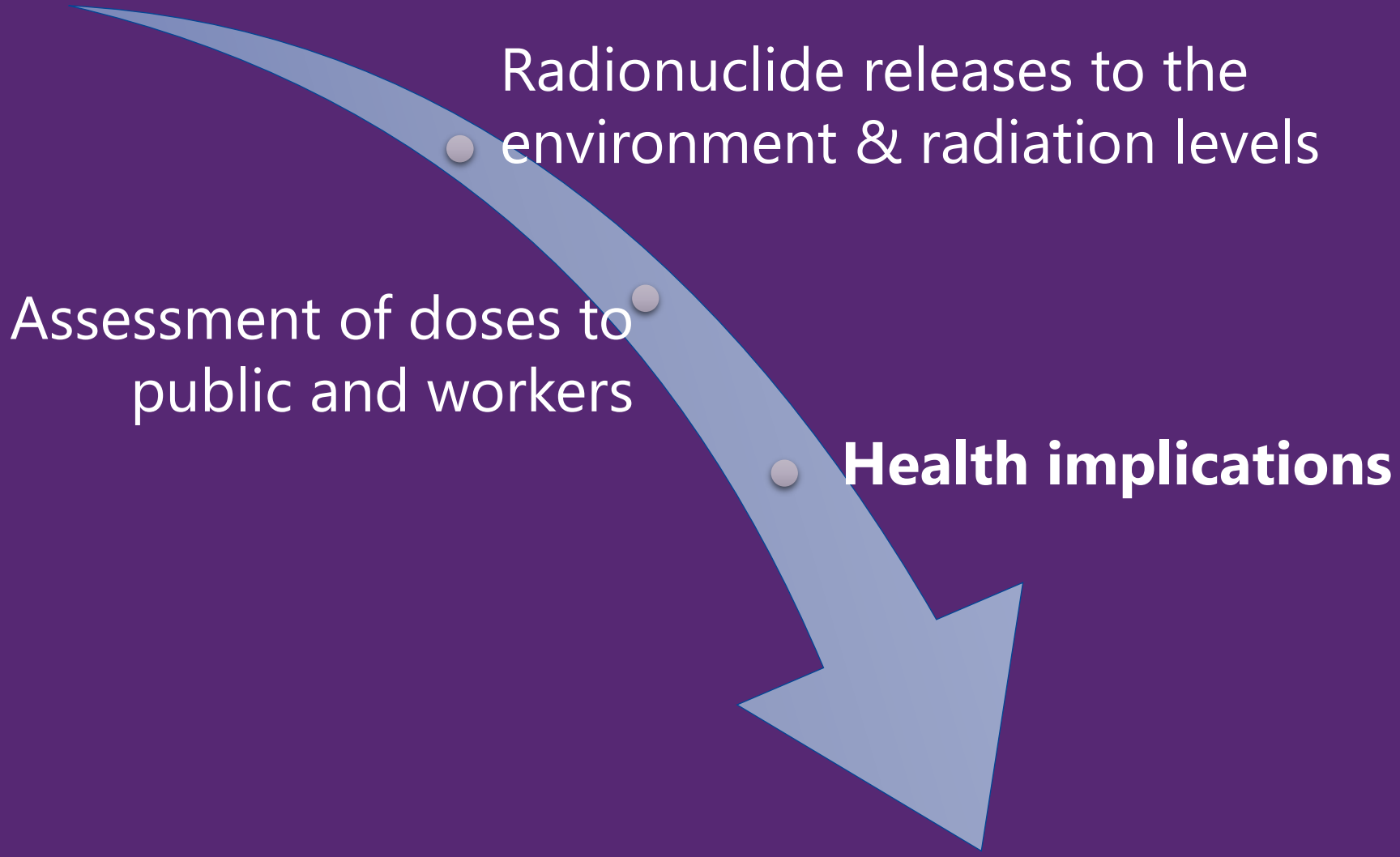
District-average **absorbed thyroid doses** in the first year for **1-year-old infants** in non-evacuated districts

District-average effective doses to infants, children and adults
living in Fukushima city



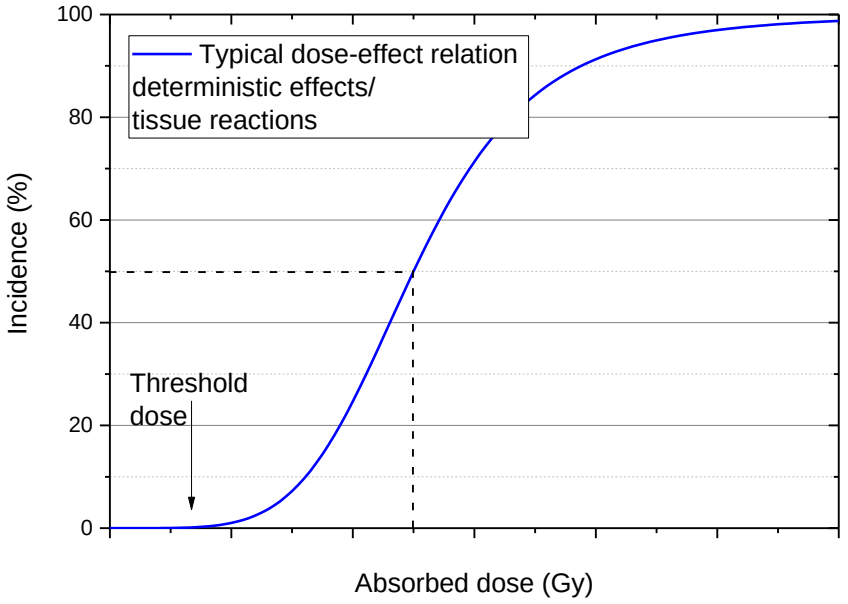
Ingestion dose is reduced in updated UNSCEAR report

Outline



Largely based on UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) evaluations.

Health effects directly attributable to radiation exposure for workers and the public



Deterministic effects

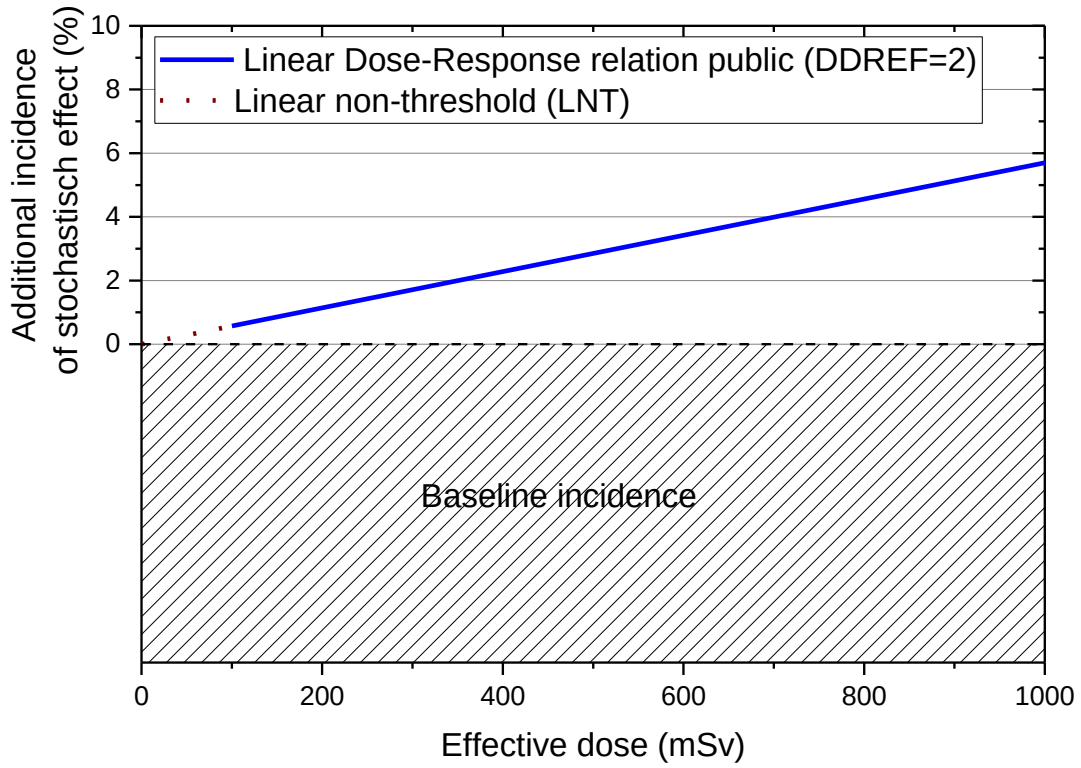
No immediate health effects have been observed among the workers and the public

- No radiation-related deaths
- No acute radiation effects

Primary goal emergency response: to prevent occurrence of deterministic effects in individuals

The most important health effect is the impact on the social well-being and mental health. Effects, such as depression and post-traumatic stress symptoms have been observed

➡ More than 50 patients were reported to have died either during or soon after evacuation due to non-radiation related effects



“Fukushima’s uncertainty problem”

Nature, 18 July 2012

Unhelpful approaches of dealing with low-dose risks

- An alarming message using the **collective dose** as an indicator of health risk
  - Based on the translation of an individual risk, with a low individual probability, to a collective risk with a theoretical number of victims
  - Based on simplistic and unproven assumptions (dose as surrogate for risk, LNT hypothesis…)

- A reassuring message using the concept of "**no discernable increase in risk to be expected**" from epidemiological studies
  - Based on the intrinsic limitations of epidemiological studies and not on scientific evidence of absence of health effects at low doses
  - Radiation epidemiology is a blunt instrument: even the billion dollar study of the atomic bomb survivors is not statistically significant below around 150 mSv

Radiation related health implications
for workers and emergency personnel (cancer)

Exposed group	Number	Average exposure	Max. exposure	Risk estimation	Decease incidence
Highest exposed (0.8%) > 100 mSv	174	140 mSv	679 mSv	Increased cancer risk expected	Unlikely increase is discernable
All	21 135	13 mSv	679 mSv	Increased cancer risk expected	No discernable increase in incidence expected

Cancer lifetime baseline risk: 38 – 41% (workers Japan)

Order of magnitude calculation assuming a 10%/Sv excess cancer incidence:

- 174 x 0.140 Sv x 0.1 = **2 to 3 excess cancer cases ← → 66 to 71 baseline cancer cases**
- 21 135 x 0.013 Sv x 0.1 = **27 to 28 excess cancer cases ← → 8031 to 8665 baseline cancer cases**

Radiation related health implications
for workers and emergency personnel (thyroid disease)

Absorbed thyroid dose

	Number	Max exposure	Risk estimation	Disease incidence
Thyroid dose > 2 Gy	13	32 Gy	Low risk of hypothyroidism Risk of thyroid cancer enhanced	Numbers likely too small
Thyroid dose > 100 mGy	1750	-	Infer small increased risk of thyroid cancer	Risk likely too small for any increase to be discernable

A lifetime baseline risk of thyroid cancer of 0.14 to 0.21%

Radiation related health implications
for members of the public (cancer)

Exposed group	Number	Average exposure First year*	Current levels (2021)*
Evacuees/ areas decontaminated and evacuation lifted	140 000	≤8 mSv	≤1 mSv
Fukushima prefecture	1 850 000	≤5 mSv	≤0.5 mSv
Other neighboring prefectures		≤1 mSv	
Rest of Japan	128 000 000	<0.5 mSv	

* In addition to natural exposure, effective dose from natural radioactivity and radaiation in Japan: 2 mSv/year

Order of magnitude calculation assuming a 13%/Sv excess cancer incidence and LNT approach:

- 1 850 000 x 0.005 Sv x 0.13 = **1 200 excess cancer cases (~ 0.2 increase)**
- 1 850 000 x 0.35 = **647 500 baseline cancer cases**

Radiation related health implications for infants (thyroid cancer)

- Extensive thyroid screening campaign among exposed children (18 year or younger), using ultrasound examinations
  - First round: 300 000
  - Second round: 270 000
  - Third round: 218 000

- Over 200 cases of thyroid cancer detected, which is much higher incidence if compared with cancer registries other prefectures, but
  - Most authors attribute this to ultrasensitive screening method (population screening);
  - Other evidence: not expected based on thyroid dose, age distribution a-typical and too early after accident.

Comparison Chernobyl – Fukushima
Deterministic effects

Acute radiation sickness (above the thresholds for deterministic effects)

- **Chernobyl:** acute radiation sickness diagnosed in 134 rescue workers
  - 28 died in the first four months (a strong dose dependence)
  - 19 died later in the period 1987-2006 of various diseases
- **Fukushima:** no acute radiation sickness diagnosed
  - No radiation-related deaths

Comparison Chernobyl – Fukushima
Stochastic effects (epidemiological evidence)

- **Chernobyl:** a clear increase of thyroid cancer in people who as children were heavily exposed to radioactive iodine
  - 1991-2015: ≈ 25% of the 20 000 thyroid cancers in under-18 in 1986 attributable to the accident (Belarus, Ukraine and most contaminated regions of Russia)
- **Chernobyl:** other health effects are probable but difficult to prove
  - Indication of an increase of leukemia among recovery workers
  - Development of cataract among recovery workers

  ➡ The bad economic situation after the collapse of the Soviet Union is a limiting factor (decrease in life expectancy, poor dose registries..)
- **Fukushima:** the expected incidence not statistically significant

  ➡ Epidemiological studies are a blunt instrument for low dose effects

Difficulties to attribute specific cancer cases to low-dose exposure

- No biomarkers that are specific to radiation exposure are presently available
- The long latency period between exposure and disease presentation (years or decades)
- The high spontaneous incidence of diseases associated with radiation in the general population

  The lifetime baseline cancer risk is about 35%

➢ The same difficulties exist for heritable effects, congenital malformations, cardio-vascular diseases, cataracts, still births, preterm deliveries or low birthweights

An increases in incidence in cardiovascular and metabolic conditions have been observed among evacuated adults but probably associated with changes in lifestyle.

Most important health effect is the impact on the social well-being and mental health.

-> Empower the affected population

Thank you

Acknowledgement: Hans Vanmarcke and Joke Kenens (SCK CEN)