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Method for Estimating the Dose Distribution of People to be returned in Long-term Contaminated Areas

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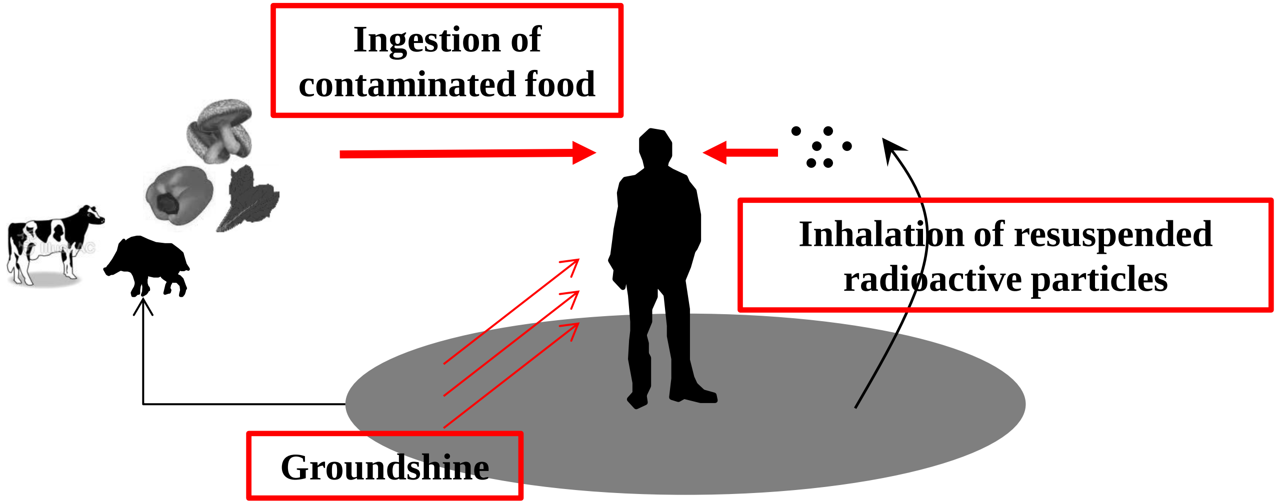
Exposure Pathway in Long-Term Contaminated Areas

- Decision on people to be returned to their homes should only be taken when the exposures that would result from returning can be assessed appropriately.

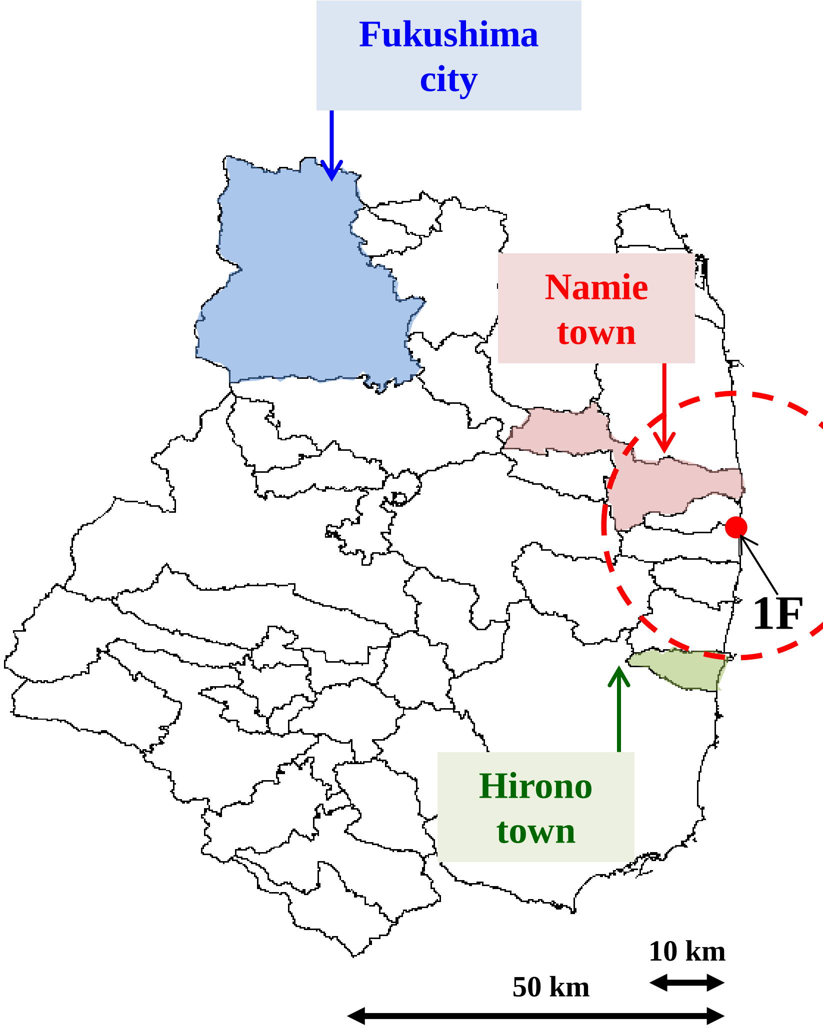


- Doses to **representative persons** were assessed from external exposures due to **groundshine** and internal exposures through **inhalation of resuspended radioactive particles**.
- A **probabilistic approach** was adopted based on surface activity density of cesium-137, and habit data gained from actual surveys in Fukushima Prefecture.
- Air concentration of radioactive particles were calculated using **resuspension factor** which was gained from the air concentration trend in Fukushima city.

Surface concentration of ^{137}Cs measured in Fukushima city, Namie town and Hirono town

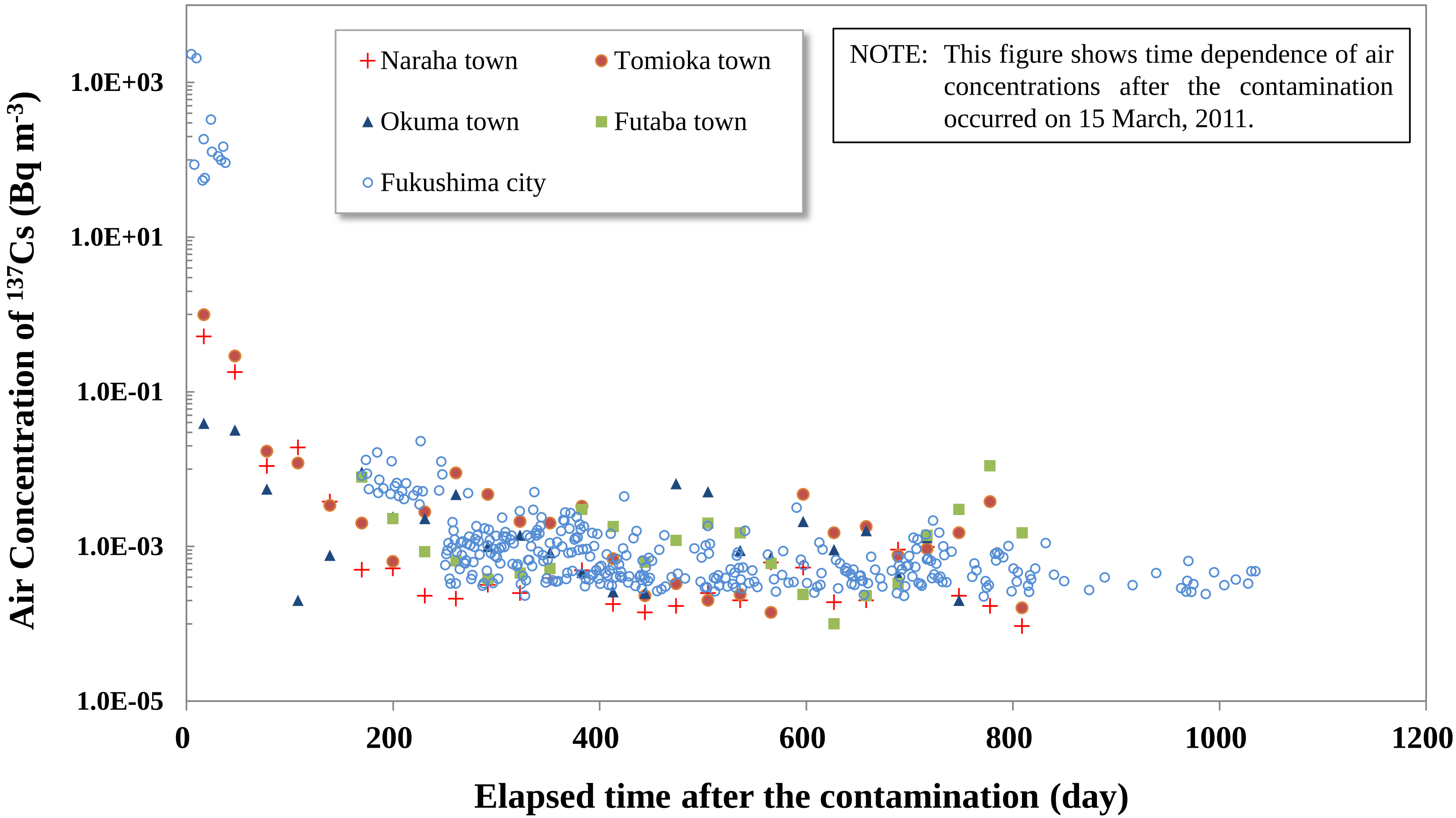
Municipality	The surface concentration of ^{137}Cs for each municipality		
	Sample Size	GM (MBq m^{-2})	GSD
Fukushima City Located in north-west area, and the distance from 1F is about 60 km. The people of this city were not evacuated, and continued to stay after the accident.	**94**	**0.13**	**2.13**
Namie Town The distance from 1F is about ~30 km. Most of the inhabitants of this town are being evacuated as of now. The evacuation directive has not been lifted yet.	**38**	**0.95**	**4.02**
Hirono Town Inhabitants of this town were evacuated after the accident. However, the directive have already been lifted and the inhabitants are returning to their home.	**14**	**0.07**	**1.77**

NOTE: The surface densities were measured by Japanese authority. The data are decay corrected to 15 March, 2011.
GM: Geometric Mean, GSD: Geometric Standard Deviation.



Air Concentration of ^{137}Cs measured in Fukushima prefecture

■ **Time dependence of air concentration of ^{137}Cs.**

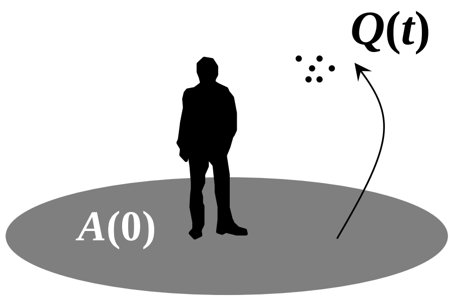


Web site of Nuclear Regulatory Authority of Japan: http://radioactivity.nsr.go.jp/en/list/200/list-1.html

Resuspension Factor Approach

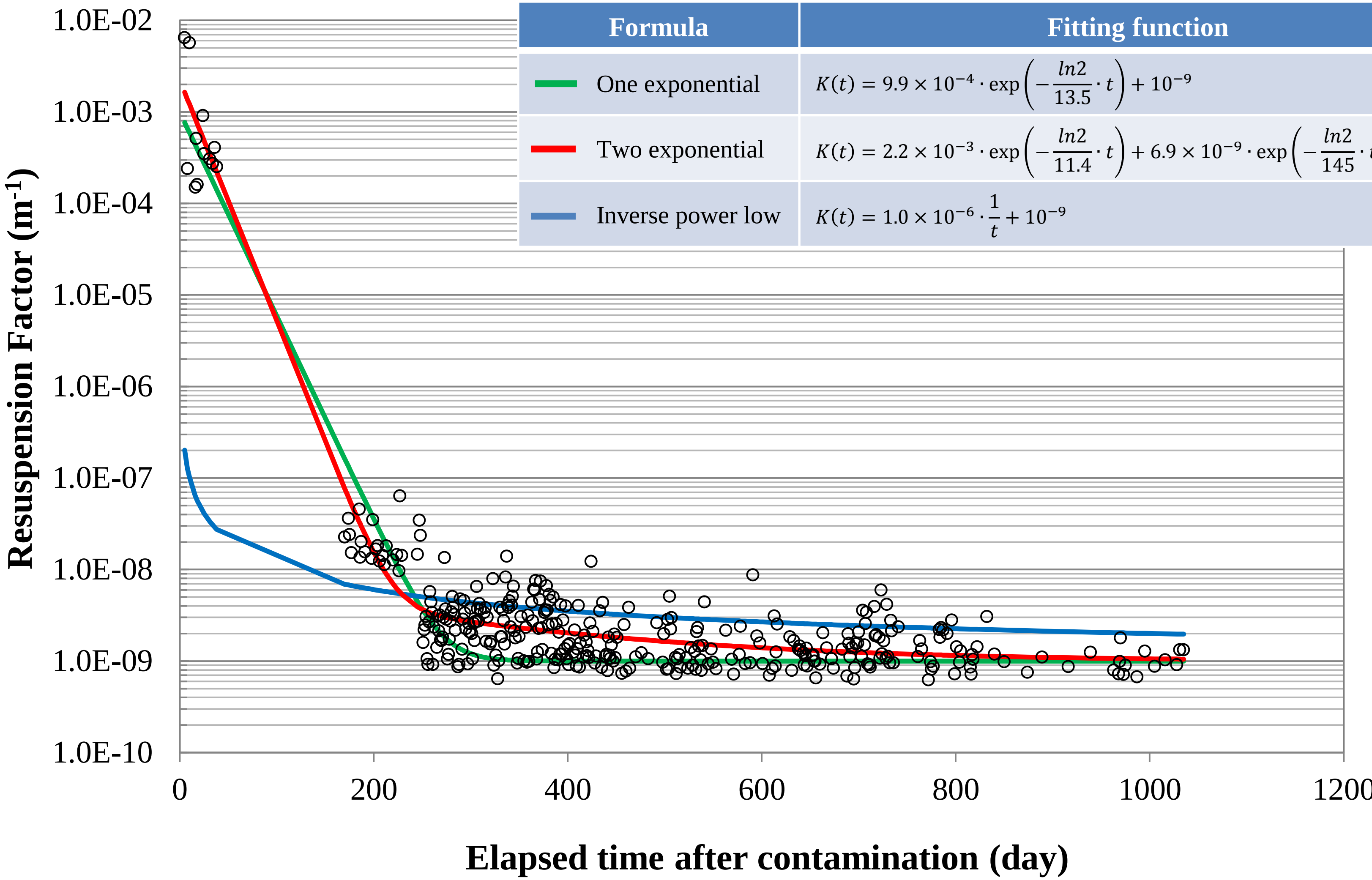
- Resuspension Factor, ***K***, is defined as:

$$\boldsymbol{K(t)} = \frac{\text{Air concentration due to resuspension, } Q(t), (\text{Bq m}^{-3})}{\text{Surface concentration, } A(0), (\text{Bq m}^{-2})}$$



Model	Examples of previous study
<u>One exponential model</u> $\boldsymbol{K(t)} = K_0 \exp(-\frac{\ln 2}{T_1}\boldsymbol{t}) + K_2$	➢ **WASH-1400 1975** $K_0=10^{-5}$ m^{-1}, T_1=374 day, $K_2=10^{-9}$ m^{-1} ➢ **Anspaugh 1975*** $K_0=10^{-4}$ m^{-1}, T_1=5 day, $K_2=10^{-9}$ m^{-1} ➢ **Linsley 1978** $K_0=10^{-6}$ m^{-1}, T_1=70 day, $K_2=10^{-9}$ m^{-1} ➢ **RODOS 1995** $K_0=5.0\times10^{-8}$ m^{-1}, T_1=231 day, $K_2=10^{-9}$ m^{-1}
<u>Multi exponential model</u> $\boldsymbol{K(t)} = K_0 \exp(-\frac{\ln 2}{T_1}\boldsymbol{t}) + K_1 \exp(-\frac{\ln 2}{T_1}\boldsymbol{t}) + K_2$	➢ **Lassey 1980** $K_0=9.0\times10^{-5}$ m^{-1}, T_1=44 day, $K_1=10^{-5}$ m^{-1}, T_2=374 day, $K_2=10^{-9}$ m^{-1} ➢ **KFKI 1995** $K_0=1.04\times10^{-7}$ m^{-1}, T_1=95 day, $K_1=6.50\times10^{-9}$ m^{-1}, T_2=1500 day, K_2=0
<u>Inverse power law model</u> $\boldsymbol{K(t)} = K_0 \frac{1}{\boldsymbol{t}} + K_2$	➢ **Garland 1982** $K_0=1.2\times10^{-6}$ m^{-1}, K_2=0 ➢ **NRPB 2002** $K_0=1.2\times10^{-6}$ m^{-1}, $K_2=10^{-9}$ m^{-1}

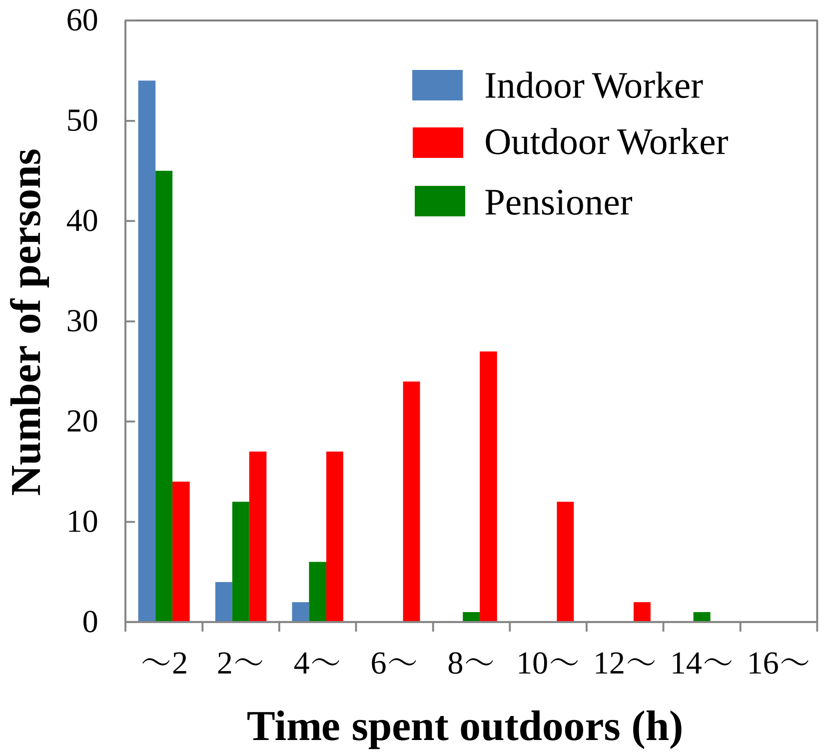
Resuspension Factor in Fukushima City



Formula	Fitting function
One exponential	$K(t) = 9.9 \times 10^{-4} \cdot \exp\left(-\frac{ln2}{13.5} \cdot t\right) + 10^{-9}$
Two exponential	$K(t) = 2.2 \times 10^{-3} \cdot \exp\left(-\frac{ln2}{11.4} \cdot t\right) + 6.9 \times 10^{-9} \cdot \exp\left(-\frac{ln2}{145} \cdot t\right) + 10^{-9}$
Inverse power low	$K(t) = 1.0 \times 10^{-6} \cdot \frac{1}{t} + 10^{-9}$

Survey on Behavioral Patterns in Fukushima prefecture

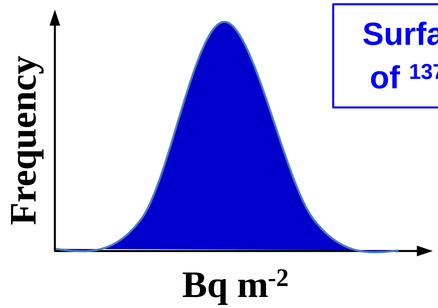
- Surveys on time spent inside and outside houses, at the workplaces and in other places were performed.
- The surveys were conducted with the cooperation of indoor workers, outdoor workers, and pensioners living in Fukushima prefecture.



Population group	Distribution form	Statistics
Indoor worker	Lognormal	GM 1.9 GSD 2.4
Outdoor worker	Normal	AM 7.0 SD 3.2
Pensioner	Lognormal	GM 0.8 GSD 2.8

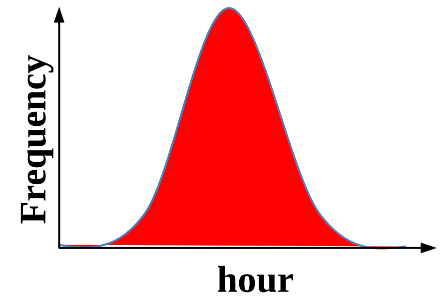
NOTE: The figure shows the results of surveys at Feb. 2012. Statistics shown in table are derived based on the results of surveys performed during the period between Feb. 2012 ~ Jan. 2013.

Dose assessment using Probabilistic Approach



Surface density of ^{137}Cs, A_{Cs137}

Time spent outdoors, t_{out}



Sampling of Model input based on the distributions

Dose Assessment Model

$$E_{total} = E_{\mathrm{ground}}(A_{Cs137}, t_{out}, C_{\mathrm{i}}, s, L, f) + E_{\mathrm{resuspnesion}}(A_{Cs137}, t_{out}, C_{\mathrm{i}}, K, F)$$

C_{i} :Ratio of surface density of radionuclide *i* to that of ^{137}Cs

s :Shielding factor

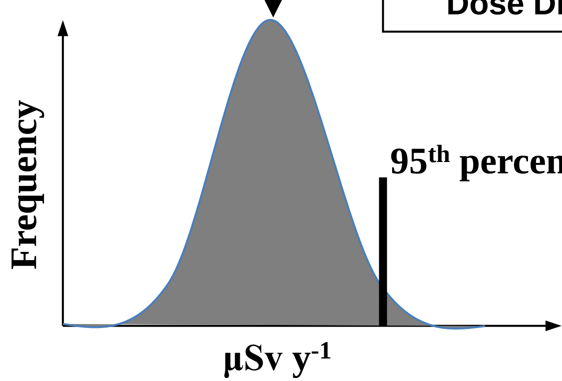
L :Location factor

K :Resuspension factor

f :Attenuation factor

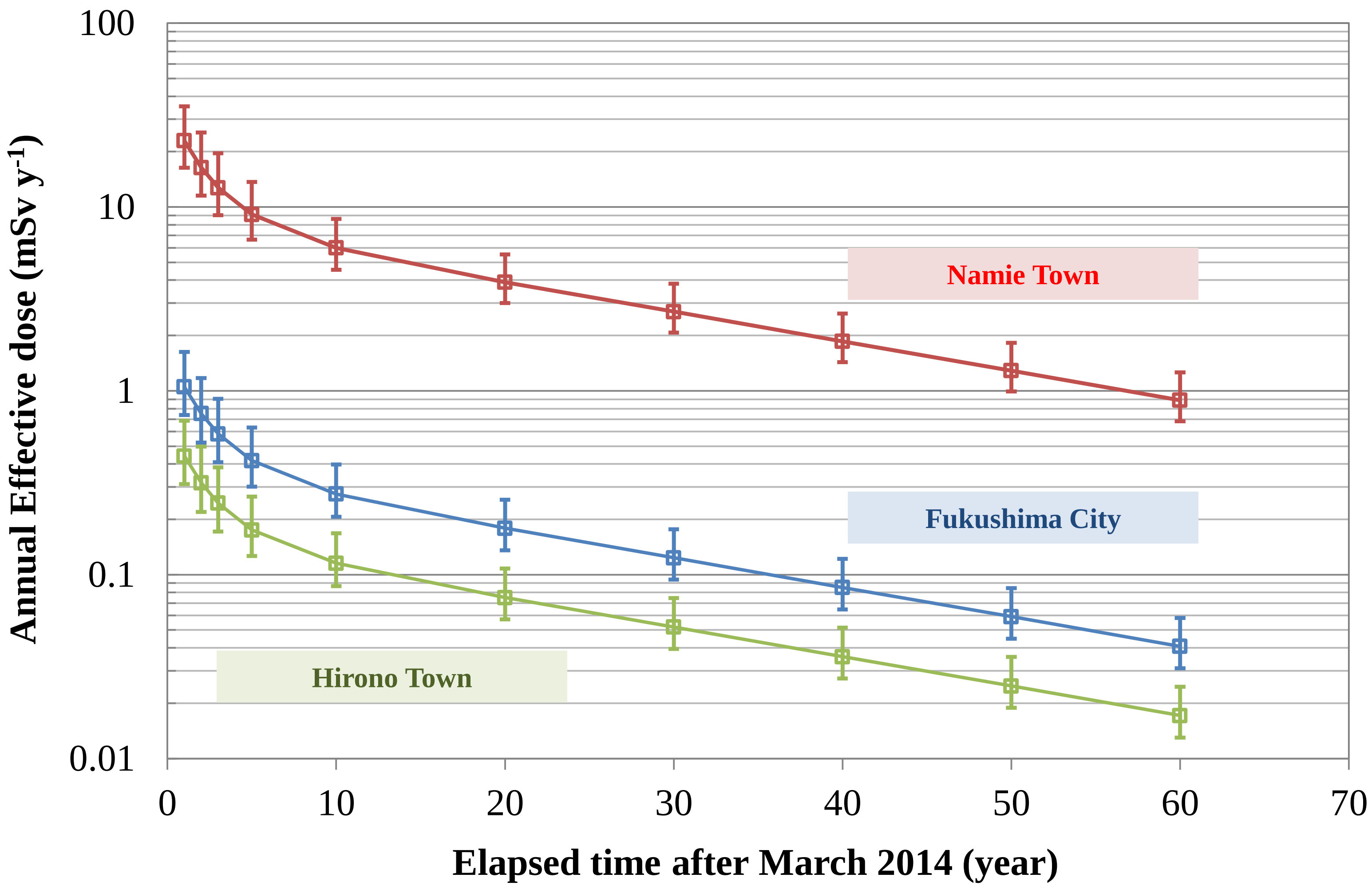
F :Filtering factor

Dose Distribution



95th percentile → **Dose of the representative person**

Results of Prospective Dose Assessment for Representative Person



Conclusions

- **Dose to the representative persons were assessed using probabilistic approach based on monitoring data and actual surveys in Fukushima prefecture.**

- **Probabilistic approach is a useful method to clarify the extent of doses to the population and to assess doses to the representative person of those groups.**
- **It was found that time dependence of resuspension factor, which were derived from time trend of air concentrations measured in Fukushima city, are fitted by the double exponential formula.**
- **The contributions of doses from inhalation of resuspended radioactive particles to the annual effective doses are almost four or five orders of magnitude less than those from groundshine.**
- **In some areas, the doses received by the people to be returned are less than those received in the continuously living areas. However, many people has not returned to their homes yet. Measurements and assessments of doses to the people after returning to their homes are important to ensure the safety of the people.**
- **Results of this study do not take into account the contribution of doses from ingestion pathway. In order to assess precisely the consequences from radiation exposures in the population living in areas contaminated by the 1F, further considerations are needed.**

Contributions of each exposure pathway