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Assessment of External Doses to the Public Considering Variability and Uncertainty

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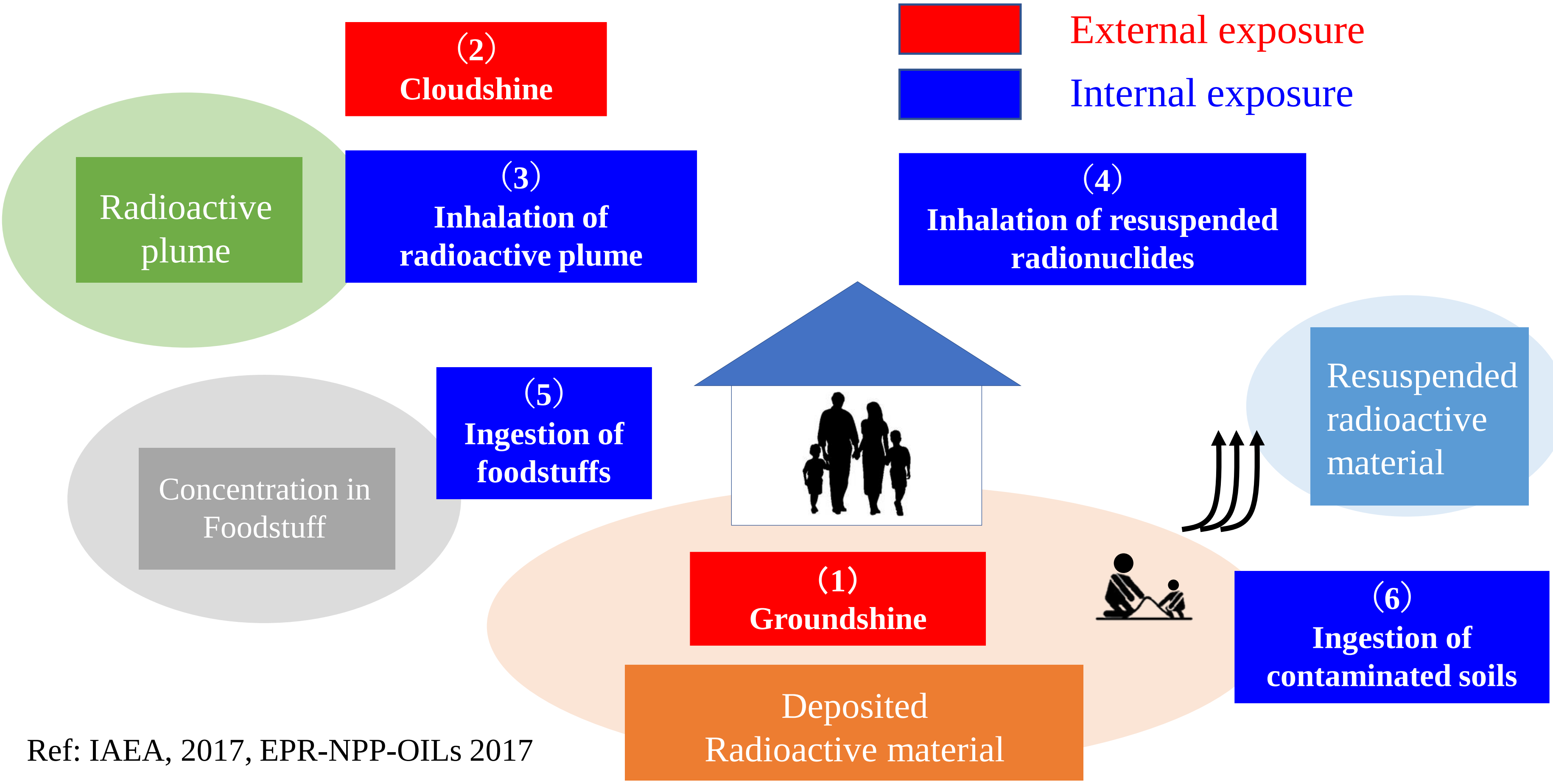
Radiation exposure pathway after nuclear accident

- People could be exposed to radiations through various exposure pathways.
- It is well known that external exposure due to deposited radioactive materials is the dominant pathway after the Fukushima Daiichi Nuclear Power Plant accident.



Ref: IAEA, 2017, EPR-NPP-OILs 2017

Dose assessment model for external exposure

Assessment process of dose from deposited radionuclides

Surface density of radionuclides（Bq/m^2）

Weathering

Migration into the soil

Surface roughness

Dose conversion coefficient （μSv/h）/（Bq/m^2）

Dose rate (Sv/h)

Behavioral pattern (h)

Population group

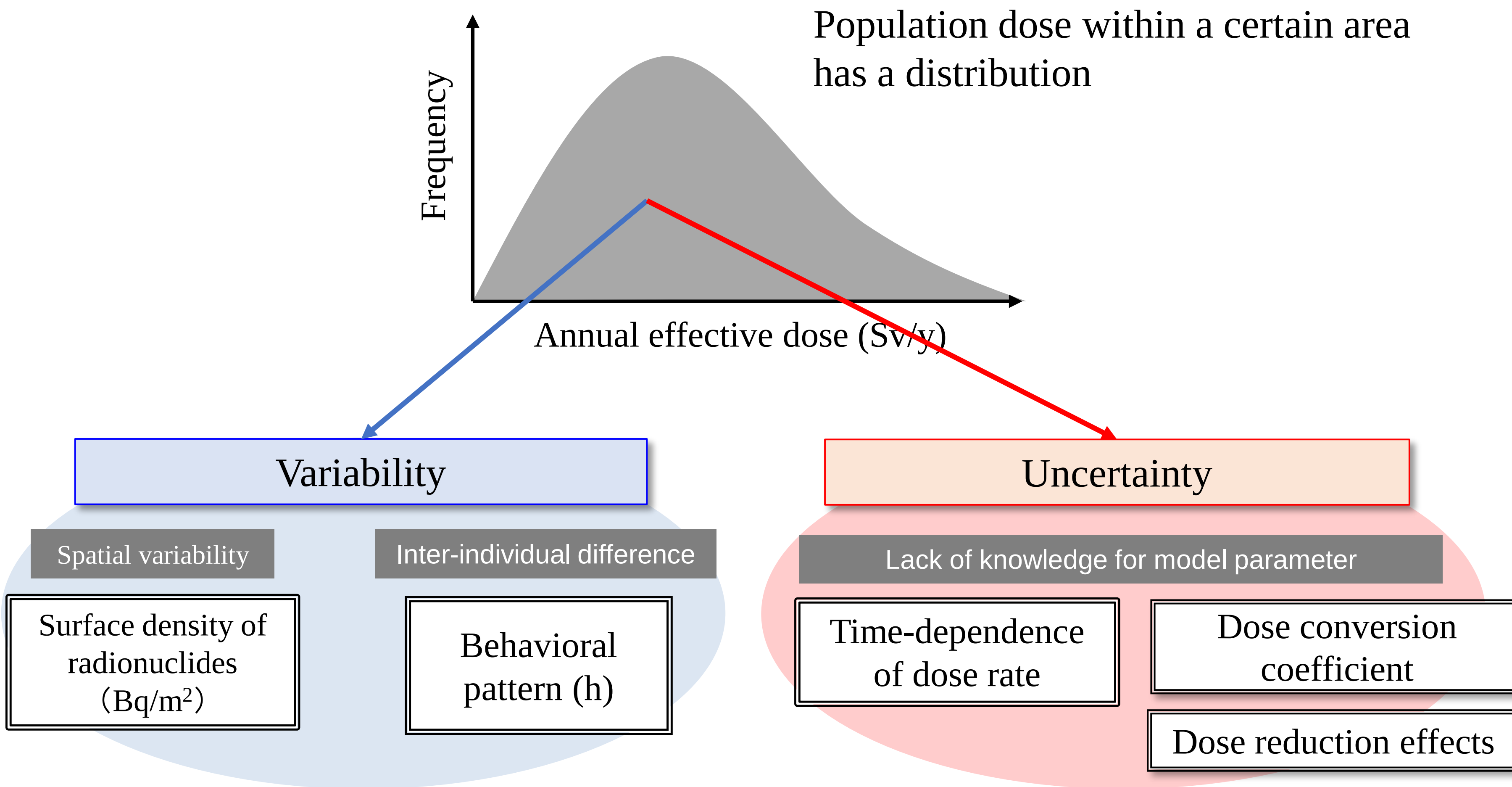
Decontamination Sheltering

Restriction of activity

External dose (Sv)

How high is dose rate?
How long do you stay at that place?

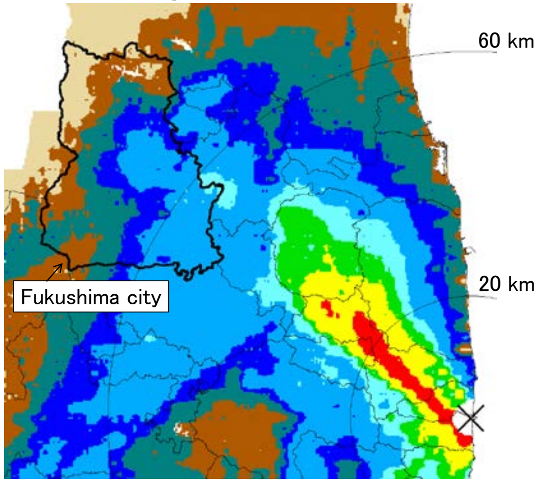
Variability and Uncertainty in external dose assessment



- How much is the influence of variability and uncertainty on dose distribution of the population group and target areas?
- What is a reasonable dose assessment to achieve the aim?

Survey and measurement in Fukushima city

- Surveys and measurements were performed in Fukushima city (February 2012 ~ March 2019)
- Based on these data, we developed an assessment model.
- Uncertainty analysis is performed for the assessment using the developed model.



Environment monitoring
Previous studies
Surface density of radionuclides（Bq/m²）
Dose coefficient（μSv/h）/（Bq/m²）
Dose rate (Sv/h)
Behavioral pattern (h)
Decontamination Sheltering
Restriction of activity
External dose (Sv)
Surveys on behavioral pattern
Measurement of dose rate inside and outside of house
Measurements of individual doses

生活行動記録シート　2015 年　10 月分

調査ID　　　ー

日　付	記入時刻	積算線量 μSv	葛尾村の自宅での滞在時間（時間） 屋内	葛尾村の自宅での滞在時間（時間） 屋外	職場での滞在時間（時間） 屋内	職場での滞在時間（時間） 屋外	その他の場所での滞在時間（時間） 屋内 コンクリート	その他の場所での滞在時間（時間） 屋内 木造	その他の場所での滞在時間（時間） 屋外
記入例	20:00	12	13	1	8	0	2	0	0
10 月　1 日									
10 月　2 日									
10 月　3 日									
10 月　4 日									
10 月　5 日									
10 月　6 日									
10 月　7 日									
10 月　8 日									

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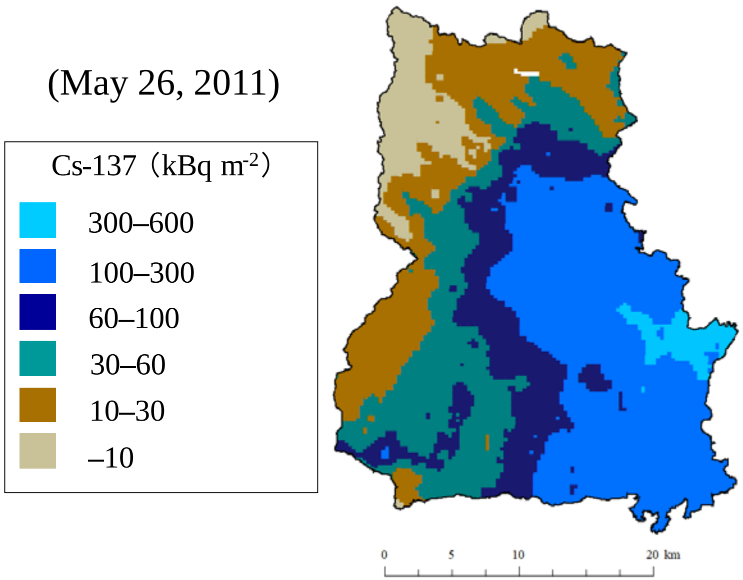
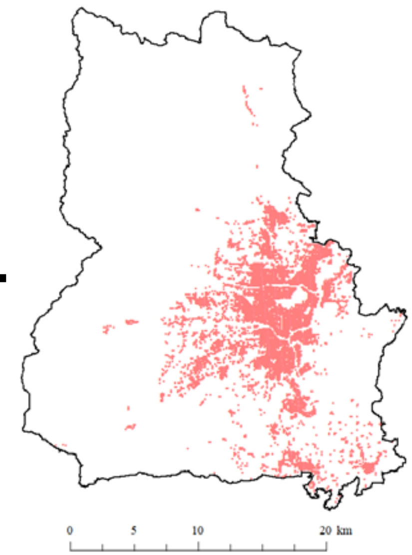
Spatial distribution of Cs-137 in Fukushima city

Surface density of Cs-137

(May 26, 2011)



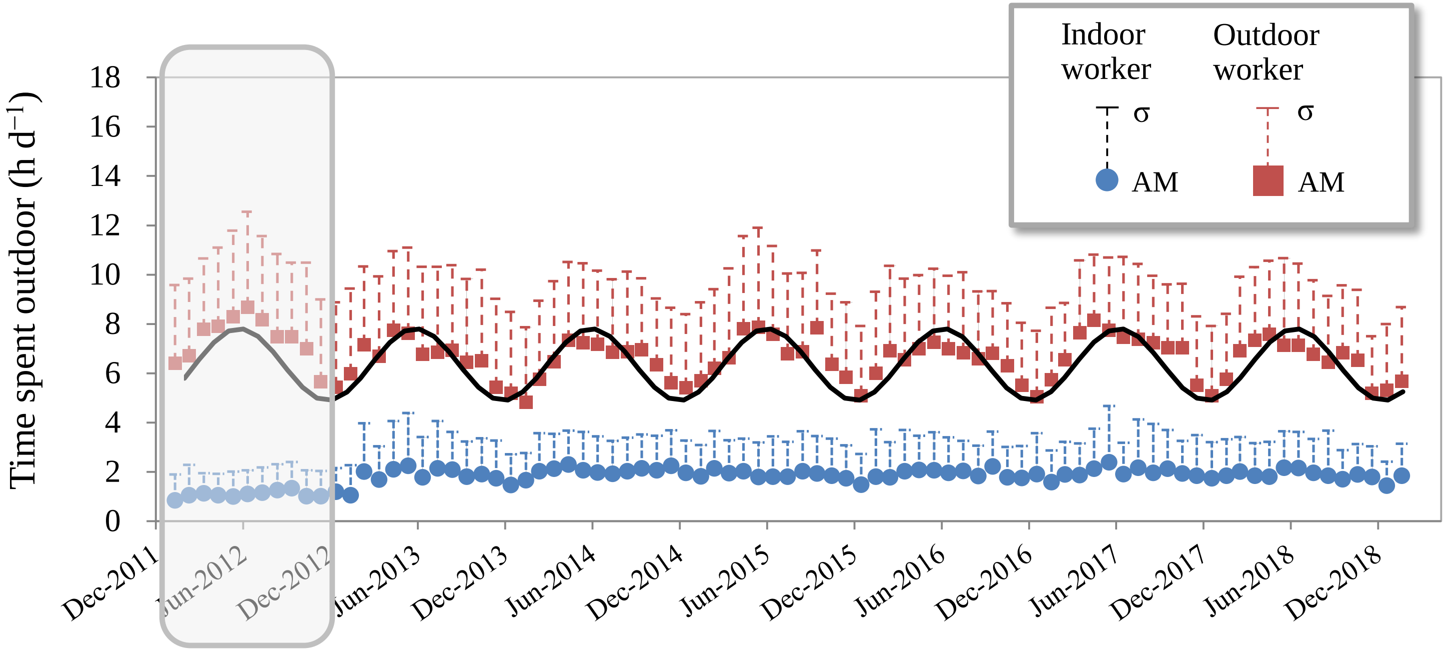
Residential area



Land use	Sample size	Surface density of the ground (June 14, 2011) GM	GSD
All type of land use	93	0.12 MBq m^{-2}	2.1
Residential area (Population-weighted)	93	0.20 MBq m^{-2}	1.5

Behavioral pattern

- Behavioral patterns at various places were surveyed (i.e. time spent inside of wooden house, concrete building, and outside of house) for indoor worker, outdoor worker, and pensioner.
- The statistics were obtained from annual data on behavioral patterns.



Number of Participant

Year	Indoor Worker	Outdoor Worker
2012	60	113
2013	41	57
2014	52	48
2015	40	38
2016	36	29
2017	25	23
2018	19	16

Annual average

Population group	Time spent per day (h)		
	t_w, Wooden house	t_c, Concrete building	t_o, Outdoor
Indoor worker	$24 - t_c - t_o$	Lognormal GM = 6.1 GSD = 1.1	Lognormal GM = 0.3 GSD = 2.5
Outdoor worker	$24 - t_c - t_o$	Lognormal GM = 0.6 GSD = 2.7	Normal AM = 7.3 SD = 2.7

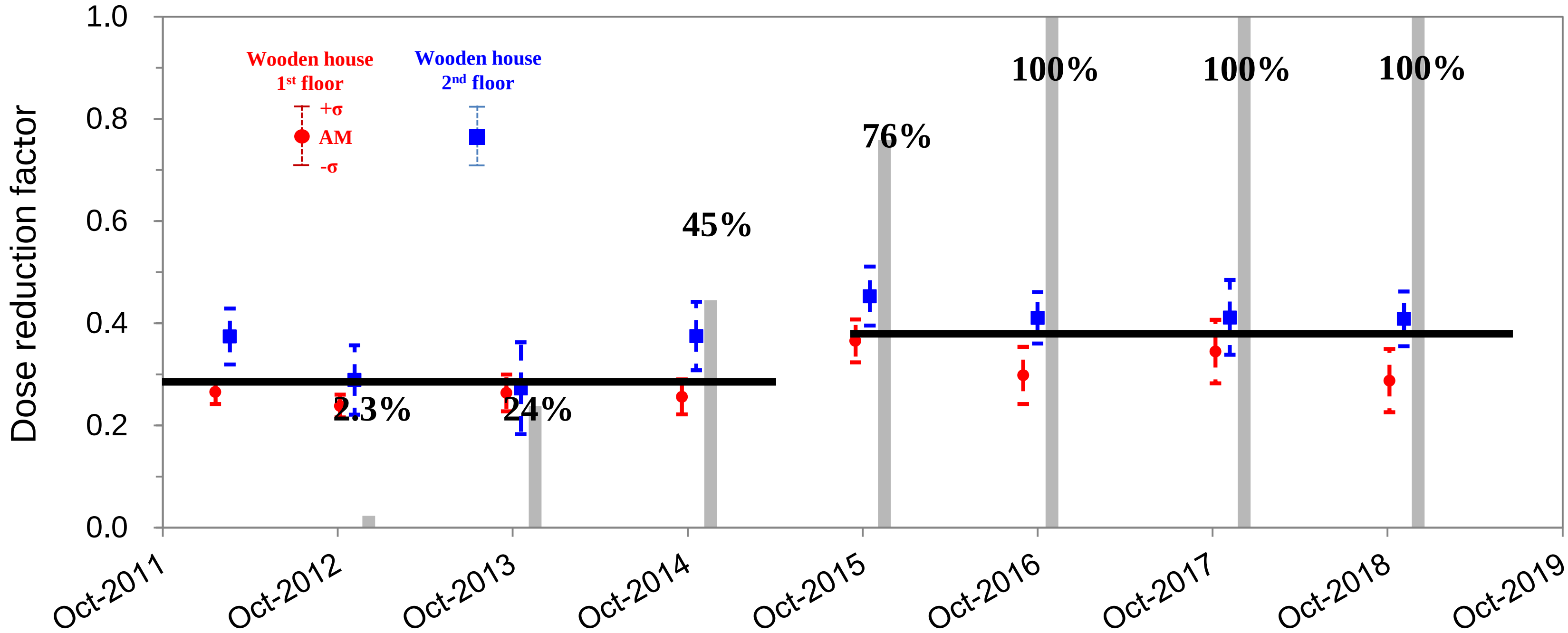
Dose reduction factor for wooden house

- Dose reduction effect of wooden house is evaluated by dose reduction factor.

$$\text{Dose reduction factor} = \frac{\text{Dose rate measured inside of house}}{\text{Dose rate measured outside of house}}$$

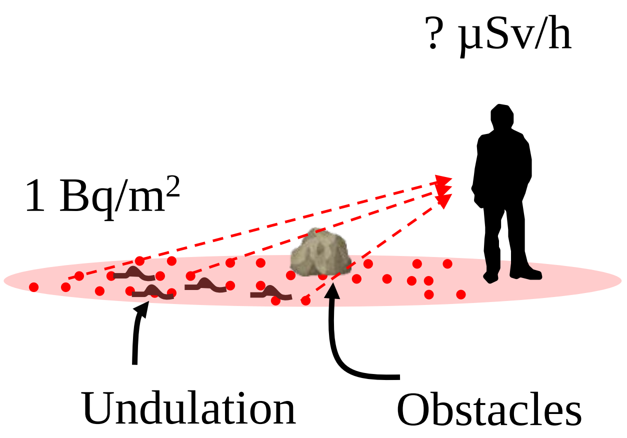
- The statistics were obtained from annual data on behavioral patterns at various places for each participant.

Note）Gray histogram represent the progress rate of decontamination in Fukushima city



Dose coefficient for external exposure from deposited radionuclides

- Dose rate from deposited radionuclides can be assessed using dose conversion factor.
- Dose conversion factor is calculated using radiation transport codes. In this analysis, an infinite plane is often assumed, but in reality radiation could be shielded by irregularities and obstacles on the ground surface.
- For example, US.EPA assumed that the relaxation depth of 0.5 g/cm^2 is suitable for simulating the shielding effect due to the roughness of the ground surface.



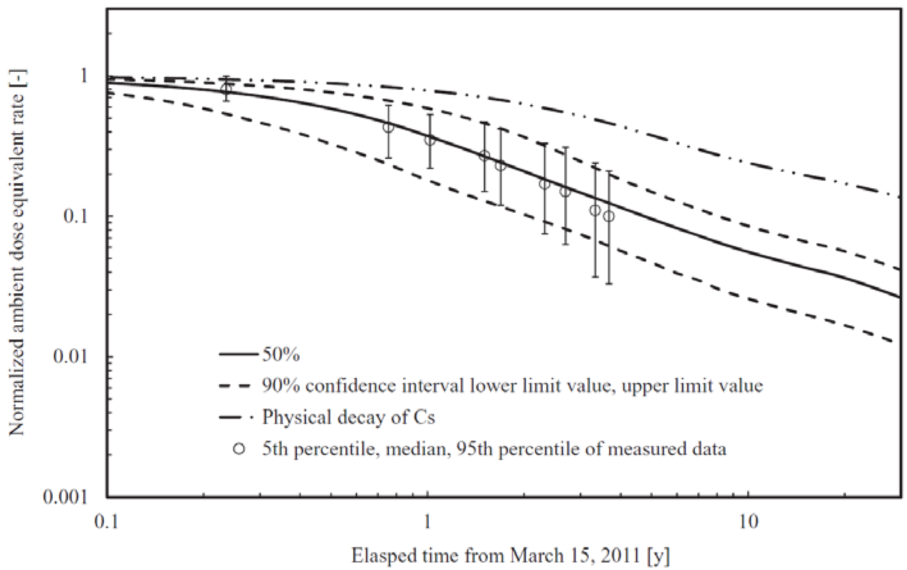
	Relative composition	Dose conversion coefficient ($\times 10^{-12}$ Sv h^{-1} per Bq m^{-2})	
		$\beta = 0$ (g cm^{-2})	$\beta = 0.5$ (g cm^{-2})
^{131}I	11.5	1.25	0.93
^{132}I	−	7.37	5.48
^{129m}Te	1.1	0.11	0.08
^{132}Te	8	0.71	0.51
^{134}Cs	1	5.1	3.79
^{136}Cs	0.17	6.86	5.1
^{137}Cs	1	1.96	1.46
^{140}Ba	0.1	7.8	5.83
^{110m}Ag	0.0028	8.81	6.56

Saito et al, 2012, Radiation Environment Biophysics, 51: 411–423.

Time dependence of ambient dose equivalent Based on the measurements in Fukushima prefecture

- Kinase (2017) reported time-dependent function of ambient dose rate based on curve fitting using a two-component model.
- The fitting were performed for monitoring data from the car/vehicle-borne surveys.

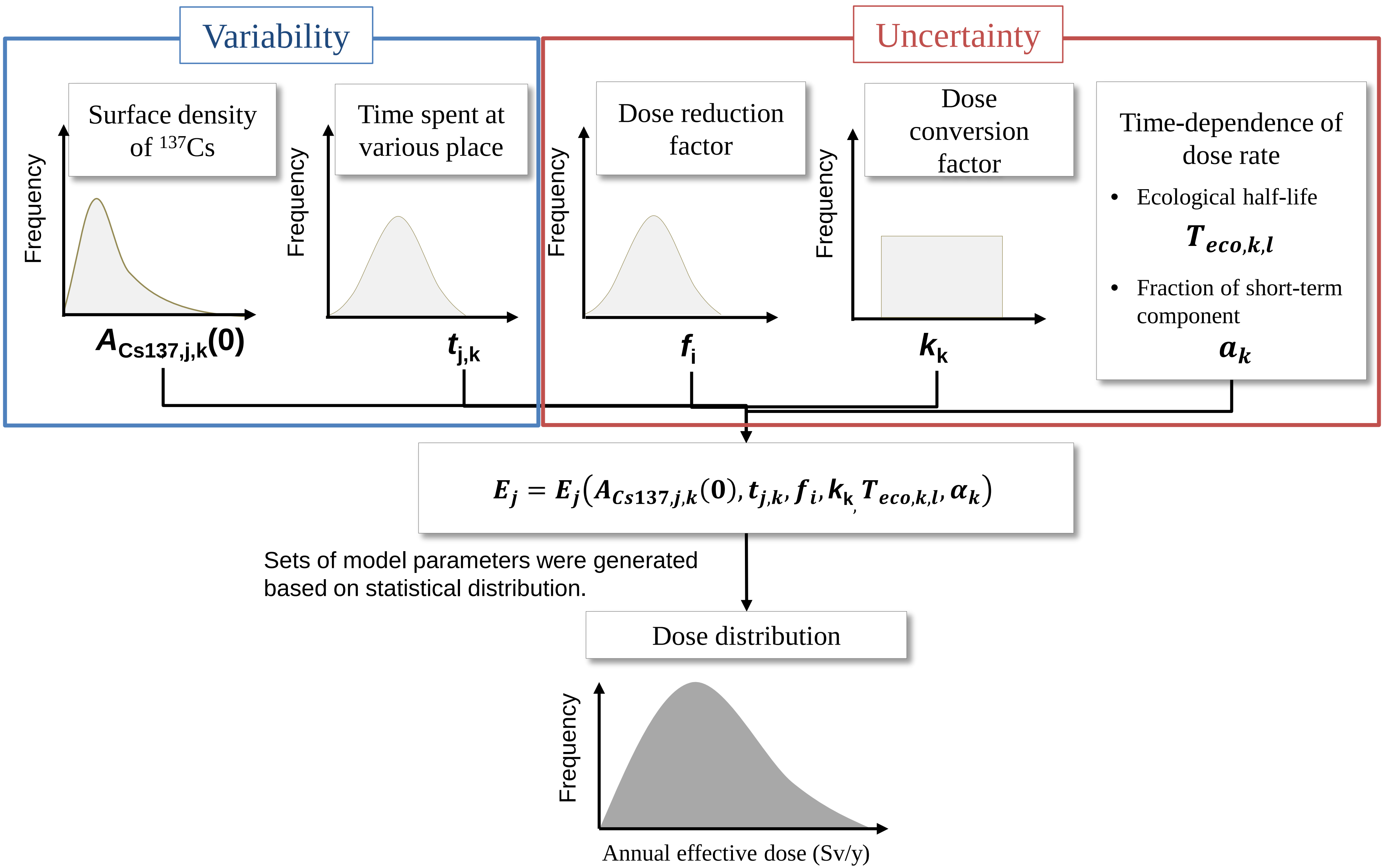
$$Y(t) = (Y(0) - Y_{BG})\left\{a_{short} \cdot \exp\left(-\frac{ln2}{T_{short}} \cdot t\right) + (1 - a_{short}) \cdot \exp\left(-\frac{ln2}{T_{short}} \cdot t\right)\right\}\frac{k \cdot \exp(-\lambda_{134} \cdot t) + \exp(-\lambda_{137} \cdot t)}{k+1} + Y_{BG}$$



Type of Land Use	Ecological half-life of short-term component, T_{short} (y)	Fraction of short-term component a_{short}
Urban	Lognormal Median = 0.59 Error Factor = 2.37	Normal Mean = 0.78 SD = 0.1
Crop	Lognormal Median = 0.64 Error Factor = 2.42	Normal Mean = 0.72 SD = 0.11.

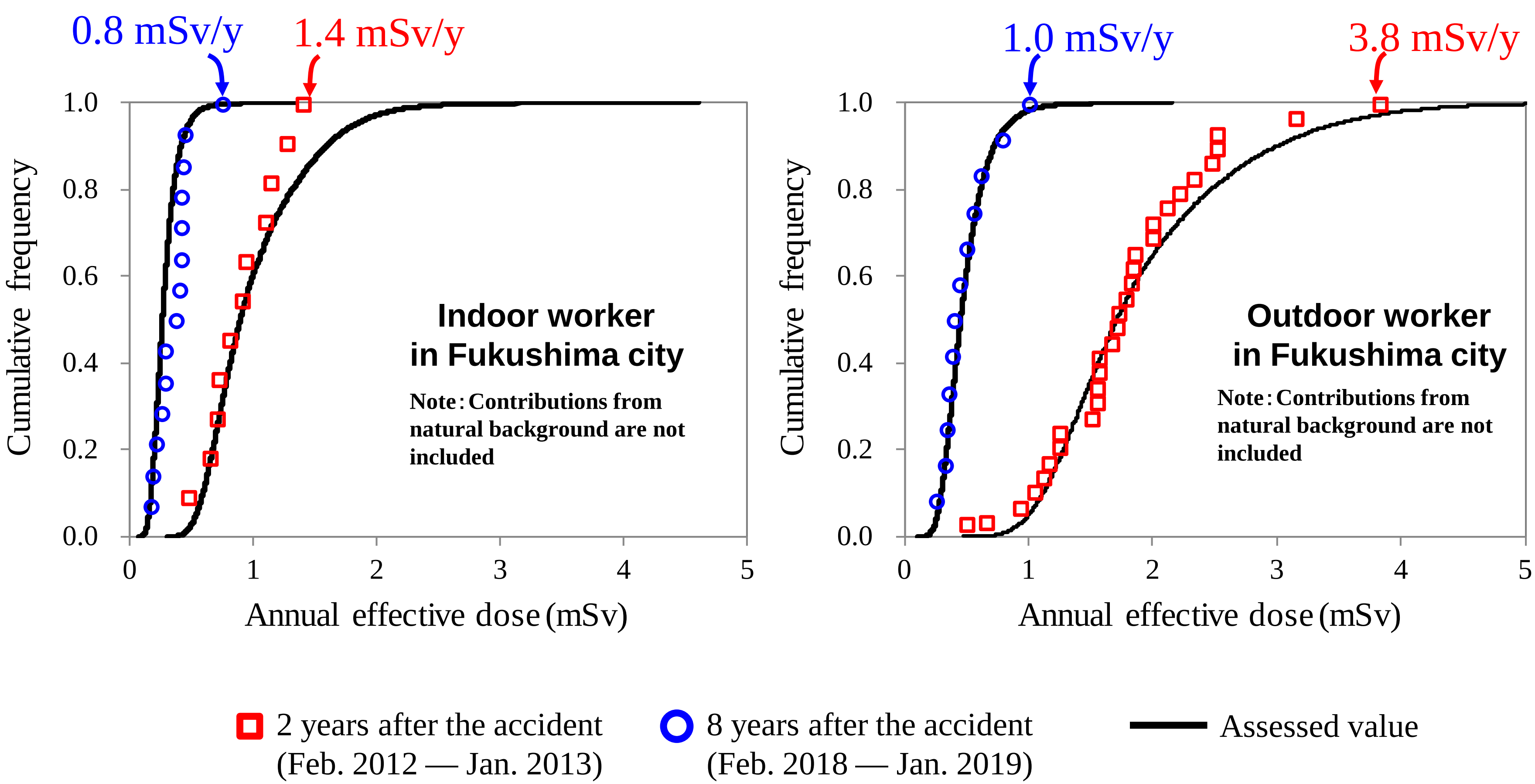
Kinase et al., 2017, Journal of Nuclear Science and Technology, 54:12, 1345-1354.

Probabilistic assessment of doses from deposited radionuclides



Validity of developed assessment model（1/2）

■ Dose distribution of assessed values were in good agreement with actual measurements.

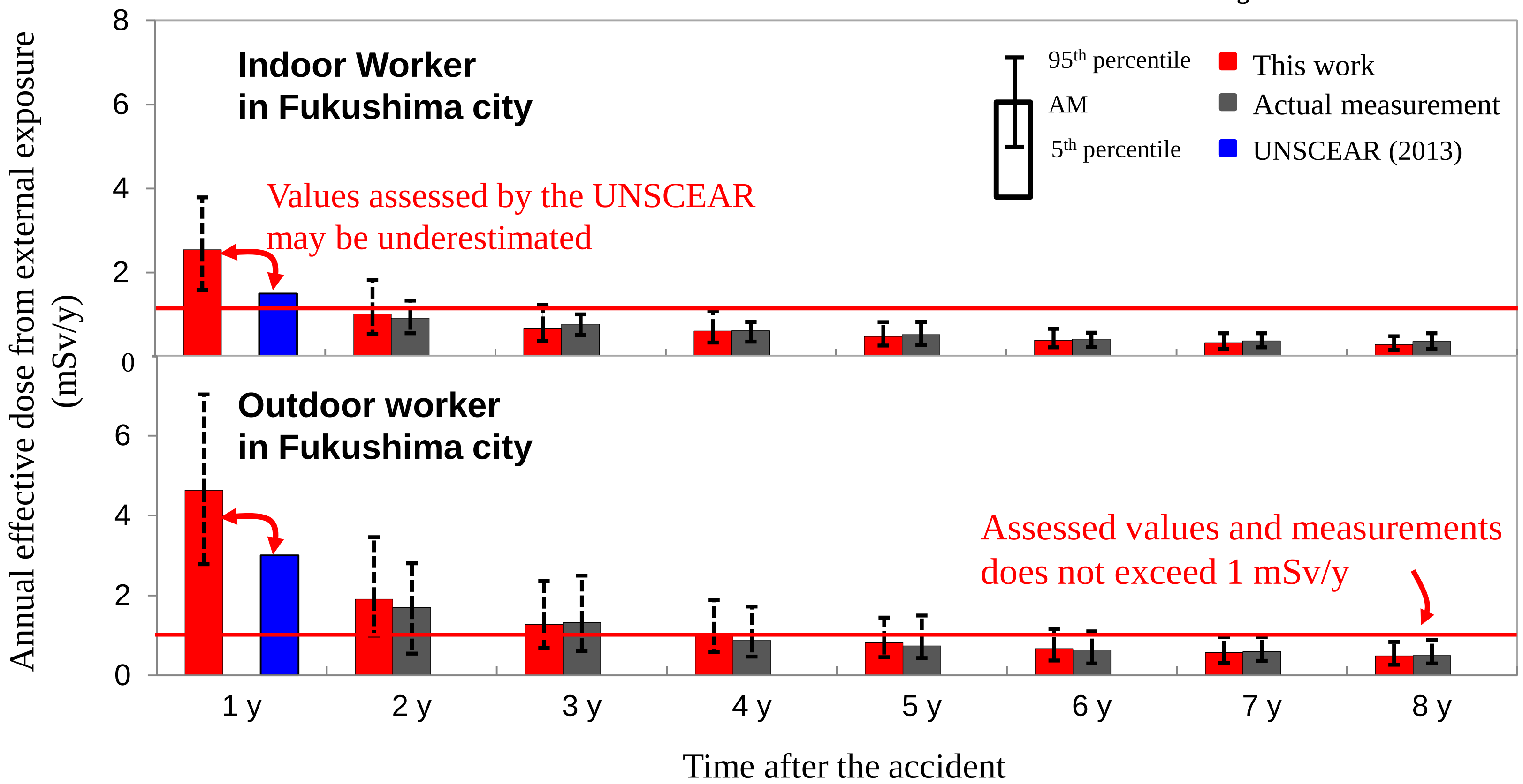


S Takahara et al. Health Physics (in press)

Validity of developed assessment model（2/2）

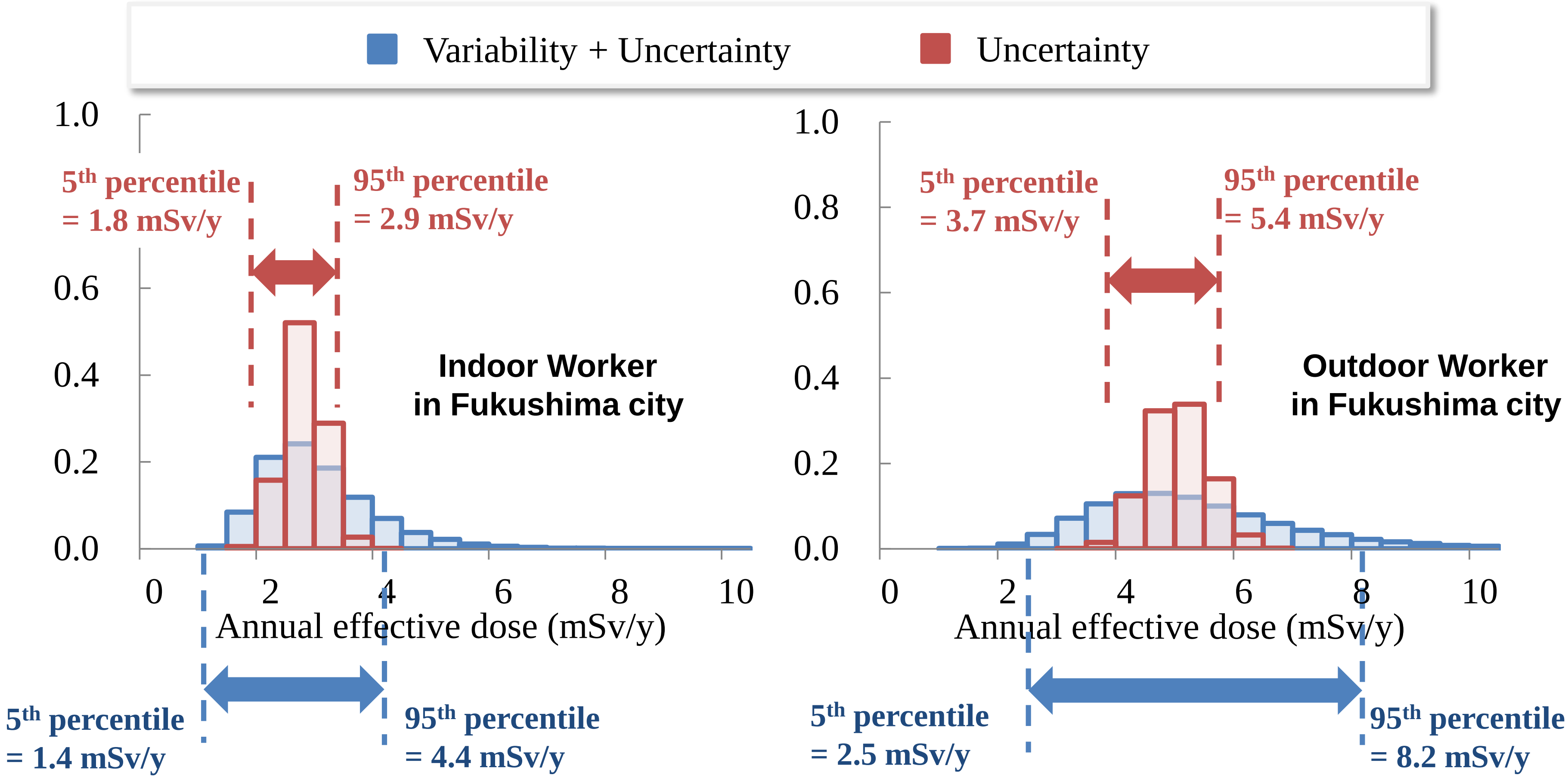
- Assessed values were in good agreement with actual measurements.

Note：Contributions from natural background are not included



S Takahara et al. Health Physics (in press)

Influence of variability and uncertainty on dose distribution



- Variability of spatial distribution of radionuclides and interindividual difference of behavior patterns are dominant factor of dose distribution.
- If variabilities (surface density and behavioral pattern) are fixed, the extent of dose distribution is within a factor of 2.

Conclusion

Assessment model of radiation doses from external exposure, and Influence of variability and uncertainty on dose distributions were quantified.

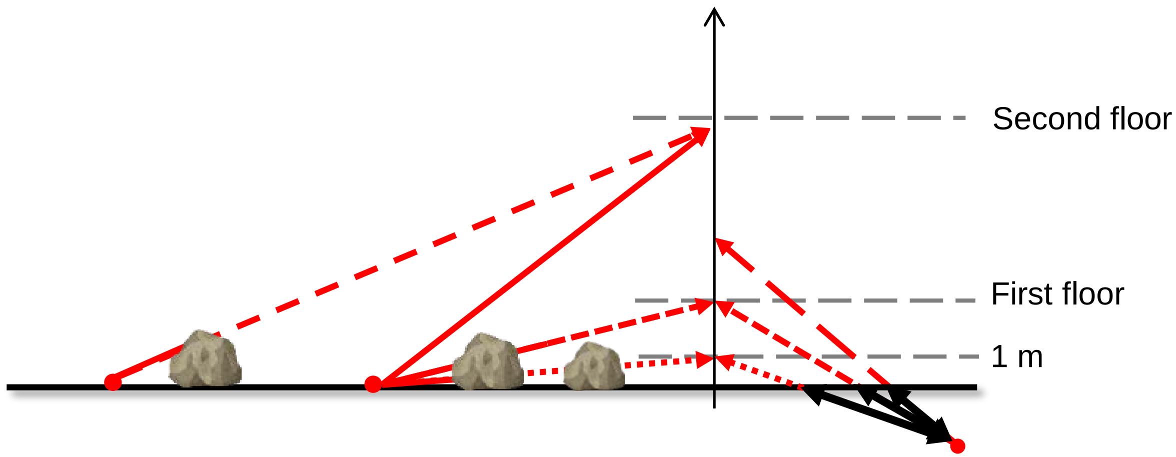
- We developed an exposure assessment model taking into account Japanese lifestyle and the effects of decontamination after the Fukushima accident.
- When assessing dose distribution for a certain area, the dominant factors were spatial variability of radioactivity and inter-individual difference in behavioral pattern.
  - Variability is important for dose assessment for decision-making on exposure management
- However, even if the radioactivity level and behavioral pattern are specified, uncertainties can make a difference of a factor 2.
  - Uncertainty is important for radiation risk communication with inhabitants

Influence of decontamination on dose rate measured inside of houses

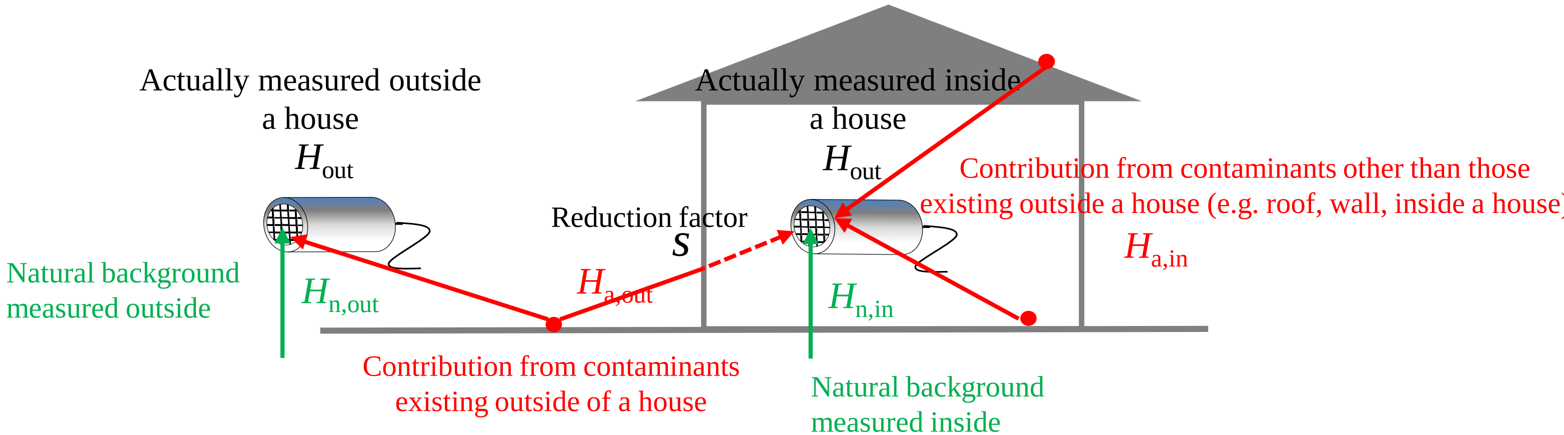
- Decontamination effect
  - Removal of radiation sources from the ground surfaces around the house
  - Covering the ground surfaces with uncontaminated soil
  - Removal of radiation sources from house material (roof, wall etc.)

What are happened due to decontamination effects？

Dose rate decrease with a height from the ground surface

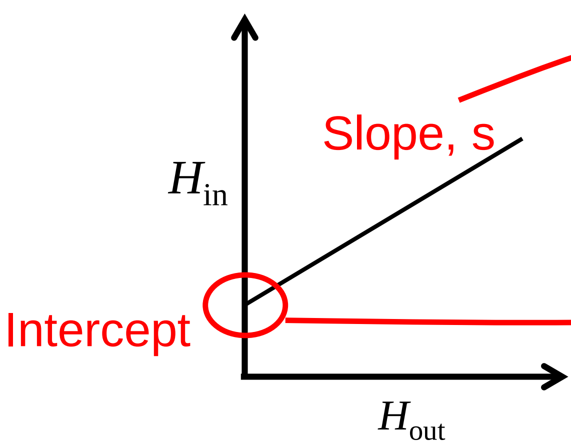


Measurement of ambient dose rate



$$\begin{cases} H_{out} = H_{a,out} + H_{n,out} \\ H_{in} = s \times H_{a,out} + H_{n,in} + H_{a,in} \\ H_{n,in} = 1.02 \times H_{n,out} \quad \text{UNSCEAR(1993)} \end{cases}$$

$$H_{in} = s \times H_{out} + \boxed{(H_{a,in} + (1.02 - s) \cdot H_{n,out})}$$



Individual dose and time spent outdoor