JAGIELLONIAN UNIVERSITY IN KRAKÓW

3rd Jagiellonian Symposium on Fundamental and Applied Subatomic Physics

Fukushima Accident

8 years after

Ryugo Hayano

The University of Tokyo

Councilor, Radiation Effect Research Foundation

東京大学 THE UNIVERSITY OF TOKYO

放影研 RERF Radiation Effects Research Foundation
A Cooperative Japan-US Research Organization

March 11, 2011 14:46 JST

Earthquake, M9

←Fukushima Dai-ichi

250 km

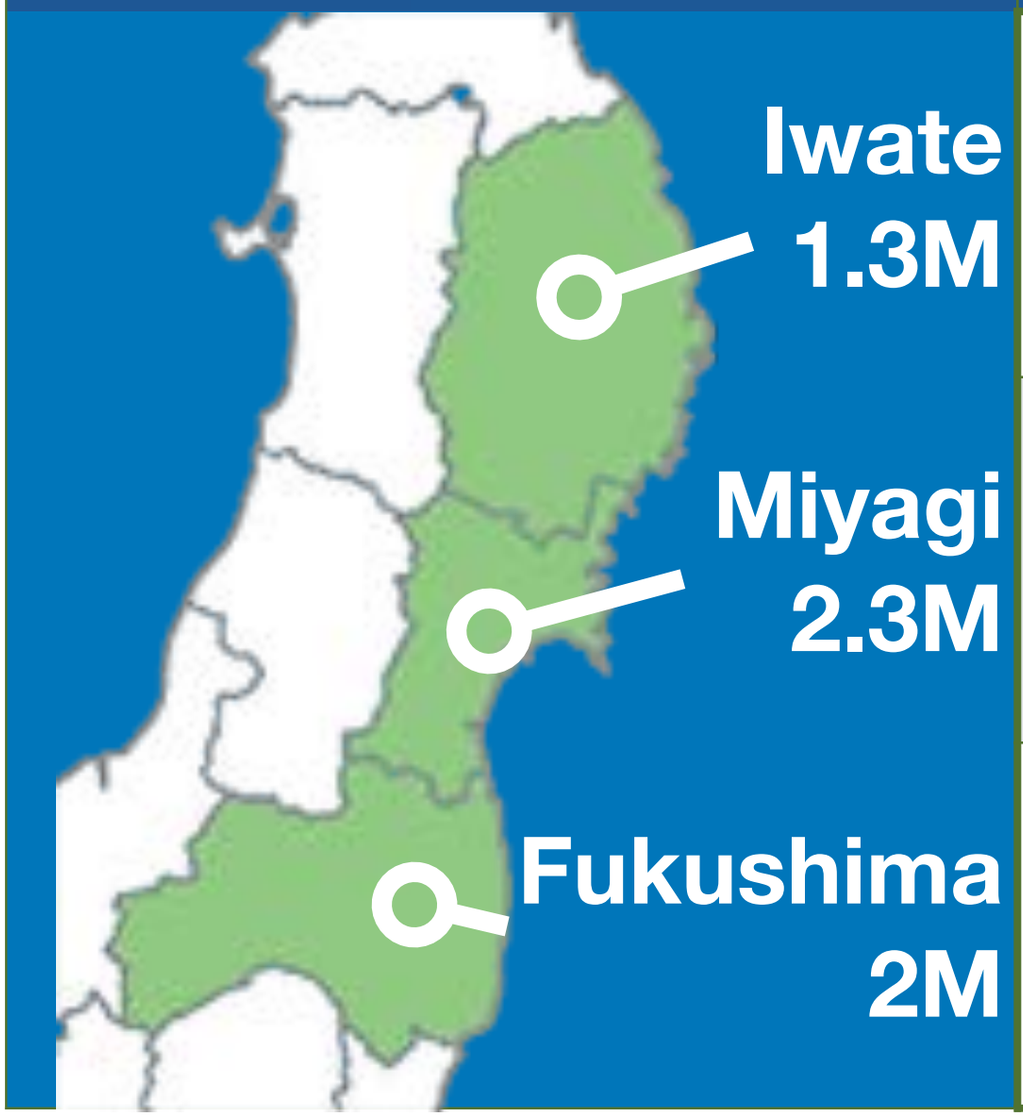
Tokyo

Hiroshima
Aug 6, 1945

Nagasaki
Aug 9, 1945

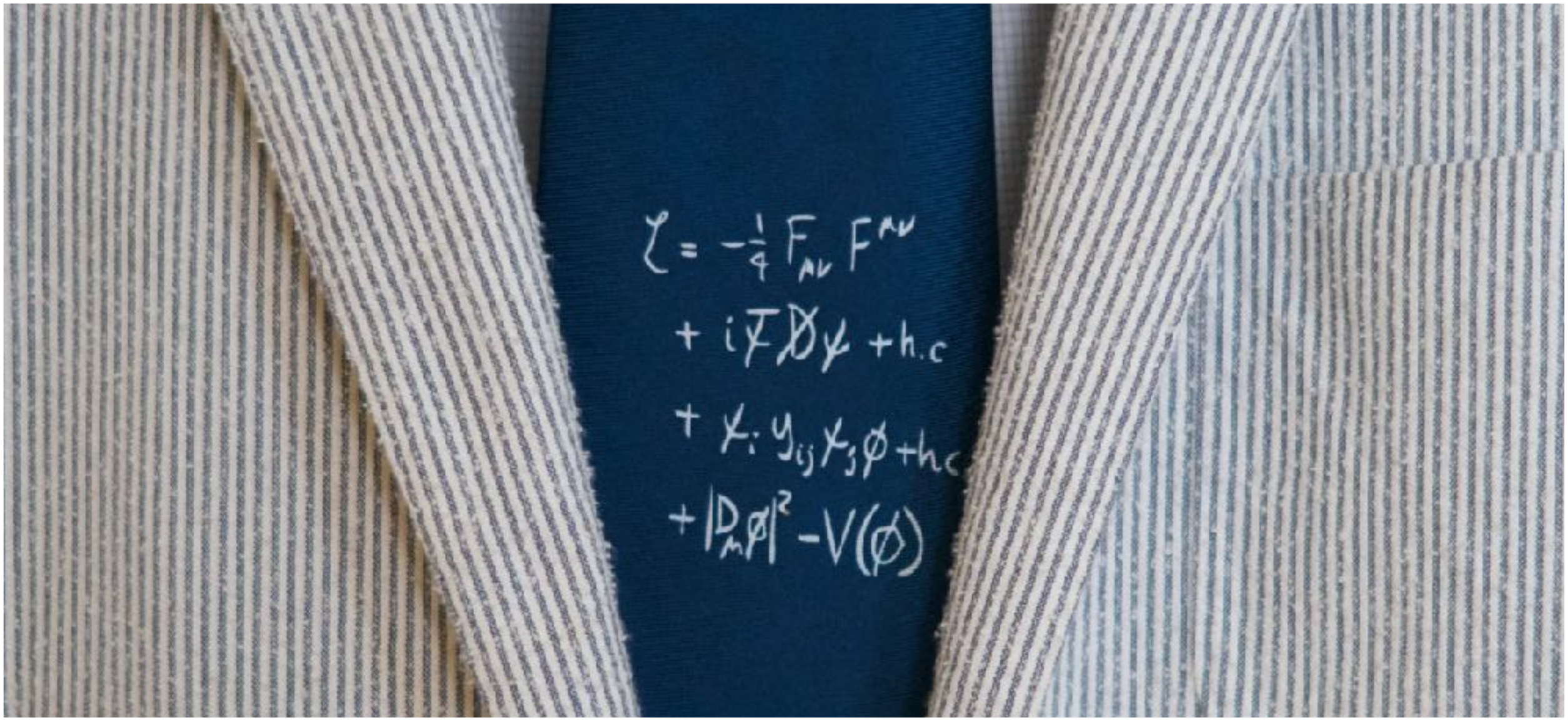
Death toll

as of March 2019, 8 years after the earthquake

	Earthquake & Tsunami Death (+missing)	Disaster-related Death	Death due to radiation
			
Iwate 1.3M	5788	467	0
Miyagi 2.3M	10761	928	0
Fukushima 2M	**1810**	**2268**	**0**

About myself

- Experimental physics professor, U. Tokyo
- 1997-2017: “Antimatter” team leader at CERN



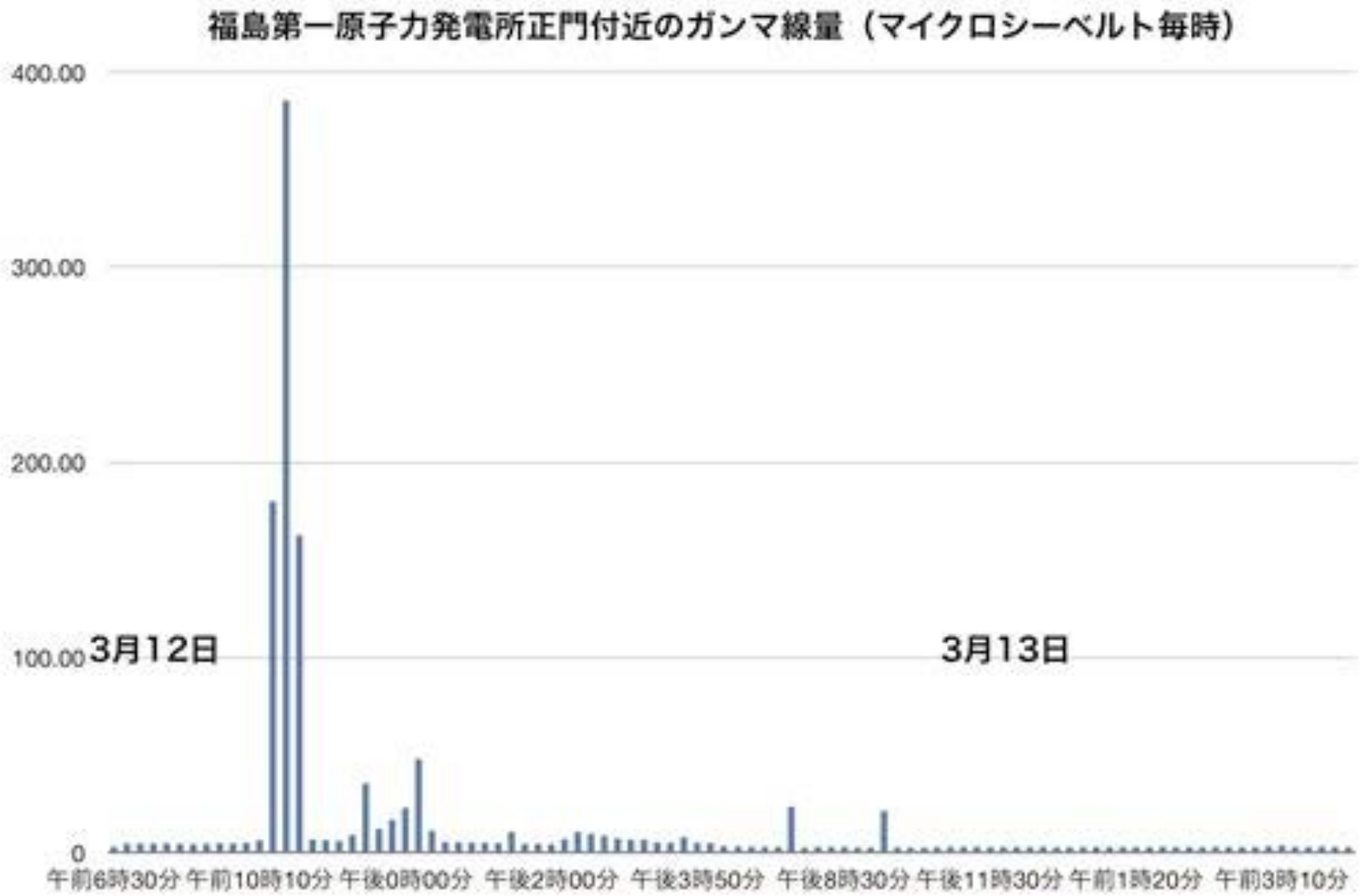
About myself

- Experimental physics professor, U. Tokyo
- 1997-2017: “Antimatter” team leader at CERN
- No past experience in radiation protection, nor risk communication
- Work on Fukushima-related problems not in my job description

I am here today because of 

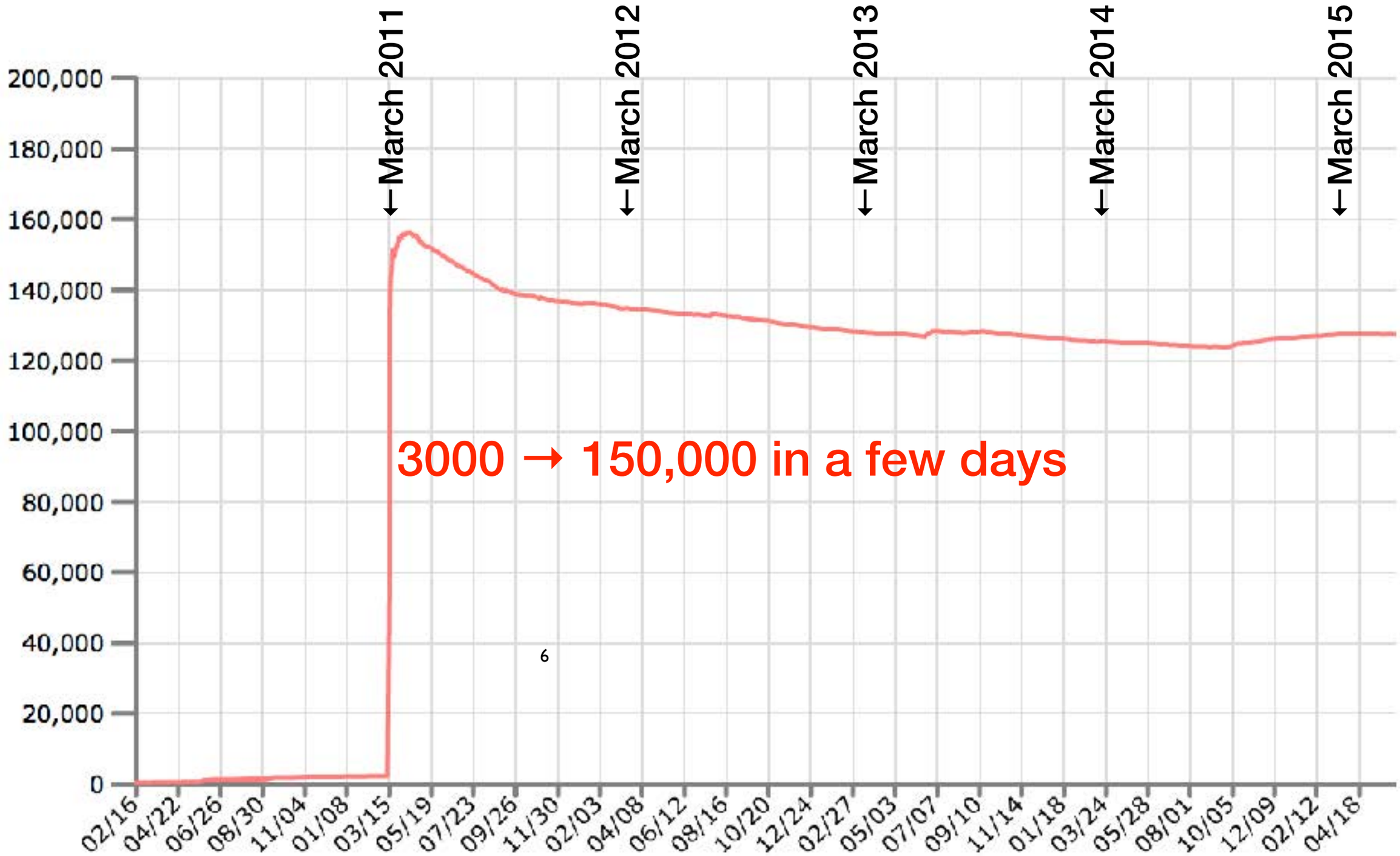
One of my first tweets: Mar 13, 2011, 07:49

Dose rate at the front gate of FDNPP
(curiosity-driven)



twitter hayano

The number of my twitter followers



3000 → 150,000 in a few days

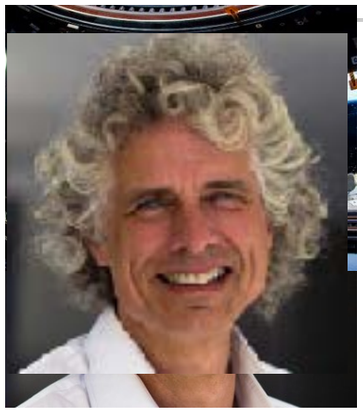
6

Top 100 scientists on twitter

Science Magazine Blog

October 2014

■ ■ ■



20. Steven Pinker, *Cognitive scientist*

145,000 followers @sapinker (http://twitter.com/@sapinker)

Citations: 49,933 K-index: 105

Total number of tweets: 1,674

Harvard University, United States

21. Richard Wiseman, *Psychologist*

135,000 followers @RichardWiseman (http://twitter.com/@RichardWiseman)

Citations: 4,687 K-index: 209

Total number of tweets: 22,600

University of Hertfordshire, United Kingdom

22. Ryugo Hayano, *Nuclear physicist*

124,000 followers @hayano (http://twitter.com/@hayano)

Citations: 956 K-index: 319 7

Total number of tweets: 56,500

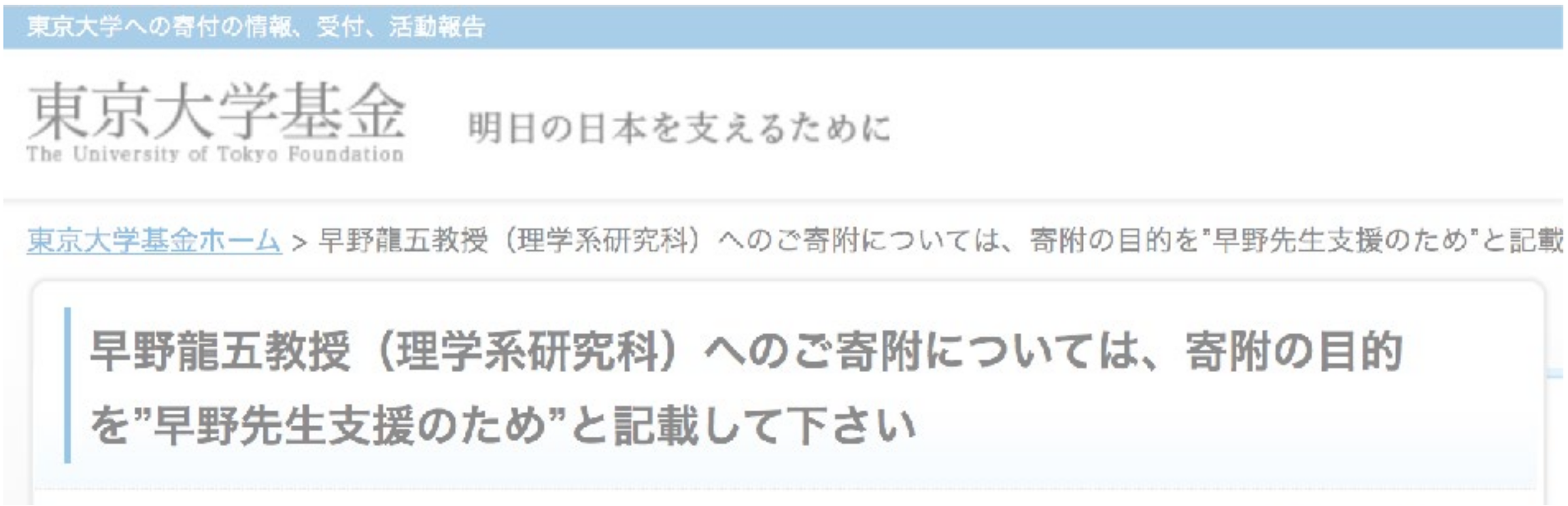
University of Tokyo, Japan

■ ■ ■

Cloud funding

My Fukushima-related work has been funded entirely by donations (which I didn't ask for) from my twitter followers

(total ~ 200,000 € equivalent)



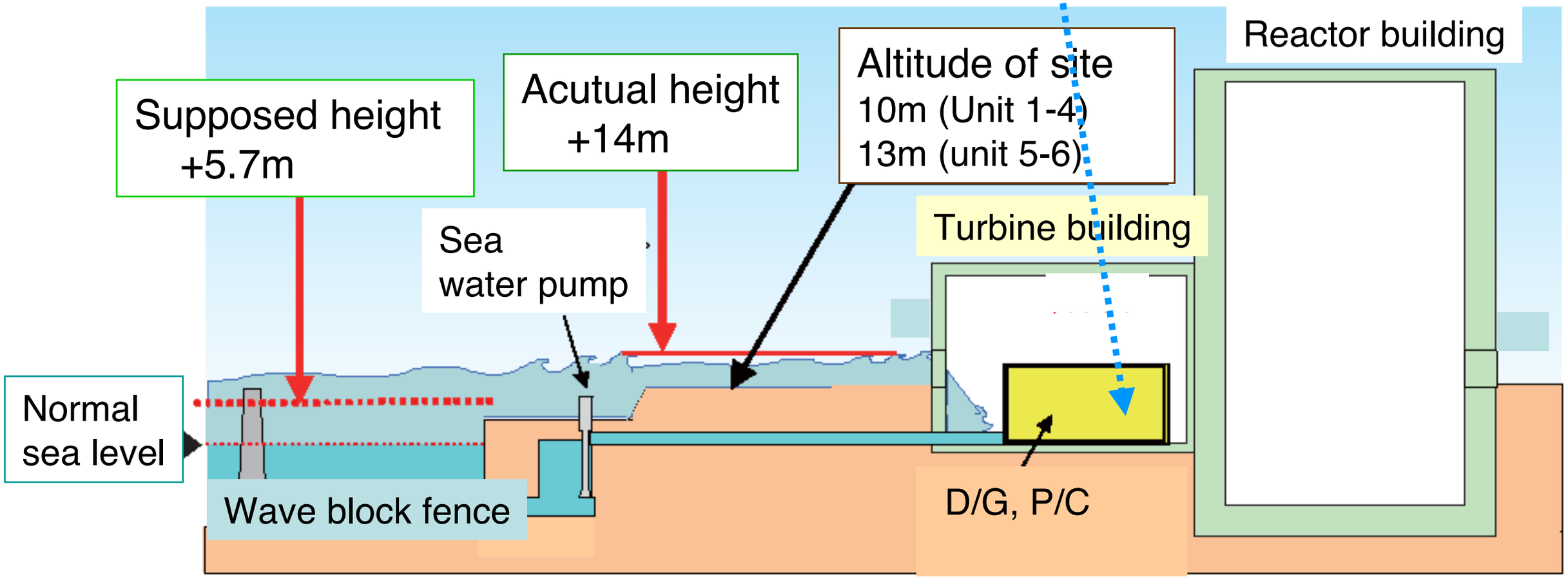
Published in Oct 2014 >100,000 copies sold

新潮文庫

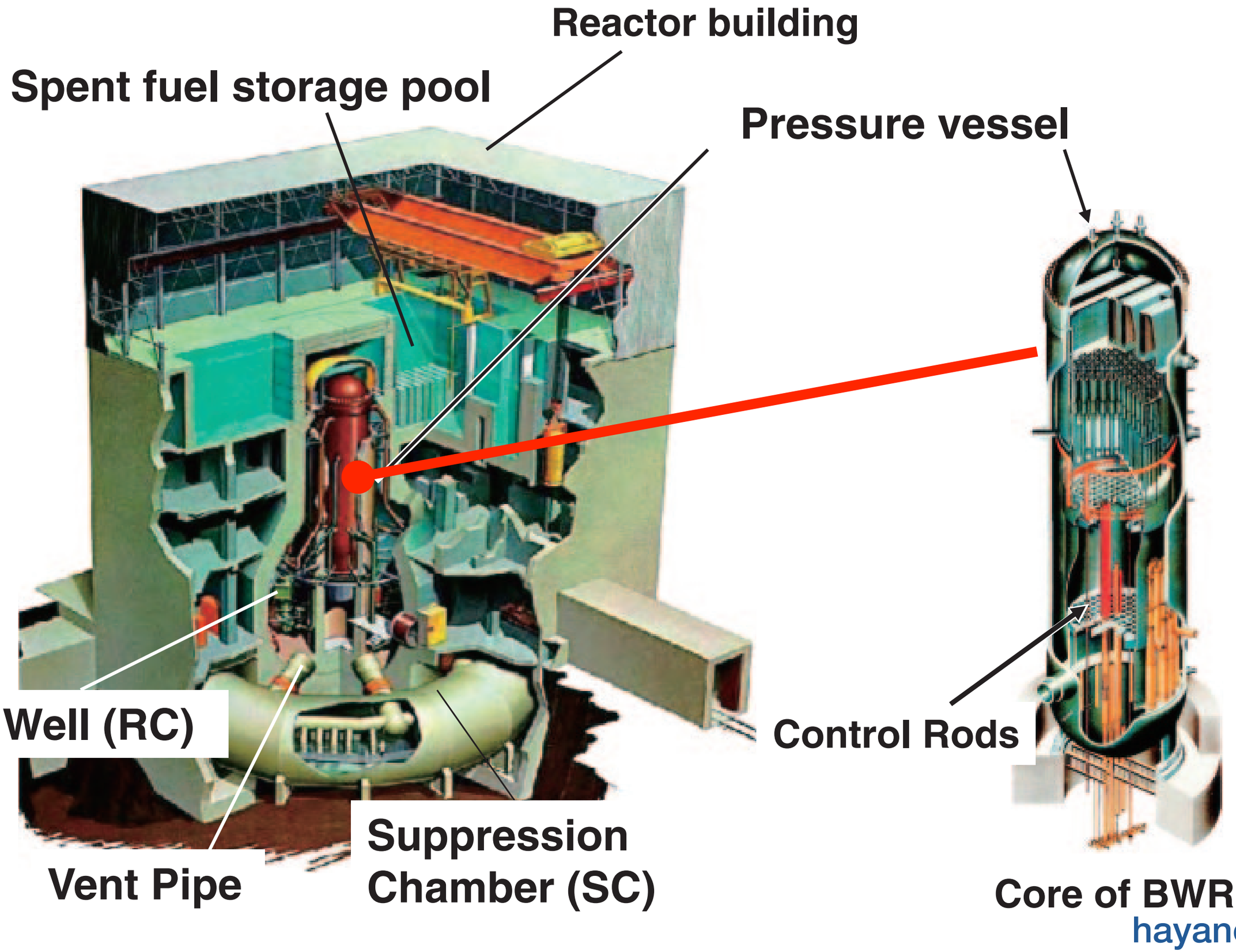
Earthquake → Tsunami → Disaster

External power line destroyed by earthquake
but diesel generators turned on

40 minutes later …
Tsunami flooded diesel generators
→ total station blackout

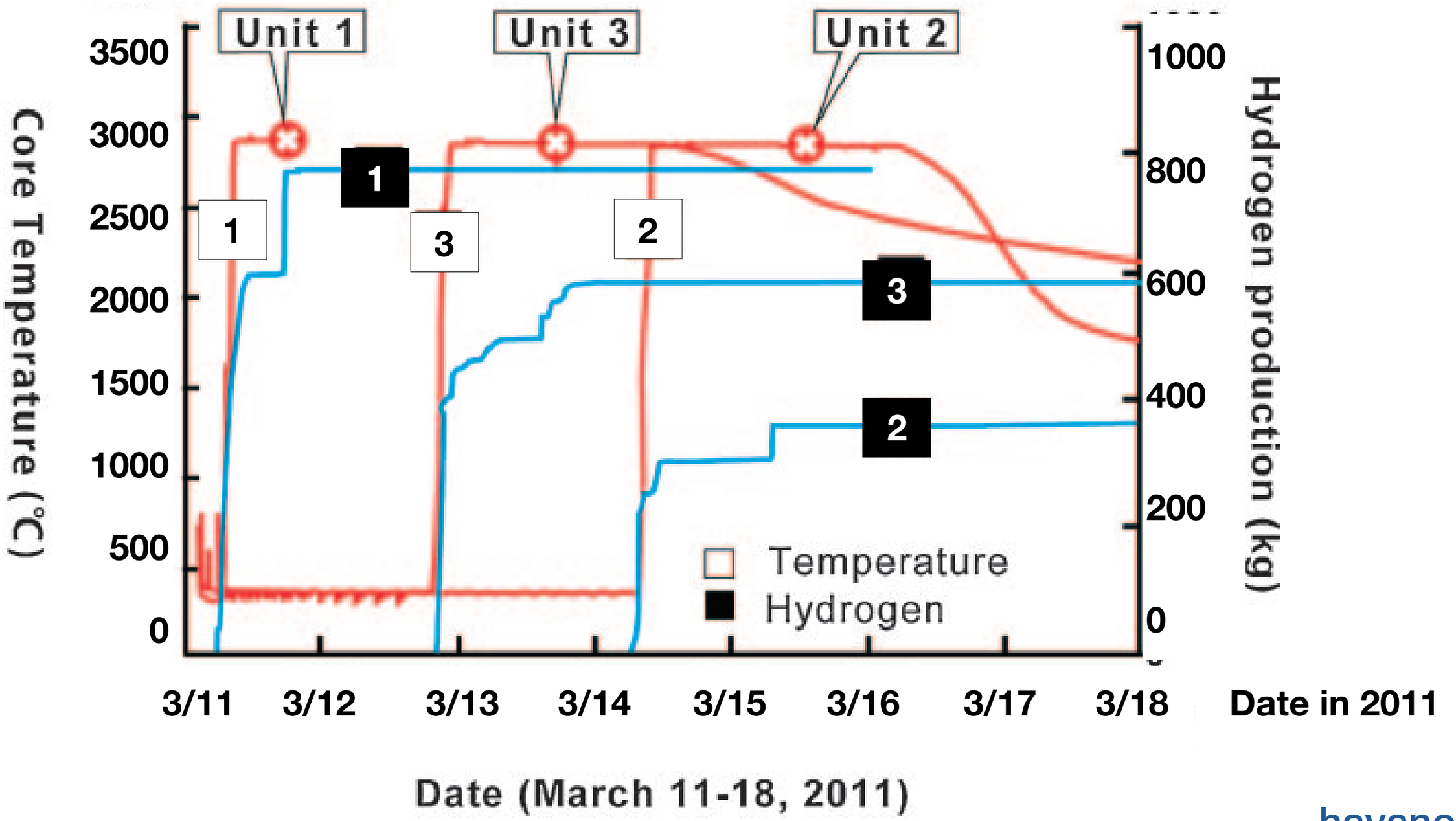


Boiling Water Reactor “Mark-1”

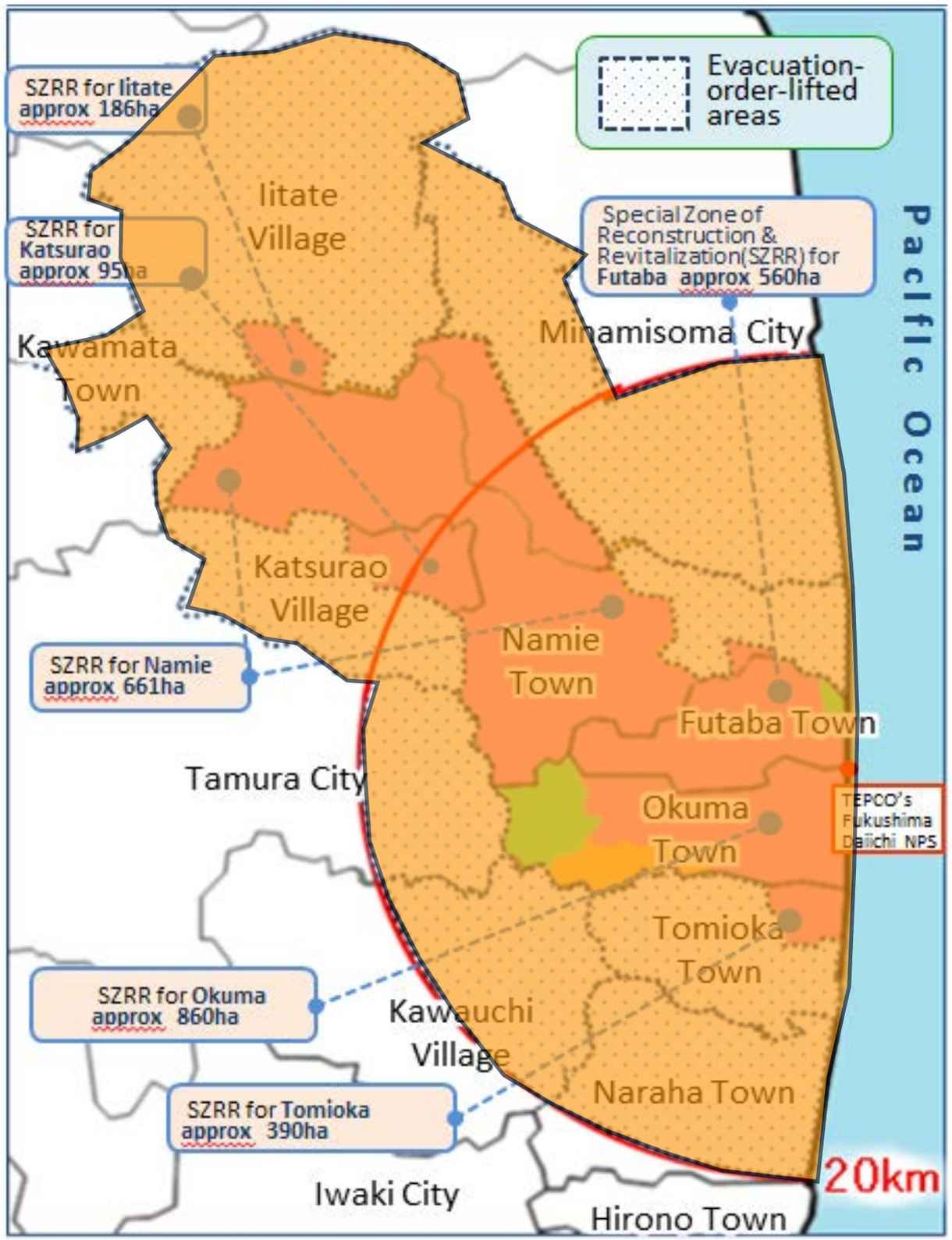


Meltdown, Hydrogen explosion

No electricity, no cooling, core temperature >2500 °C
Fuel rods melted down, hydrogen explosion,
→ release of radioactive substances



Evacuation



Evacuation order

3km - March 11 21:23

10km - March 12 5:44

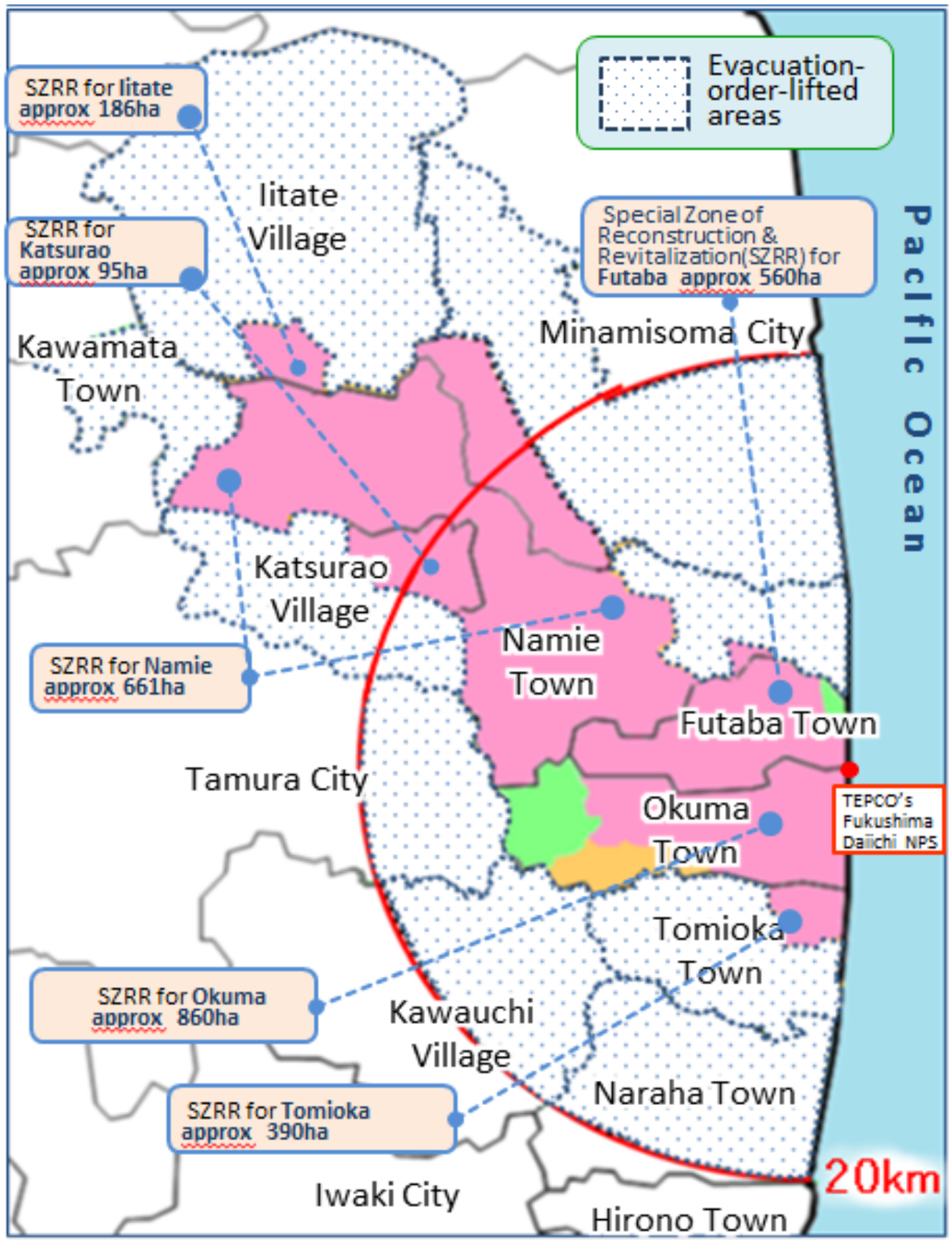
20km - March 12 18:25

(~165k people)

after ~8+ years, some 41k people still cannot return

(even though the estimated annual doses in many communities are <<20 mSv/y)

Evacuation



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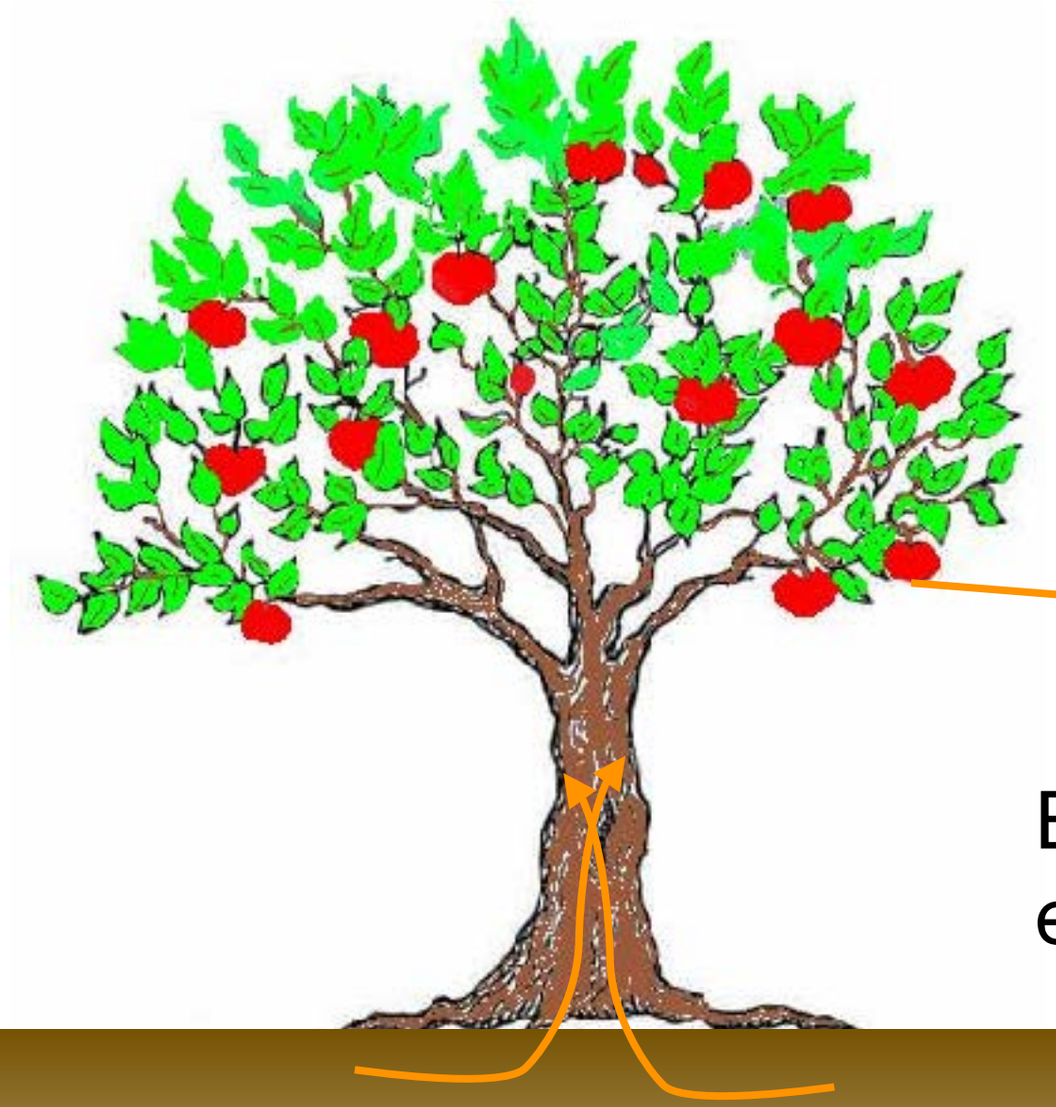
Radiation exposure pathways



Internal exposure

External exposure

$^{134,137}Cs$

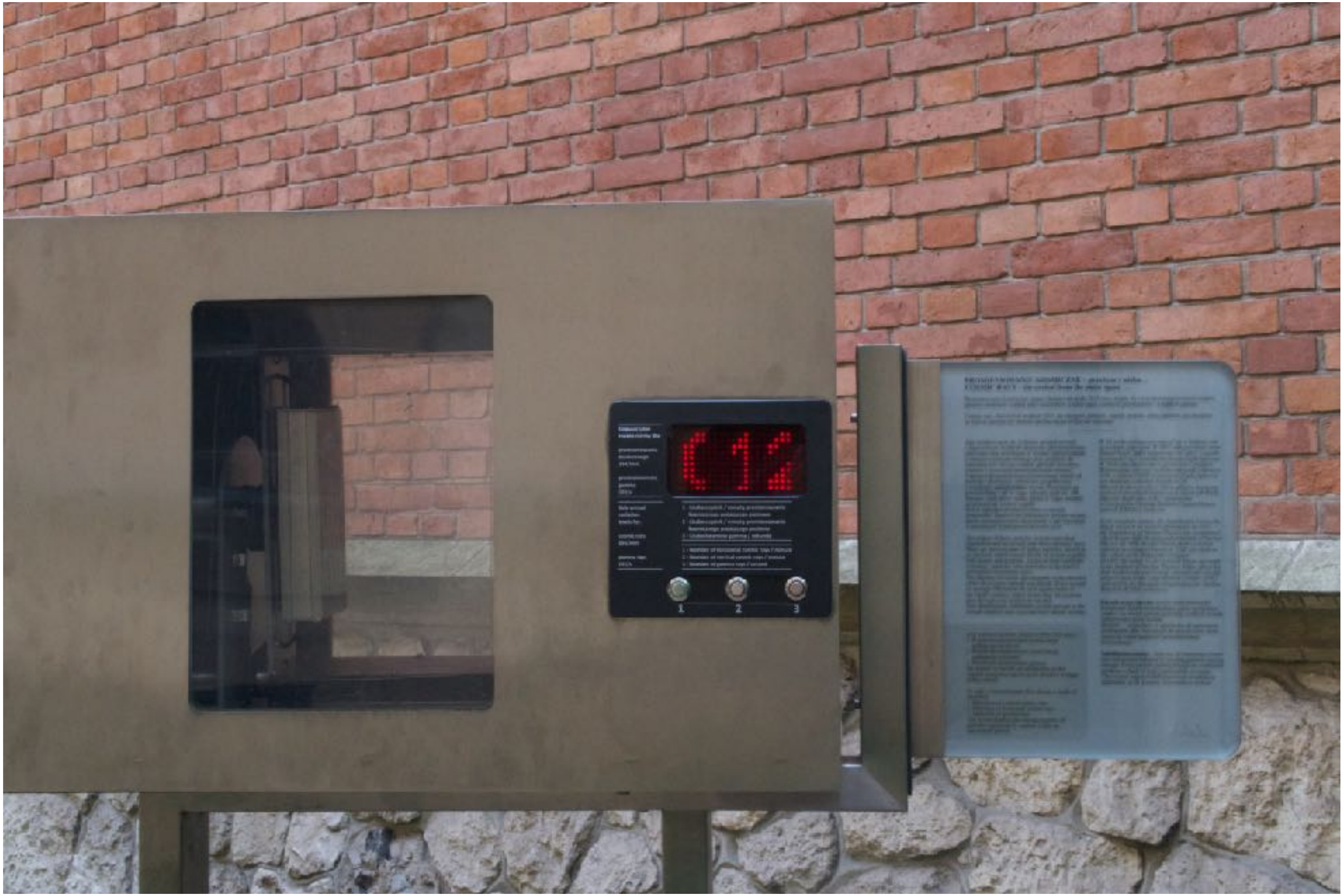
$^{134,137}Cs$

We are all exposed to natural radiation

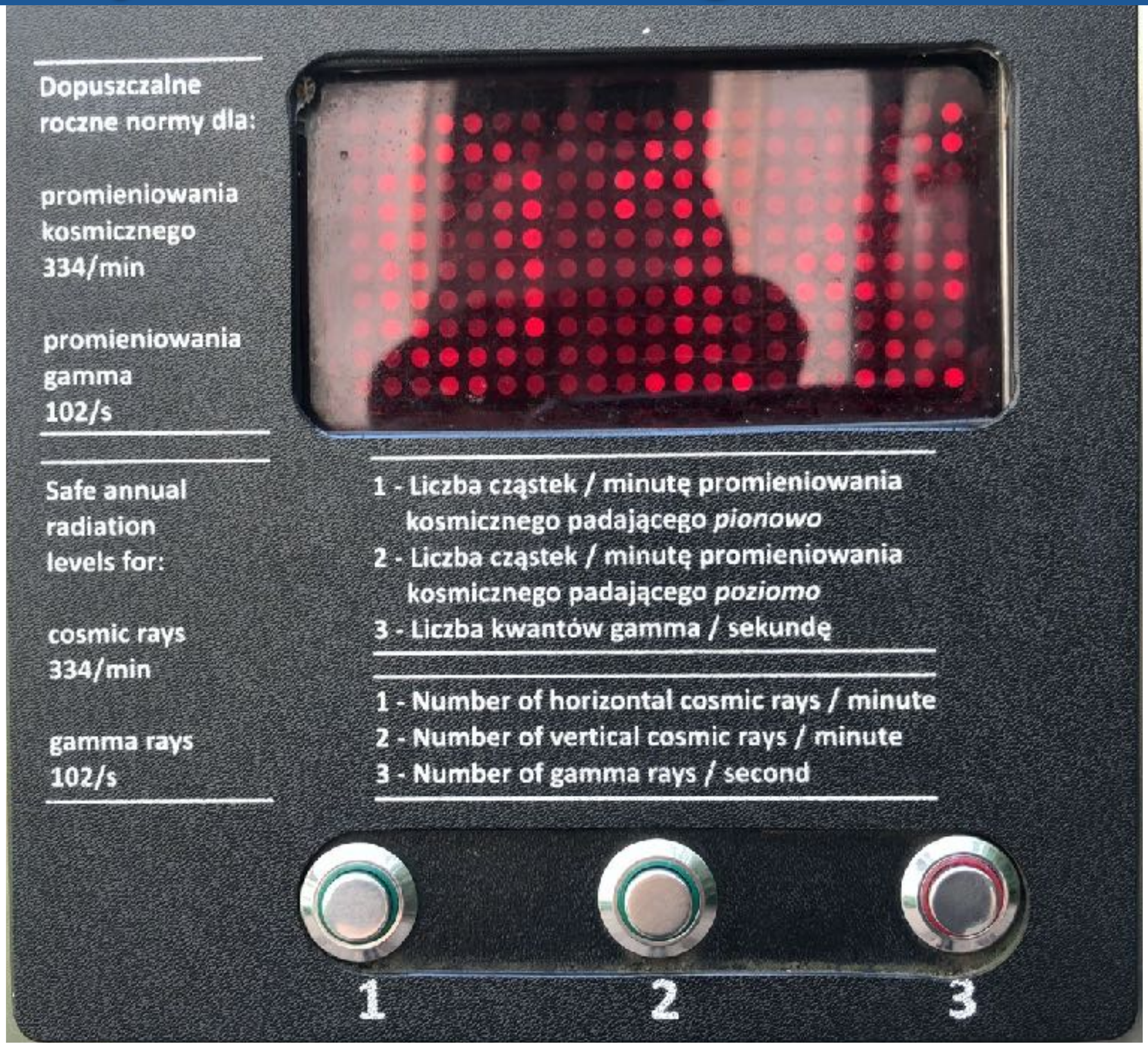
Source of exposure		Annual effective dose (mSv)	
		Agerage	Typical range
External	Cosmic	0.39	0.3-1.0
	Terrestrial	0.48	0.3-1.0
Internal	Inhalation	1.26	0.2-10
	Ingestion	0.29	0.2-1.0
Total		**2.4**	**1.0-13**

Compiled by world-nuclear.org, based on "2008 United Nations Scientific Committee on the Effects of Atomic Radiation Report to the General Assembly, Sources and Effects of Ionizing Radiation"

Is this familiar to you?



This you can find in Ogród Profesorski

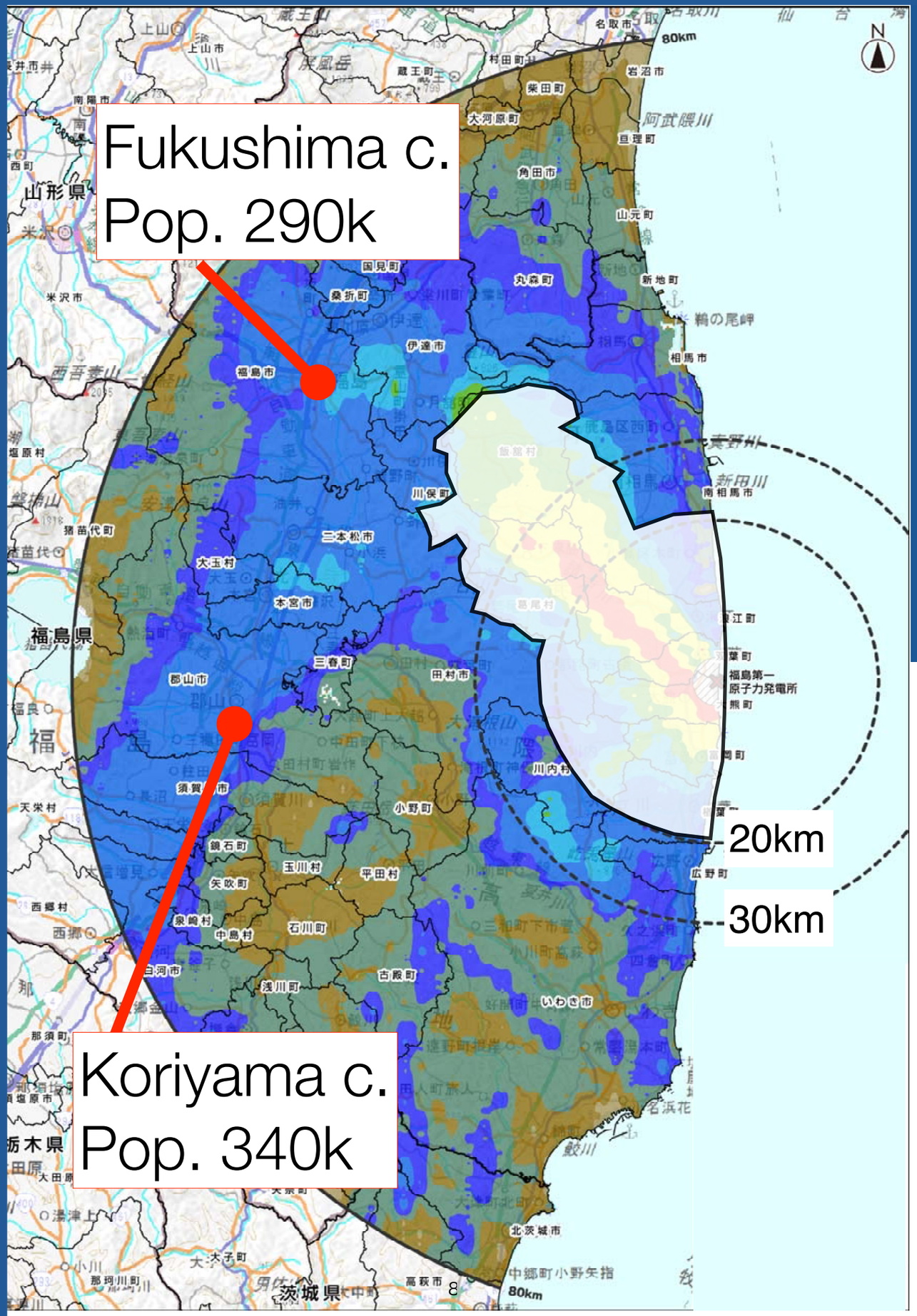


1. Internal exposures (Food safety)

Note: 1 mSv

⇅

70,000 Bq of ^{137}Cs



Chernobyl studies,
i.e., soil→food→people
infer:

average internal dose of
e.g., Fukushima city
residents ~ 5 mSv/y
(initial estimate)

^{137}Cs deposition
Bq/m^2
(2011/11/5)

- 1000k - 3000k
- 600k - 1000k
- 300k - 600k
- 100k - 300k
- 60k - 100k
- 30k - 60k
- 10k - 30k
- ≦ 10k

Food, water, milk … regulatory criteria

Was this necessary?

2011 Mar 17 ~

○ **Provisional regulation values for radioactive cesium[1]**

Category	Limit
Drinking water	200
Milk, dairy products	200
Vegetables	500
Grains	
Meat, eggs, fish, etc.	

Bq/kg

2012 Apr 1 ~

○ **New standard limits for radioactive cesium [2]**

Category	Limit
Drinking water	10
Milk	50
General Foods	100
Infant Foods	50

Bq/kg

EU

1250

Food Safety (School Lunch)

Summer, 2011 - Increasing number of mothers started to tweet: "school lunches safe to eat?"

©hayano

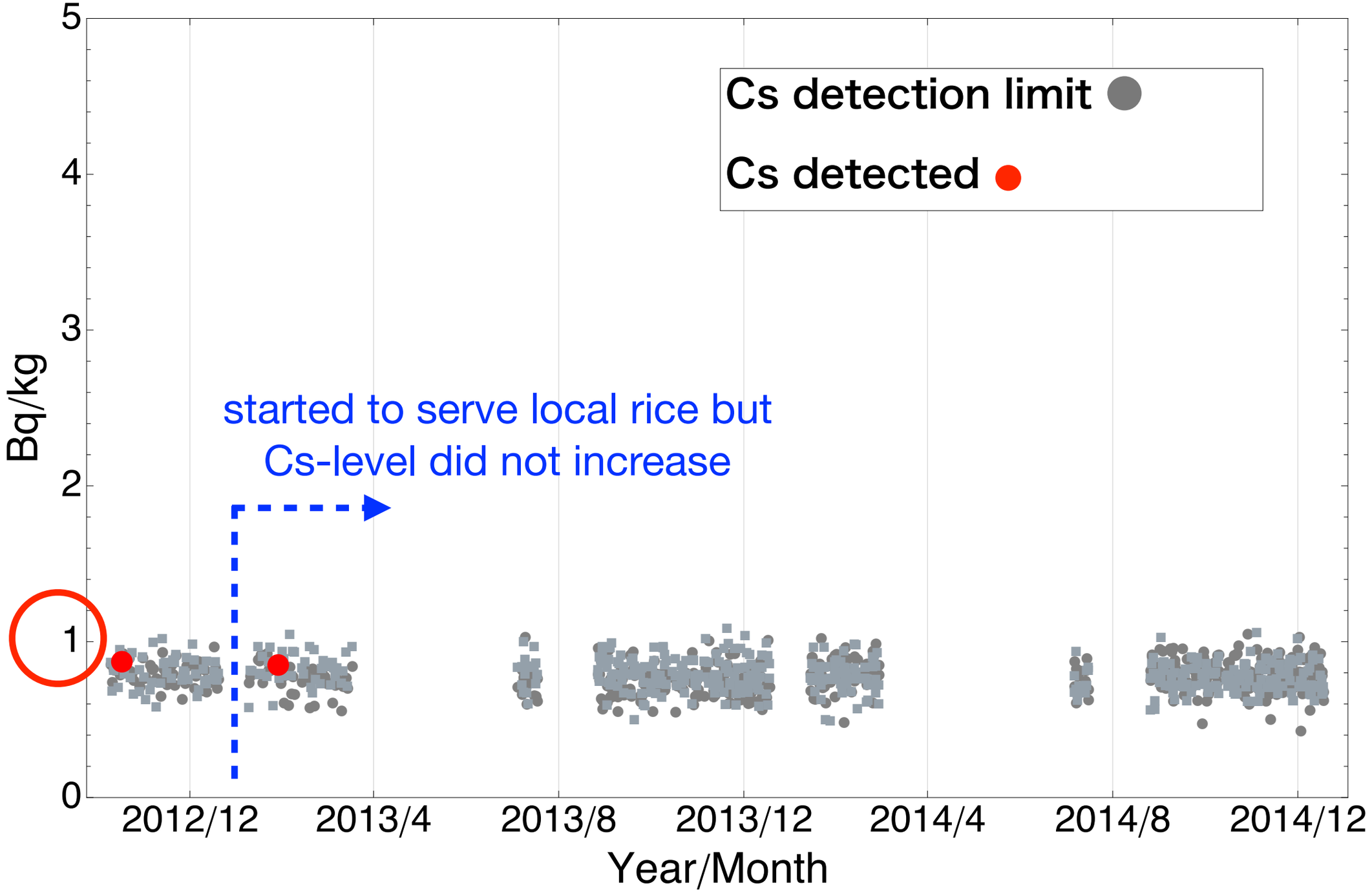
Food Safety (School Lunch)

I proposed to measure school lunch
the government funded the project from 2012

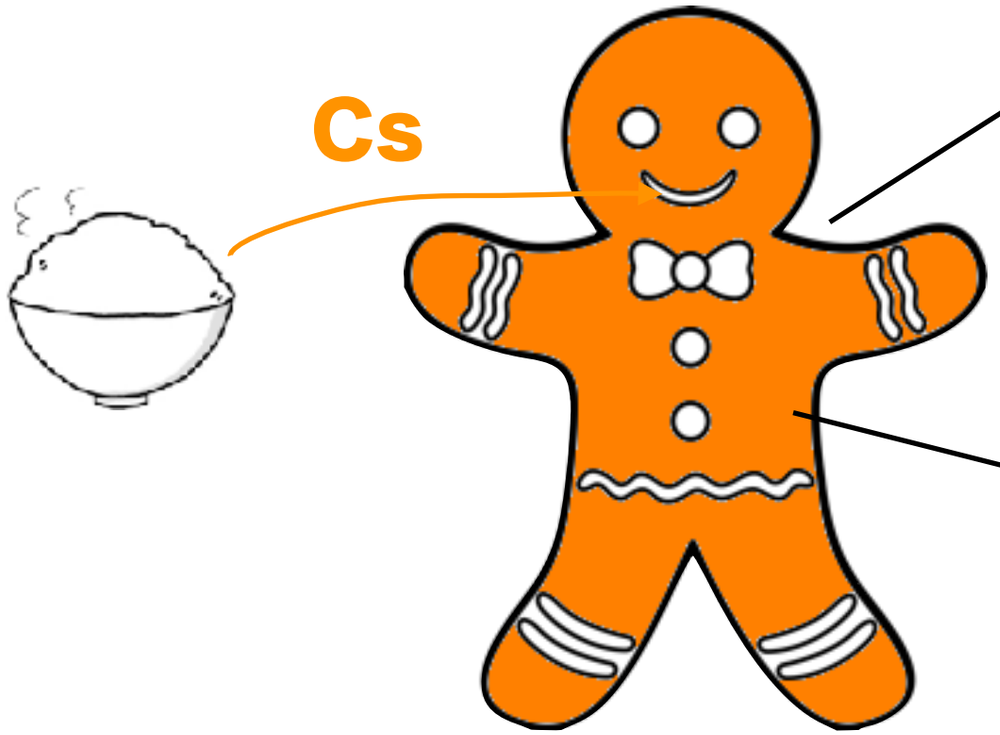
Food Safety (School Lunch)

Fukushima-city school lunch: free of radiocaesium

(results of other municipalities are similar)



Food Safety (WBC)



Food Safety (WBC)

WBC measurements of some 30,000 residents in 2011-2012

The first actual data published in English

No. 4] Proc. Jpn. Acad., Ser. B **89** (2013) 157

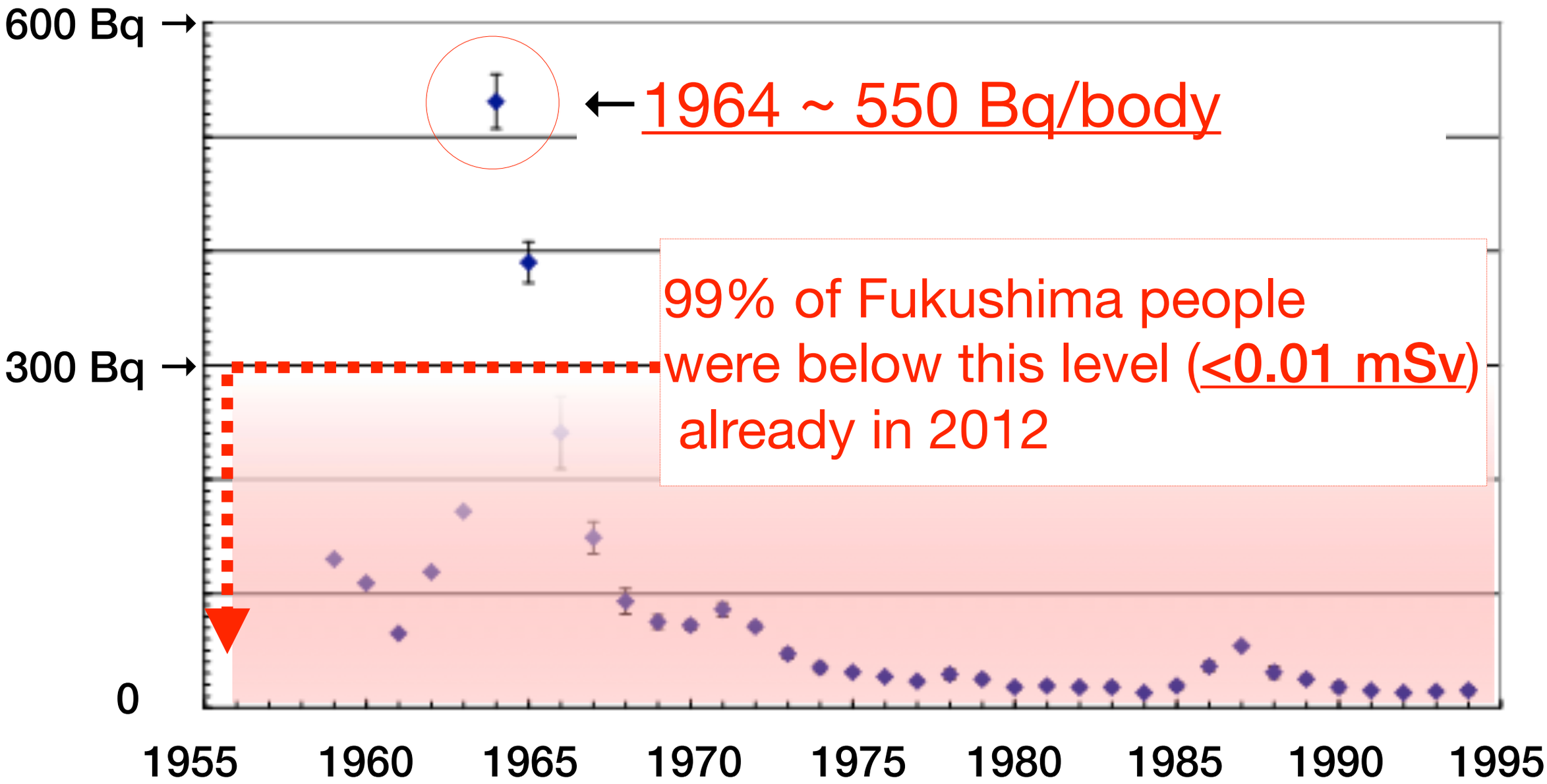
Internal radiocesium contamination of adults and children in Fukushima 7 to 20 months after the Fukushima NPP accident as measured by extensive whole-body-counter surveys

By Ryugo S. Hayano,[*1,†] Masaharu Tsubokura,[*2] Makoto Miyazaki,[*3] Hideo Satou,[*4] Katsumi Sato,[*4] Shin Masaki[*4] and Yu Sakuma[*4]

- Internal exposure of Fukushima people surprisingly low

Food Safety (WBC)

^{137}Cs in Japanese adult male in 1964
was much higher than in Fukushima



Why so low?

favorable geological features,
experts,
government,
farmers …

Food Safety (rice)

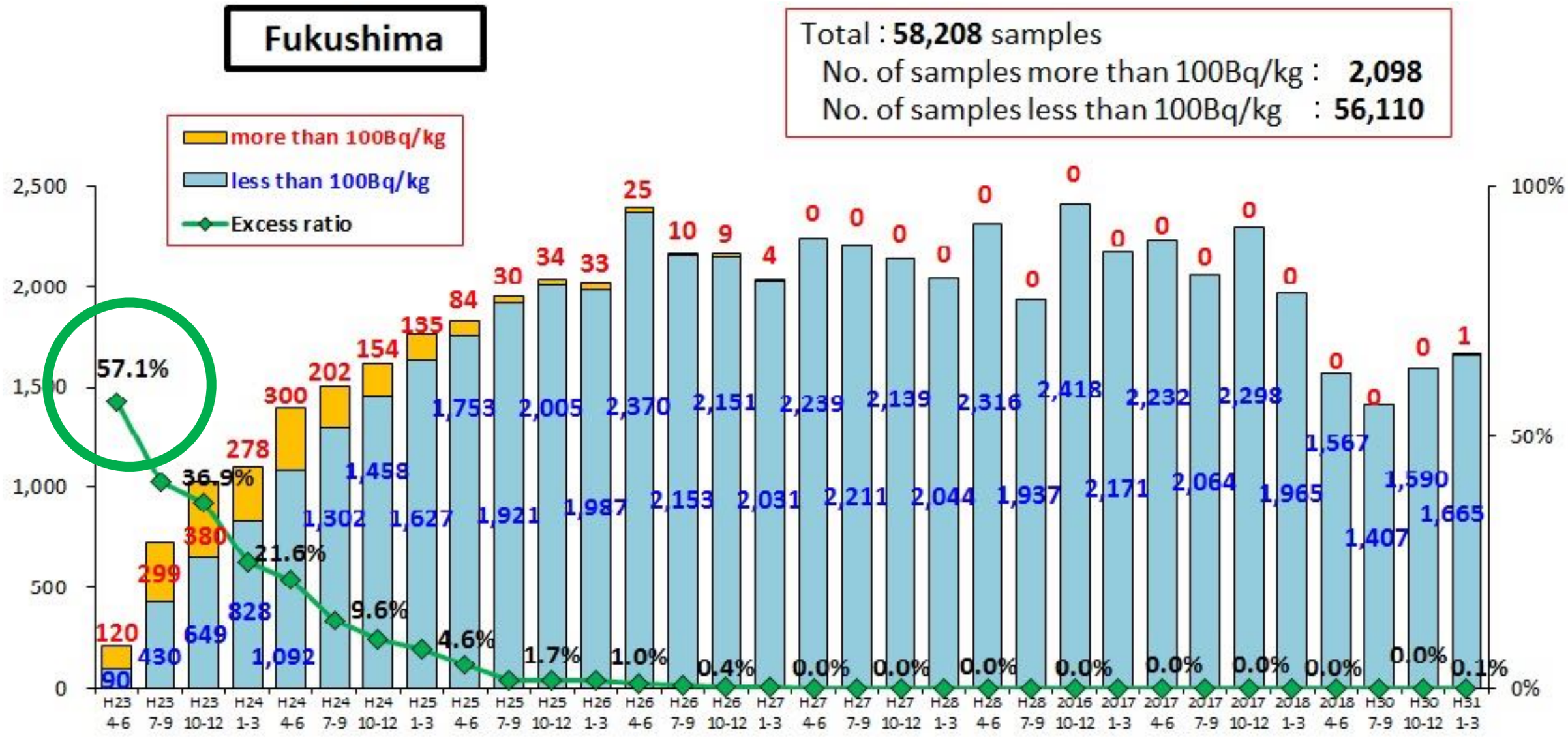
Every rice bag harvested in Fukushima, more than 10,000,000 (30 kg each), measured every year

The number of bags which exceeded the 100 Bq/kg limit

71	in 2012
28	in 2013
2	in 2014
0	in 2015
0	in 2016
0	in 2017
0	in 2018

Food Safety (Fish)

Fishery products monitoring results (Apr 2011 - Mar 2019)



Source: Fishery agency - http://www.jfa.maff.go.jp/e/inspection/index.html

Mothers were unconvinced

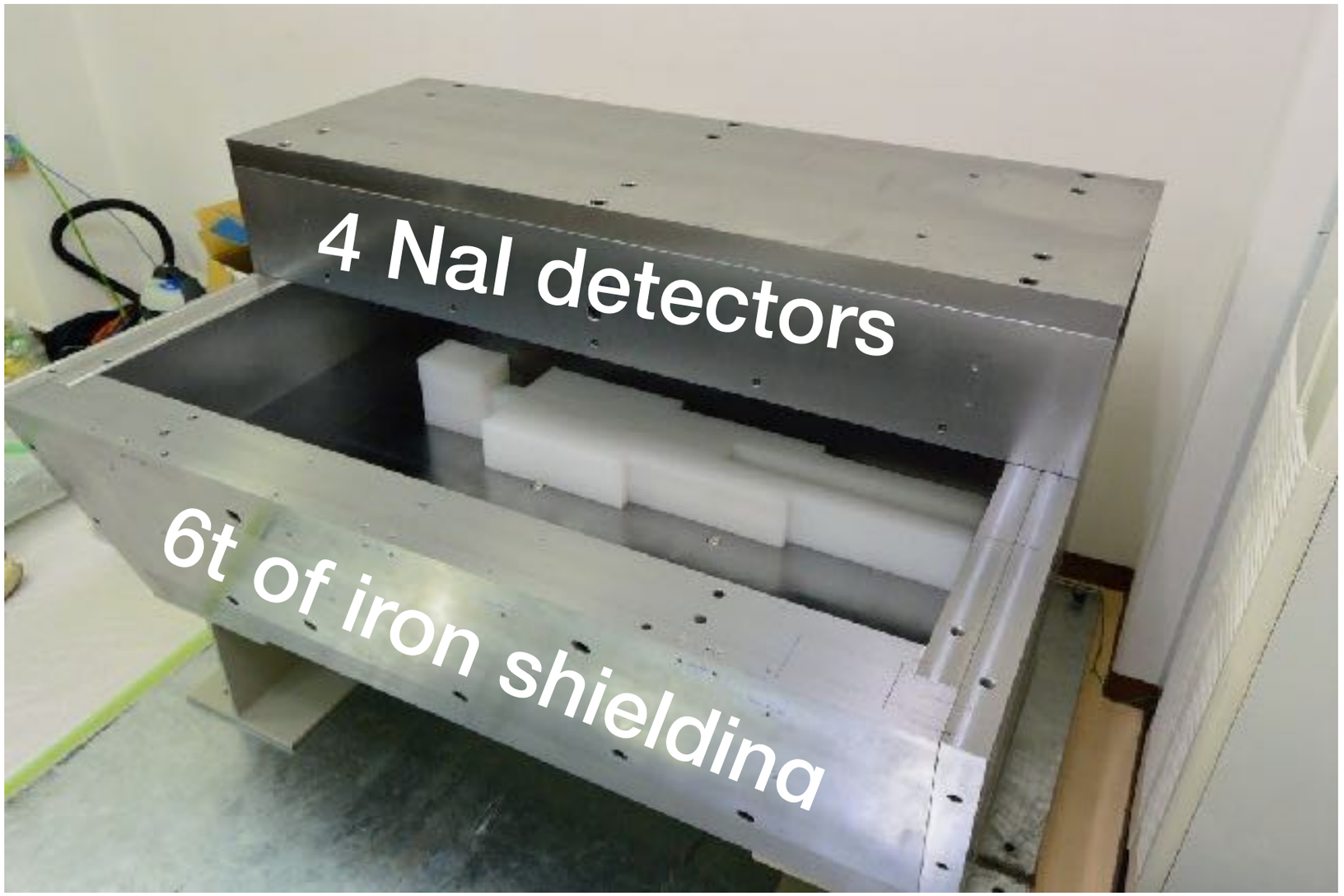
Internal exposure - negligible
food - safe enough

However, parents were unconvinced

So, I made a special device called the “BABYSCAN”

BABYSCAN

As a detector, this works.
but mothers would never like this



BABYSCAN - is a communication tool

Courtesy, NHK World

BABYSCAN - Babies are "clean"

Detection limit < 30 Bq/body

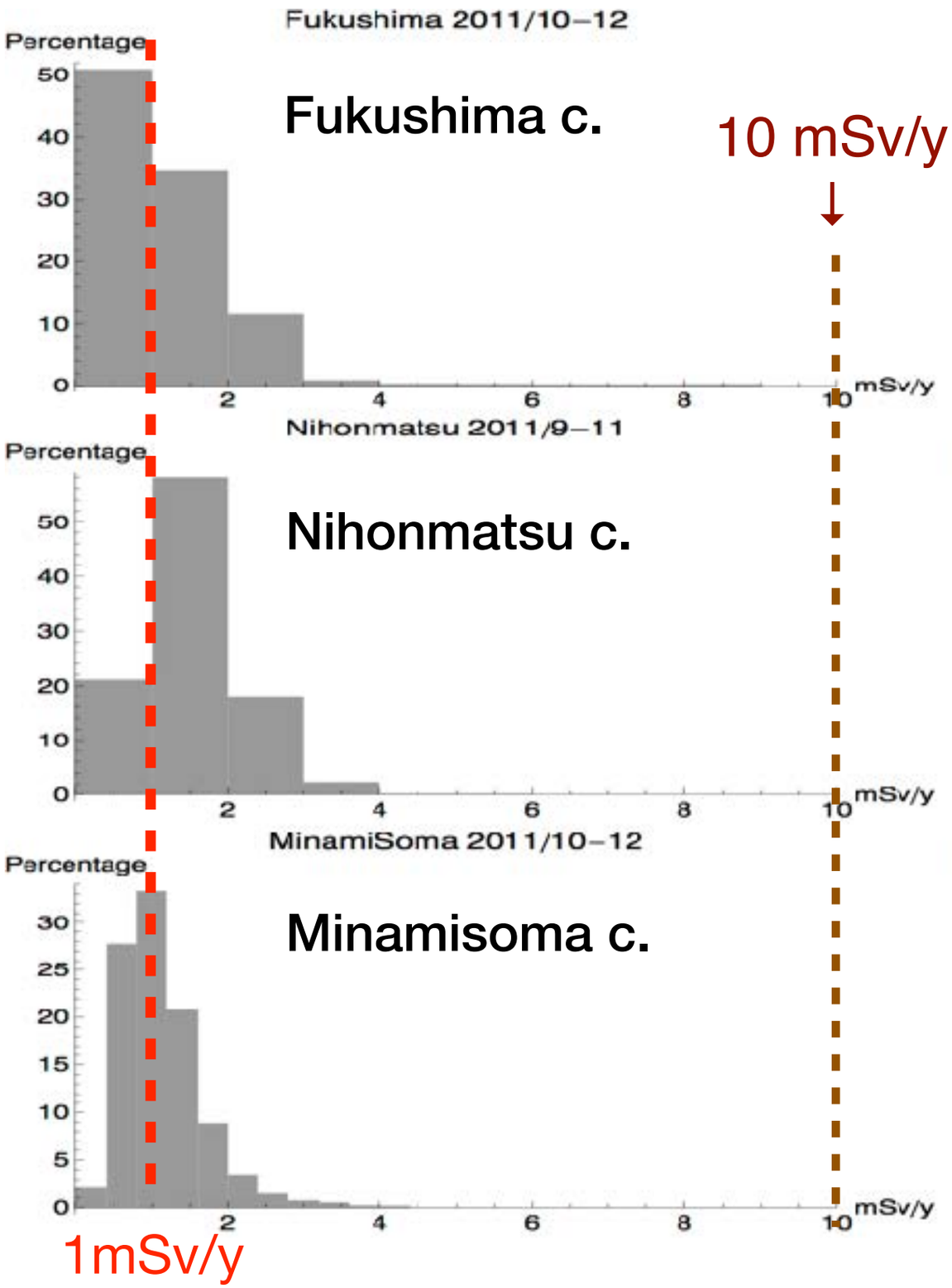
Whole-body counter surveys of over 2700 babies and small children in and around Fukushima Prefecture 33 to 49 months after the Fukushima Daiichi NPP accident

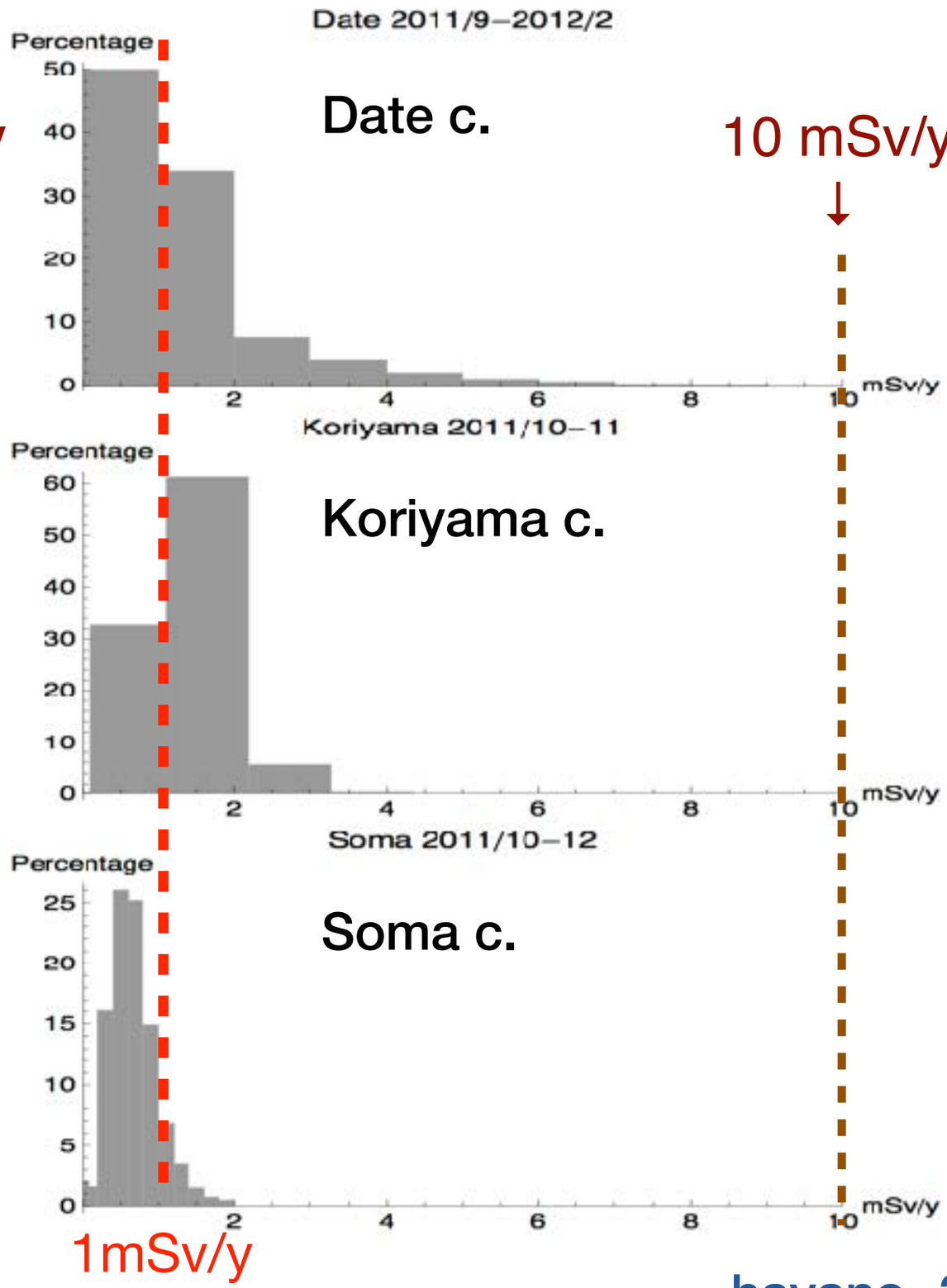
By Ryugo S. Hayano,[*1,†] Masaharu Tsubokura,[*2] Makoto Miyazaki,[*3] Akihiko Ozaki,[*4] Yuki Shimada,[*4] Toshiyuki Kambe,[*4] Tsuyoshi Nemoto,[*4] Tomoyoshi Oikawa,[*4] Yukio Kanazawa,[*4] Masahiko Nihei,[*5] Yu Sakuma,[*5] Hiroaki Shimmura,[*6] Junichi Akiyama[*6] and Michio Tokiwa[*6]

2. External exposures

External exposures (school children data)

~50% below 1mSv/y in winter 2011

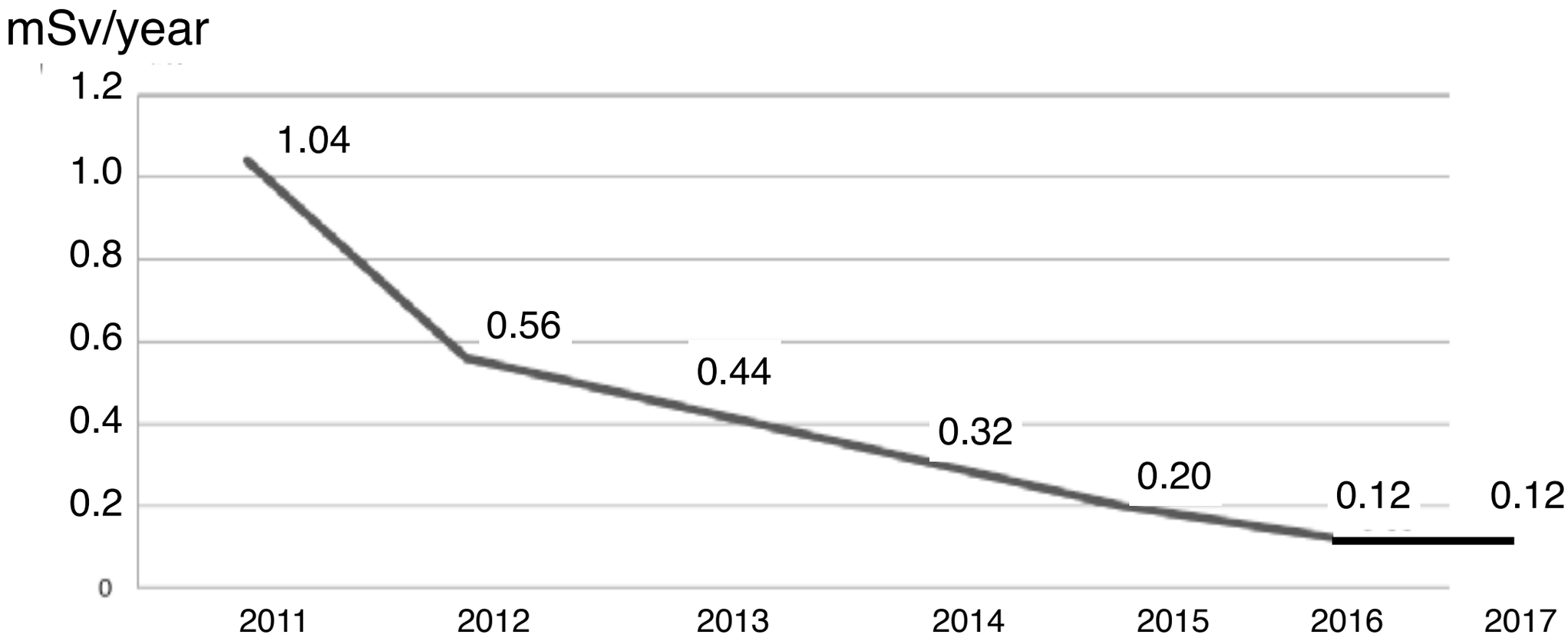




2~3 mo. results extrapolated to 1 year

External exposures (school children data)

Fukushima-city school children (below 15 yo)
mean "additional" annual exposures - 7-year trend



Source: Fukushima City

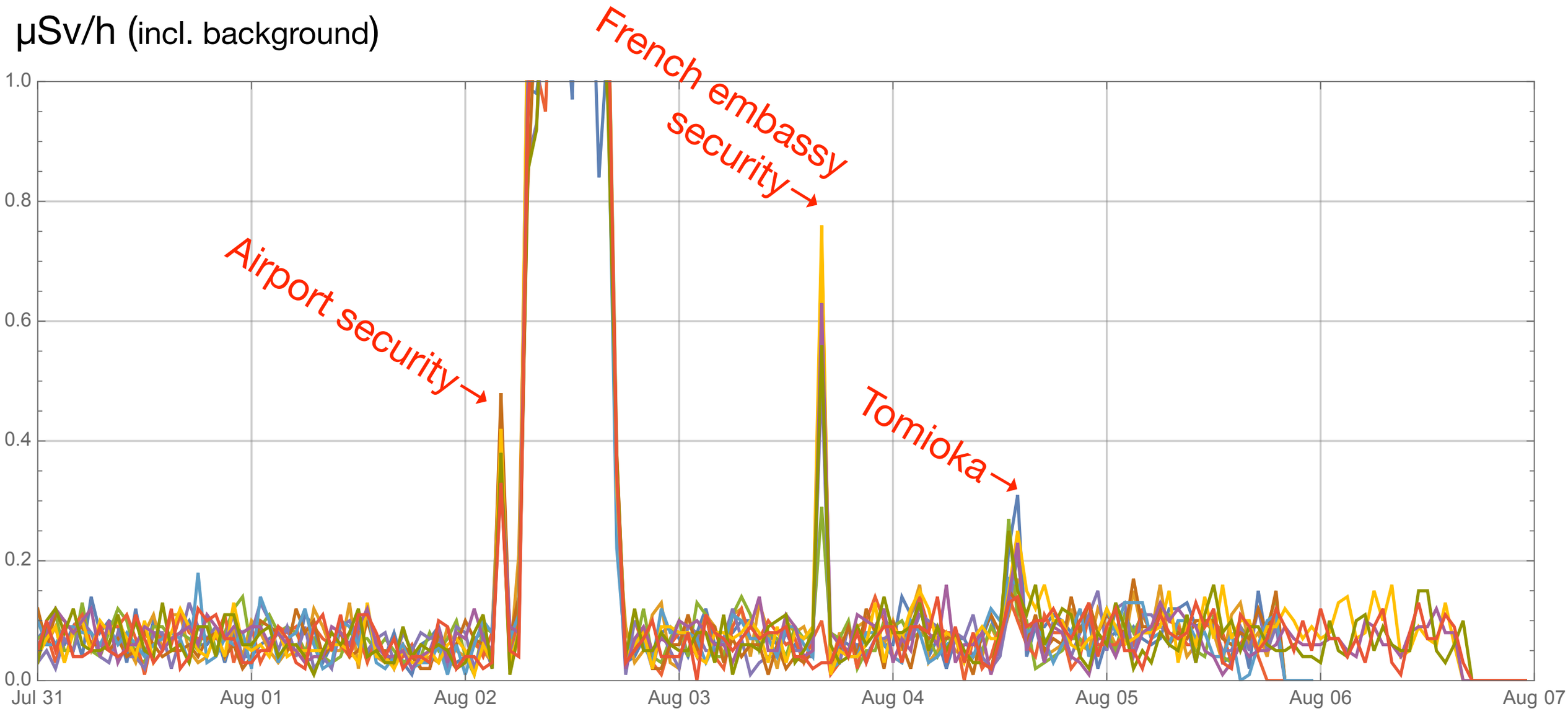
The "D-shuttle" project

"D-shuttle", a personal dosimeter
with 1-hour integrated-dose readout

Adachi et al 2016 J. Radiol. Prot. 36 (2016) 49

External exposures (high school data)

D-shuttle data:
8 students & 4 teachers came to Fukushima in 2015



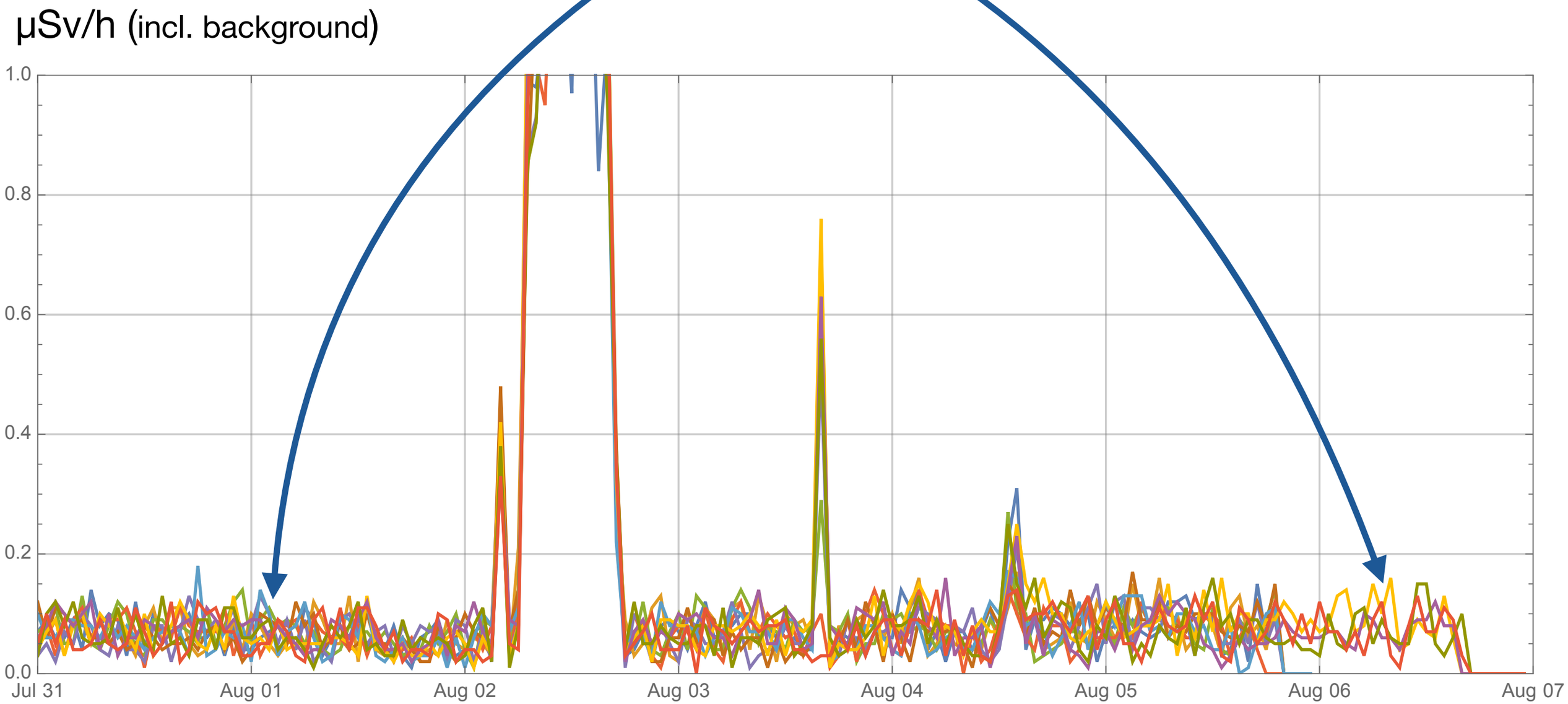
Visit "Tomioka" (in the evacuation zone)

39

© Hayano

External exposures (high school data)

Not much difference



← Paris → ← Tokyo → ← Fukushima →

External exposures (high school data)

Fukushima students analyzed the data

External exposures (high school data)

co-authored by 233 high school students, teachers, and experts from Japan, France, Poland and Belarus

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Journal of Radiological Protection
J. Radiol. Prot. **36** (2016) 49–66
doi:10.1088/0952-4746/36/1/49

Measurement and comparison of individual external doses of high-school students living in Japan, France, Poland and Belarus—the 'D-shuttle' project—

N Adachi[1], V Adamovitch[2], Y Adjovi[3], K Aida[4], H Akamatsu[5], S Akiyama[6], A Akli[7], A Ando[8], T Andrault[9], H Antonietti[3], S Anzai[10], G Arkoun[3], C Avenoso[11], D Ayrault[9], M Banasiewicz[12], M Banaśkiewicz[13], L Bernardini[11], E Bernard[7], E Berthet[11], M Blanchard[3], D Boreyko[14], K Boros[15], S Charron[16], P Cornette[9], K Czerkas[15], M Dameron[11], I Date[17], M De Pontbriand[3], F Demangeau[9], ł Dobaczewski[18], L Dobrzyński[19], A Ducouret[3], M Dziedzic[20], A Ecalle[9], V Edon[9], K Endo[21], T Endo[21], Y Endo[21], D Etryk[12], M Fabiszewska[18], S Fang[4], D Fauchier[9], F Felici[7], Y Fujiwara[10], C Gardais[9], W Gaul[20], L Gurin[9], R Hakoda[22], I Hamamatsu[6], K Handa[10], H Haneda[10], T Hara[10], M Hashimoto[1], T Hashimoto[8], K Hashimoto[21], D Hata[1], M Hattori[10], R Hayano[23], R Hayashi[22], H Higasi[5], M Hiruta[6], A Honda[6], Y Horikawa[8], H Horiuchi[24], Y Hozumi[17], M Ide[25], S Ihara[8], T Ikoma[24], Y Inohara[22], M Itazu[24], A Ito[8], J Janvrin[9], I Jout[11], H Kanda[5], G Kanemori[5], M Kanno[10], N Kanomata[10], T Kato[24], S Kato[24], J Katsu[5], Y Kawasaki[21], K Kikuchi[4], P Kilian[26], N Kimura[25], M Kiya[10], M Klepuszewski[15], E Kluchnikov[14], Y Kodama[5], R Kokubun[10], F Konishi[22], A Konno[6], V Kontsevoy[2], A Koori[6], A Koutaka[6], A Kowol[27], Y Koyama[4], M Kozioł[13], M Kozue[1], O Kravtchenko[14], W Kruczała[12], M Kudła[28], H Kudo[29], R Kumagai[24], K Kurogome[25], A Kurosu[29], M Kuse[25], A Lacombe[3], E Lefaillet[3], M Magara[17], J Malinowska[26], M Malinowski[18], V Maroselli[7], Y Masui[29], K Matsukawa[29], K Matsuya[17], B Matusik[20], M Maulny[9], P Mazur[27], C Miyake[29], Y Miyamoto[4], K Miyata[1], K Miyata[5], M Miyazaki[30], M Molęda[20], T Morioka[1], E Morita[24], K Muto[1], H Nadamoto[5], M Nadzikiewicz[28], K Nagashima[29], M Nakade[22], C Nakayama[25], H Nakazawa[17],

Y Nihei[4], R Nikul[2], S Niwa[8], O Niwa[30], M Nogi[6], K Nomura[29], D Ogata[8], H Ohguchi[31], J Ohno[24], M Okabe[17], M Okada[22], Y Okada[6], N Omi[25], H Onodera[10], K Onodera[25], S Ooki[21], K Oonishi[29], H Oonuma[10], H Ooshima[8], H Oouchi[1], M Orsucci[11], M Paoli[11], M Penaud[9], C Perdrisot[9], M Petit[9], A Piskowski[15], A Płocharski[15], A Polis[13], L Polti[3], T Potsepnia[14], D Przybylski[12], M Pytel[28], W Quillet[9], A Remy[3], C Robert[9], M Sadowski[19], M Saito[10], D Sakuma[1], K Sano[5], Y Sasaki[24], N Sato[4], T Schneider[32], C Schneider[3], K Schwartzman[2], E Selivanov[14], M Sezaki[25], K Shiroishi[21], I Shustava[14], A Śniecińska[28], E Stalchenko[14], A Staroń[27], M Stromboni[7], W Studzińska[26], H Sugisaki[17], T Sukegawa[21], M Sumida[22], Y Suzuki[17], K Suzuki[10], R Suzuki[10], H Suzuki[10], K Suzuki[6], W Świderski[18], M Szudejko[33], M Szymaszek[27], J Tada[34], H Taguchi[22], K Takahashi[4], D Tanaka[5], G Tanaka[29], S Tanaka[24], K Tanino[4], K Tazbir[13], N Tcesnokova[14], N Tgawa[5], N Toda[6], H Tsuchiya[17], H Tsukamoto[8], T Tsushima[1], K Tsutsumi[25], H Umemura[8], M Uno[24], A Usui[25], H Utsumi[29], M Vaucelle[9], Y Wada[17], K Watanabe[4], S Watanabe[22], K Watase[29], M Witkowski[26], T Yamaki[21], J Yamamoto[4], T Yamamoto[17], M Yamashita[22], M Yanai[21], K Yasuda[22], Y Yoshida[1], A Yoshida[21], K Yoshimura[25], M Żmijewska[15] and E Zuclarelli[7]

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[3] Notre Dame High School, 1 Avenue Charles de Gaulle, 92100 Boulogne-Billancourt, France
[4] Aizu Gakuho High School, Ikkimachi Oaza Yahata, Yahata-1-1, Aizuwakamatsu, Fukushima 965-0003, Japan
[5] Nada High Shool, 8-5-1 Uozakikitamachi, Higashinada-ku, Kobe, Hyogo 658-0082, Japan
[6] Iwaki High School, Taira Aza Takatsuki 7, Iwaki, Fukushima 970-8026, Japan
[7] Giocante de Casabianca High School, Avenue Jean Zuccarelli, 20200 Bastia, France
[8] Ena High School, 1023-1 Ohi-cho, Ena, Gifu 509-7201, Japan
[9] Bois d'Amour High School, 9 Rue de la Garenne, 86000 Poitiers, France
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[11] Paul Vincensini High School, Rue de la Quatriéme Division Marocaine de Montagne, 20600 Bastia, France
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[13] I LO im. J. Słowackiego, Częstochowa, Poland
[14] Blaise Pascal High School n°46, 14, rue de Clermont-Ferrand, 246027 Gomel, Belarus
[15] ZS nr 5 im. Unii Europejskiej, III LO, Ostroleka, Poland
[16] Institute for Radiation Protection and Nuclear Safety (IRSN), BP17,92262 Fontenay-aux-Roses Cedex, France
[17] Asaka High School, 5-25-63 Kaisei, Koriyama, Fukushima 963-8851, Japan

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J. Radiol. Prot.
36 (2016) 49

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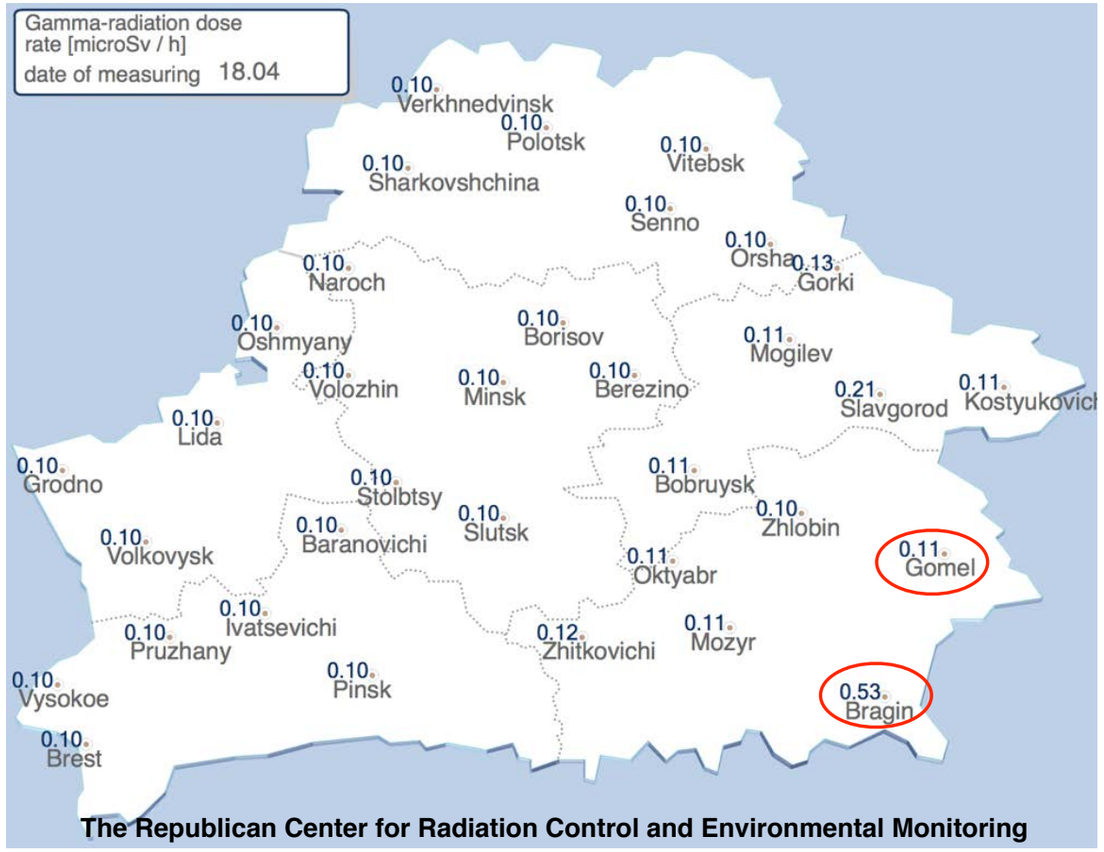
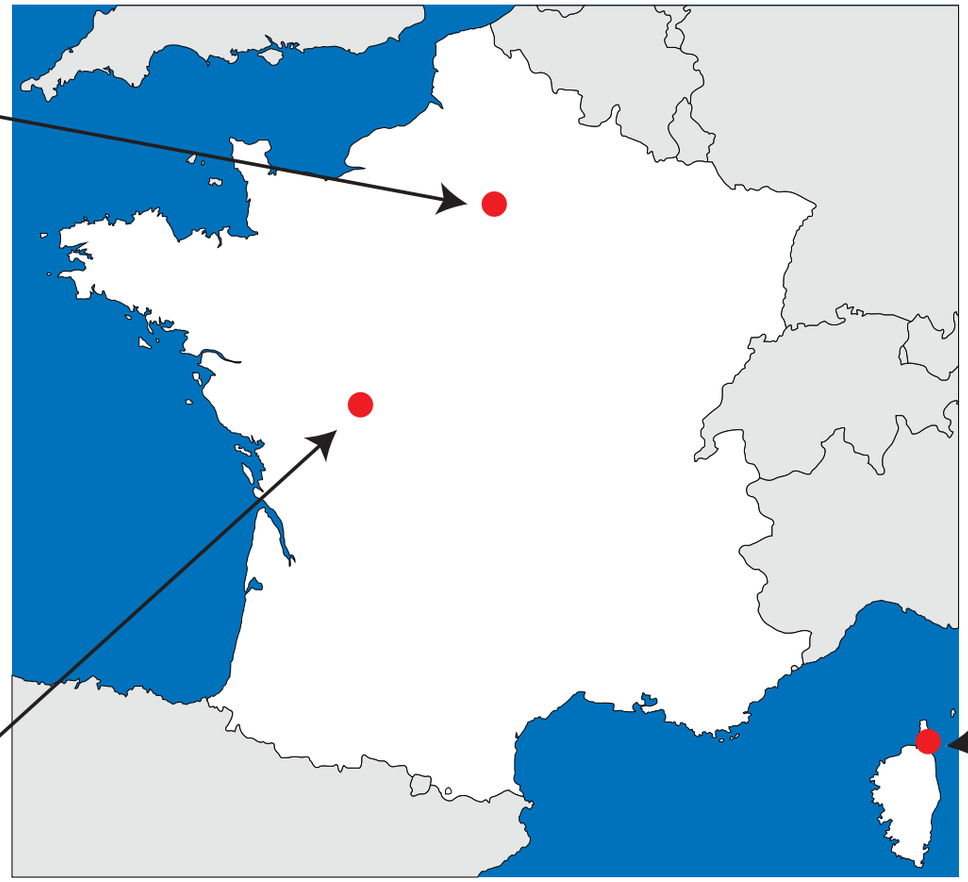
External exposures (high school data)

Belarus



France

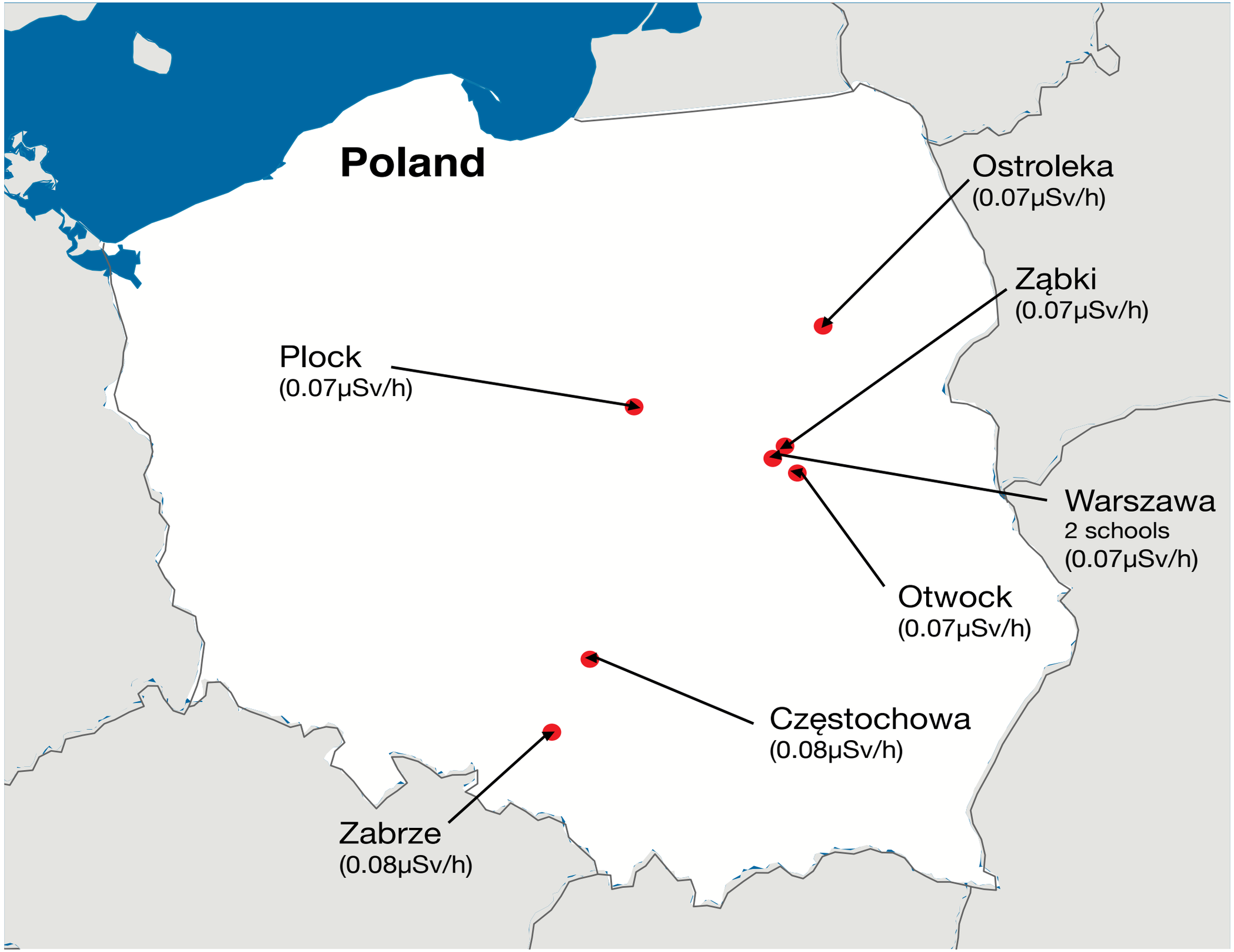


Boulogne
(0.06μSv/h)

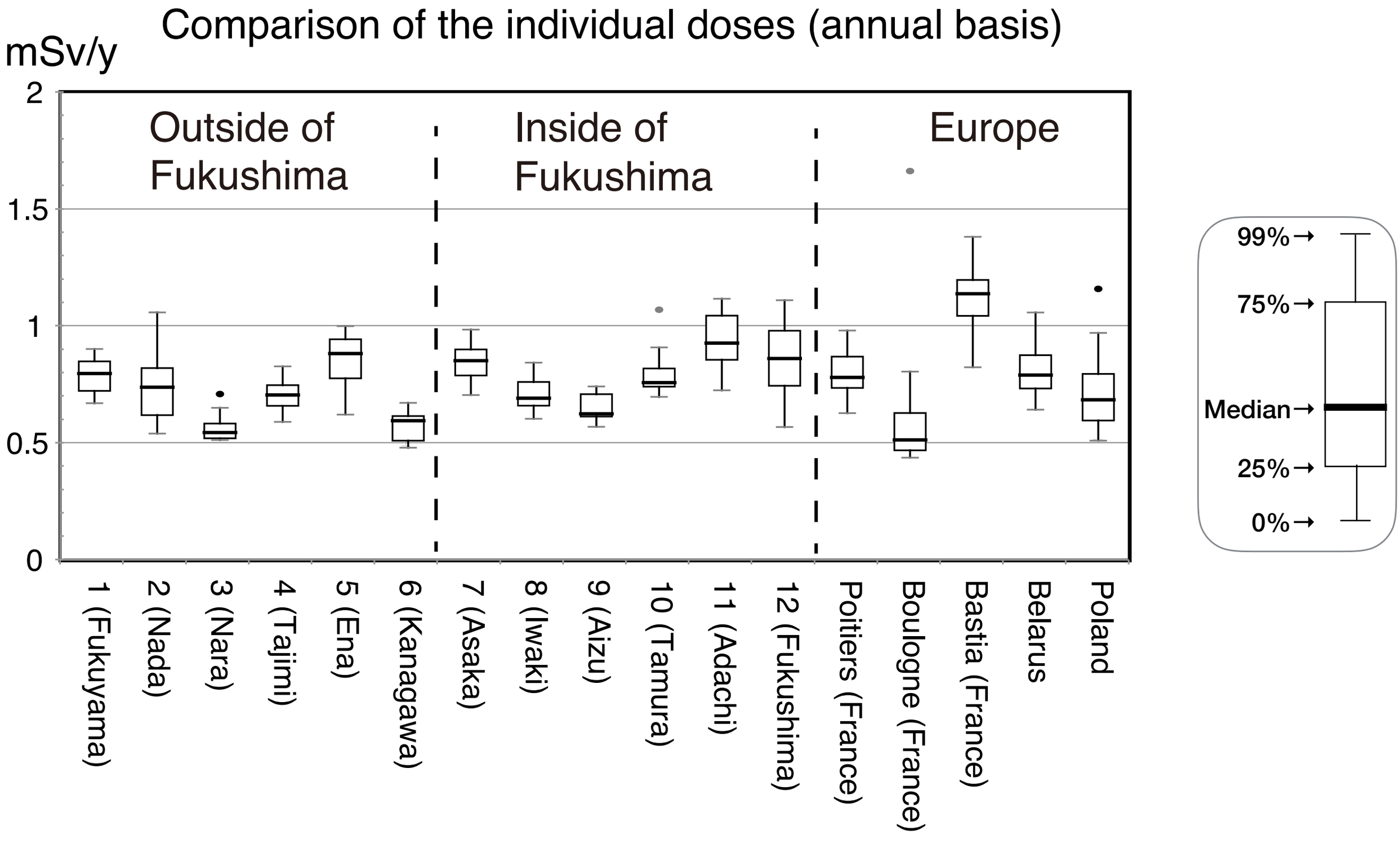
Poitiers
(0.08μSv/h)

Bastia
2 schools
(0.10μSv/h)

External exposures (high school data)



External exposures (high school data)



Adachi et al., J. Radiol. Prot. 36 (2016) 49

3. Psychosocial problems remain

Hereditary effets in Fukushima?

Q: Do you think the radiation exposure in Fukushima will affect your descendants?

Year	2012	2013	2014	2015	2016	2017
likely + very likely	60%	48%	48%	38%	38%	36%

Questionnaire filled out by >40,000 Fukushima adults
Source: Fukushima Medical University

Year						2017
likely + very likely						50%

Same question, Tokyo residents → even worse!!

Questionnaire filled out by 1,000 Tokyo adults
Source: Mitsubishi Research Institute

Conclusions

- Normal life is returning to ~2 M Fukushima residents (although there are still ~41 k evacuees).
- Fukushima food: safe to eat,
  Fukushima is safe to live in.
- The risks due to internal/external exposures have been found to be small.
- However, psychosocial and economical problems still remain.
- Prolonged evacuation destroyed communities, families...