ICRU Symposium

Revitalization of Fukushima and Radiation Measurement

Evaluation of dose reduction factors for wooden houses in the affected areas based on in situ measurements

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1. Background

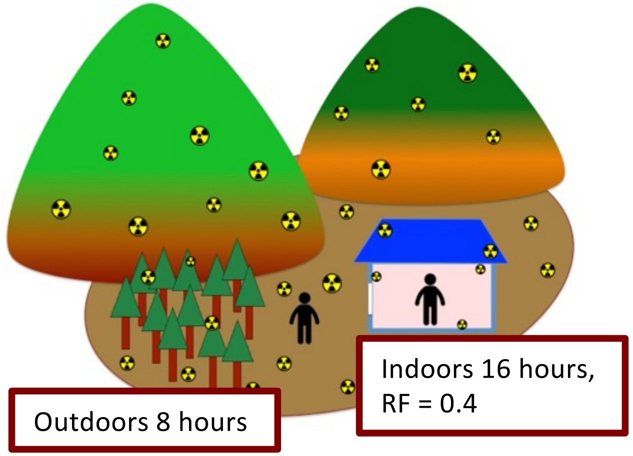
- In order to estimate external exposure of the public and residents, reduction factors are taken into account as most individuals spend a large portion of their time indoors.

additional exposure dose, D_y (mSv/ year);

$D_y = f$ x (Outdoor air dose rate – D_N) x (8h + 16h x RF) x 365 days

f ; Conversion coefficient from ambient dose equivalent to effective dose, f =1

D_N ; air dose rate due to natural radiation from the earth



- Measurement data of reduction factors for Japanese houses were lacking.

- Japanese government used reduction factors given in the International Atomic Energy Agency, IAEA documents from American and European settlements.

The method to estimate external dose of the public and residents

(1) By wearing a personal dosemeter

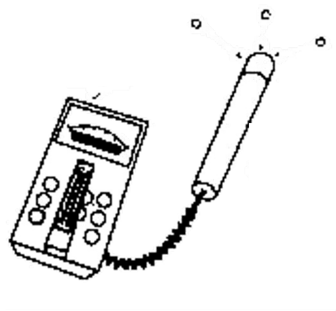
(GlassBadge, OSL dosemeter, D-Shuttle, etc.)

○ small, light, compact, enables to evaluate individual dose
helpful for returners and residents to temporarily access to the area

△ impossible to estimate external dose beforehand, uncertainties derived from usages, individual dose can not be generalized

(2) By using air dose rates

$$\dot{H} = \sum_i \dot{H}_i T_i \, , \, (i = \mathrm{L, B, D, A}, \ldots),$$ ➡ Effective dose, *E*



$\dot{H}_i$: air dose rate in each point (L,B,D,A....), T_i: staying time in each point

○ enables to evaluate external dose beforehand

△ might overestimate in most cases

Both methods should be complementary to each other, depending on situations.

In Method (2) , indoor radiation dose is obtained by $H_{outdoor}$ x reduction factor.

Most individuals spend a large portion of their time indoors. → Proper value for the reduction factor should be used.

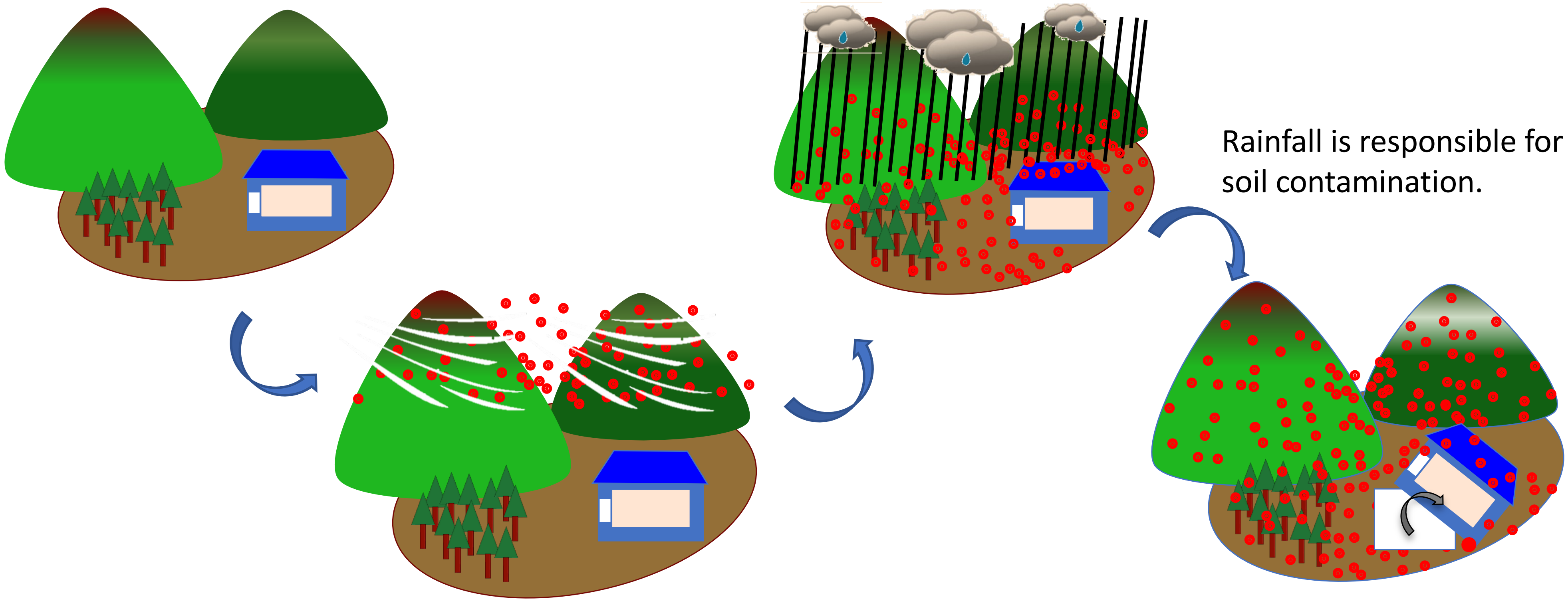
2. Definition of the reduction factor, RF

- Definition; $\dot{D}_{in}/\dot{D}_{out}$
  $\dot{D}_{in}$ is the dose rate inside the structure
  $\dot{D}_{out}$ is the outdoor dose rate (both include natural radiation)

- Shielding factors, protection factors, reduction factors, and location factors; the meaning is essentially the same.
  (some differences in their definition. the location factor, modeled as a function of the time elapsed.)

- For lightweight constructions such as wooden houses, the term (dose) reduction factor is often used.
  The reductions in indoor dose rates are derived from
  <u>the shielding effect by house materials and structures</u> + <u>Uncontaminated effect</u>
  Shielding ability of a wooden house is 0.7 - 0.9. (by Monte Carlo calculation)
  From Furuta and Takahashi, *JAEA Research*, 2014

Uncontaminated effect



Radioactive plume passes over the area, with causing dry deposition.

Rainfall is responsible for soil contamination.

A patch of ground under each house is not contaminated. (Uncontaminated effect)

From Matsuda N et al., *J Environ. Radioact.* 166, 427-435, 2016

Reduction factors (Shielding factors) of buildings for surface deposition

From Generic Procedures for Assessment and Response during a Radiological Emergency (IAEA-TECDOC-1162)

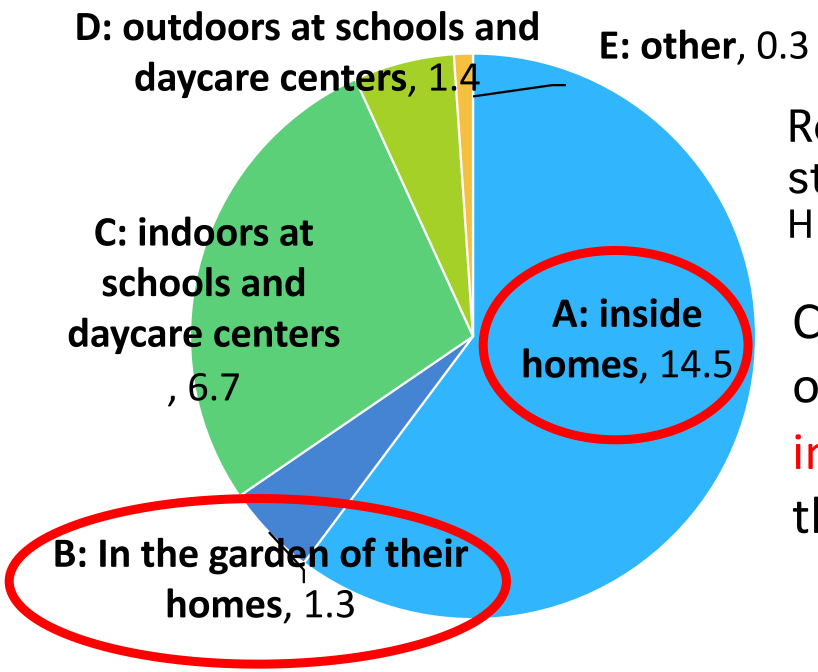
Structure or location	Representative SF*	Representative range
One and two story wood-frame house (no basement)	0.4	0.2−0.5
One and two story block and brick house (no basement)	0.2	0.04−0.4
House basement, one or two walls fully exposed		
- one-story, less than 1 m of basement wall exposed	0.1	0.03−0.15
- two story, less than 1 m of basement wall exposed	0.05	0.03−0.07
Three or four story structures (500 to 1,000 m^2 per floor)		
- first and second floor	0.05	0.01−0.08
- basement	0.01	0.001−0.07
Multi-story structures (> 1,000 m^2 per floor)		
- upper floors	0.01	0.001−0.02
- basement	0.005	0.001−0.15
1 m above an infinite smooth surface	1.0	-

* Away from doors and windows

- Note: the uncontaminated effect mainly contributes to the reduction factor for wooden house, 0.4.

Reduction factors for wooden houses

78.7% of constructions and 97.3% of detached houses in Fukushima prefecture are wooden (Statistics Bureau, Ministry of Internal Affairs and Communications, 2008)

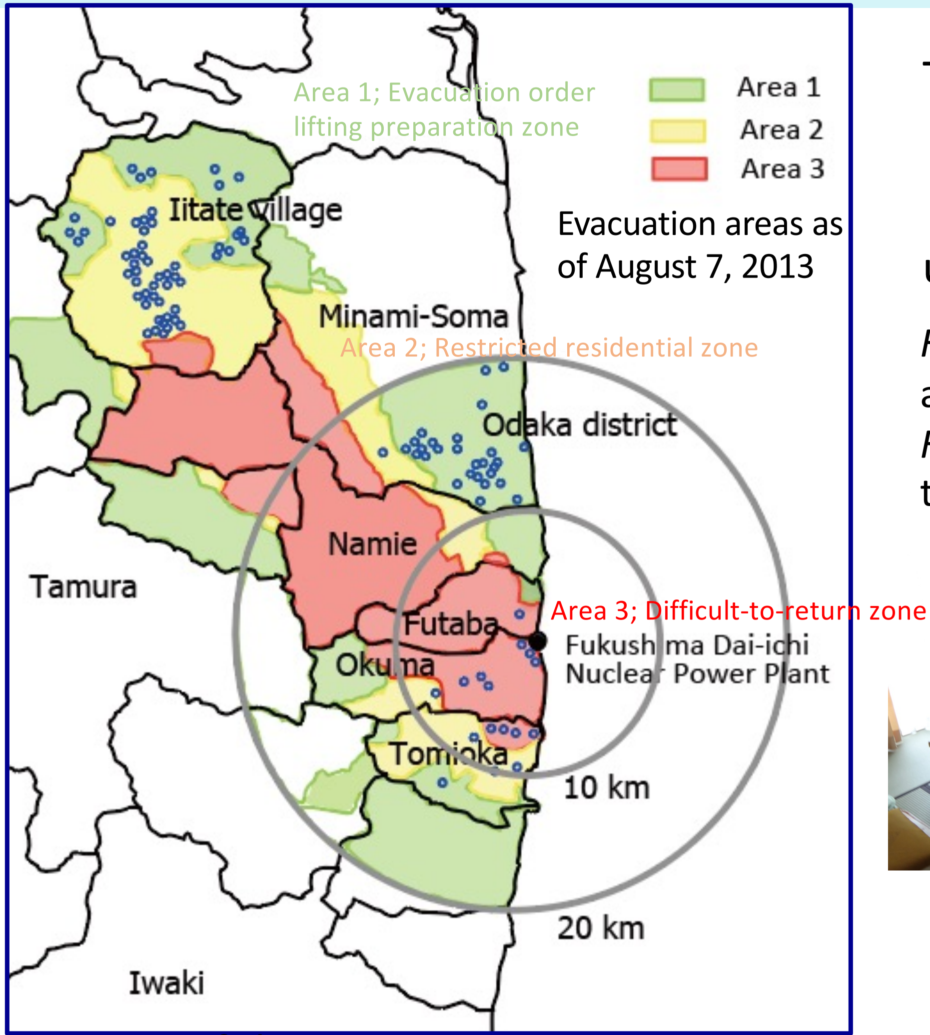


Results from a survey report (2011-2013) on indoor and outdoor staying time for 1,500 children in Southern Miyagi Prefecture area
H Yoshida *et al.* Radioisotopes 2015 and 2017

Children spend about 70% of the day (16 hours) inside and outside their homes, of which about 14-15 hours are spent indoors. → The key point is to evaluate radiation doses at their residences.

For proper evaluation of exposure doses of residents, particular attention was paid to the Reduction factors for wooden houses.

In situ measurements of the indoor and outdoor dose



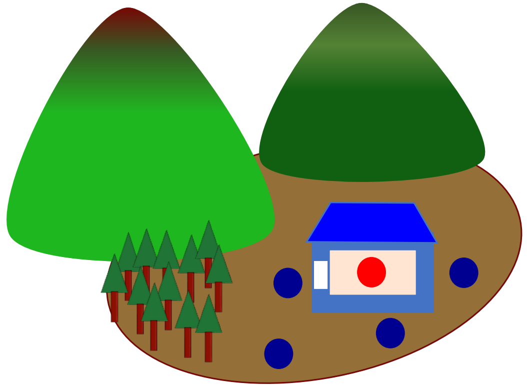
Locations of the measurements 69 detached wooden houses

The Reduction factor, *Rf*:

$$Rf = H^*(10)_{in} / H^*(10)_{out} \quad (1)$$

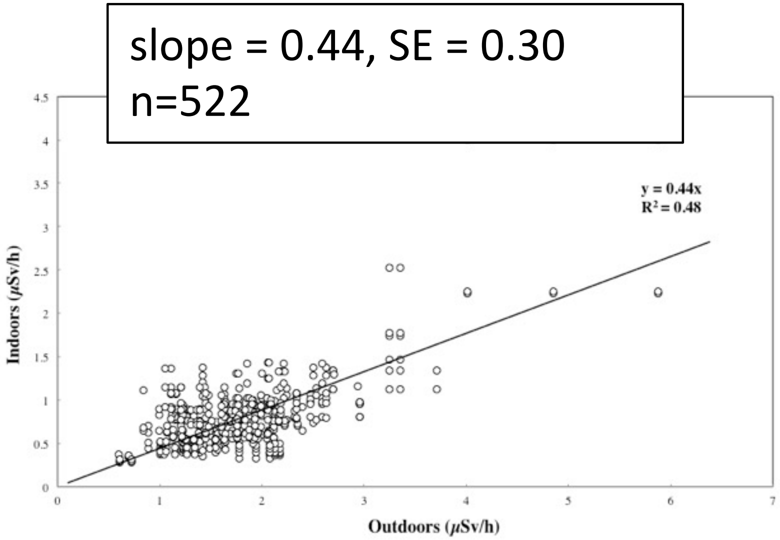
$H^*(10)$: Ambient dose equivalents using the NaI (Tl) scintillation survey meter

$H^*(10)_{in}$; at the center of the room away from doors and windows at a height of 1 m above the floor. Collected from two to four rooms.
$H^*(10)_{out}$; at a height of 1 m above the ground. Collected from one to four locations in an open field in an uncovered yard.

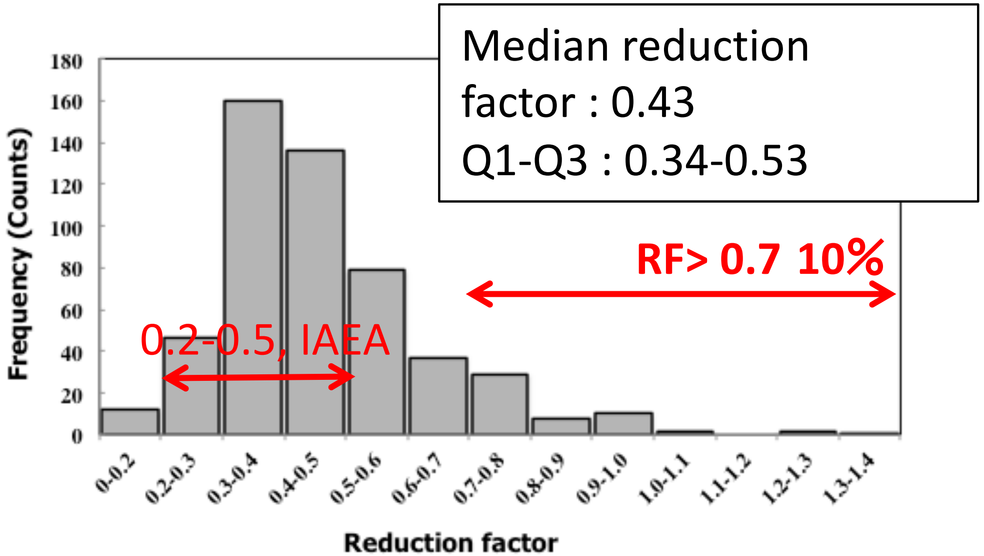


3. Reduction Factors for Japanese wooden houses in the early phase

From Yoshida-Ohuchi H et al., *Sci. Rep.* 4 (7541), 1-6,2014



Relationship between the indoor and outdoor ambient dose equivalents



Frequency distribution of the reduction factor for 522 results

- ✓ No statistically significant difference in the median reduction factor to the representative value of 0.4 in the IAEA-TECDOC-document. All RF obtained by measurements are summarized in the next Table.
  - ✓ In the range of 0.2 to 0.5, IAEA, only 66.5% of all of the data were covered.
  - ✓ 10.0% of the data were within the range of 0.7 to 1.4 of the higher RF.

Two factors led higher RF values.

Reduction Factors for Japanese wooden houses in the early phase

From H Yoshida et al J. Environ. Radioact. (2018)

Structure type	Location	Number of houses or buildings	Reduction factor	Measurement date	Ref.
Wooden house	Kawamata town	2	0.4	May 2011	Kamada et al. (2012)
	Iitate village	4			
Concrete building	-	-	0.1		
Wooden building	Kawamata town	1	0.48*	Jan 2012	Yajima et al. (2012)
Steel construction building		1	0.23 - 0.34*		
Concrete building		1	0.10 - 0.16*		
Wooden construction	Fukushima city, Motomiya town, Koriyama city, Iwaki city, Kawamata town, Minami-Soma city, Iitate village, Kawauchi village, Marumori town	1	0.55 ± 0.04**	March 2011- July 2011	Monzen et al. (2014)
Aluminum building construction		4	0.15 ± 0.02**		
Reinforced concrete construction		13	0.19 ± 0.04**		
Detached wooden house	Iitate village	59	0.43 (0.34-0.53)***	December 2012 - December 2013	Yoshida-Ohuchi et al. (2014)
	Odaka district in Minami-Soma city	10			
Light construction materials					
Wooden house	Iwaki City, Koriyama city, Shirakawa city, Tamura city, Kawauchi village and Hirono town etc.	158	0.38 (the first floor), 0.49 (the 2nd)	June 2011 -	Matsuda et al. (2016)
Lightweight steel house		5			
Steel-framed concrete		30	No correlation in/around houses		

* At the center of the room

**mean ± S.E.

***median (Q1-Q3). The measurements were obtained at thecenter of the room away from doors and windows at a height of 1 m above the floor.

****Dosimeters were installed at a height of 50 cm from the floor and at a position close to a wall.

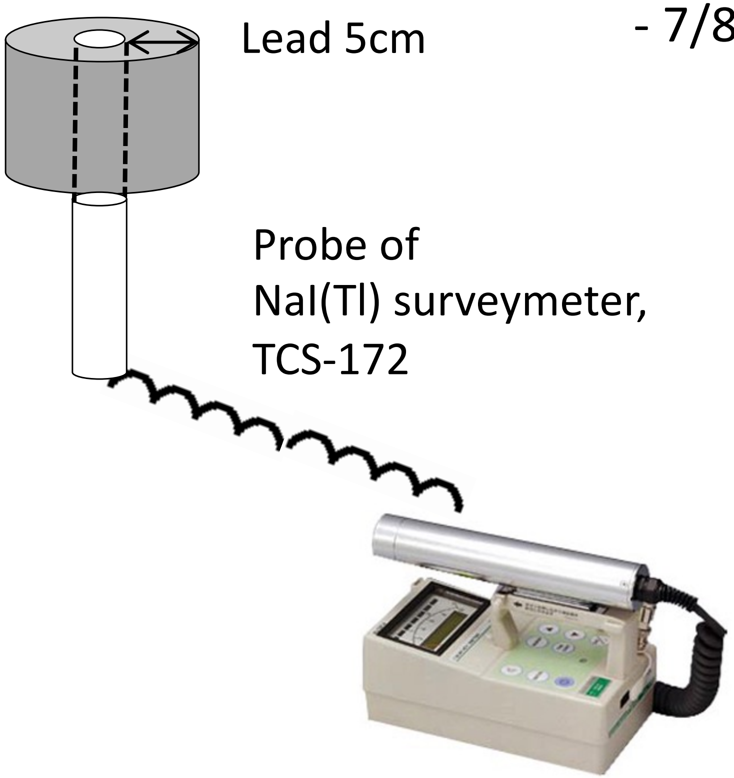
Roofs contaminated with fall-out deposition increases indoor gamma radiation level ➡ raise Reduction Factors

The radiation from the upper direction was high in the rooms with cement roof tiles.

- 44/81 (54.3%) : tiled roofs
- 30/81 (37.0%) : galvanized-iron roofs
- 7/81 (8.6%) : cement tile roofs

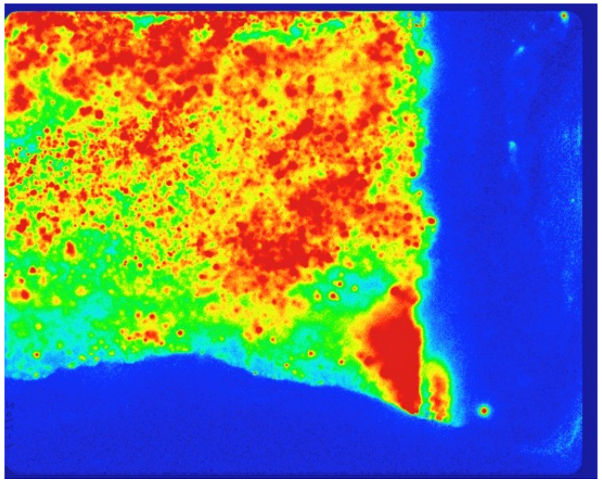
  4/7 :Four of seven cement tile roofs

  RF ranges 0.7 to 1.0 to all the rooms below.

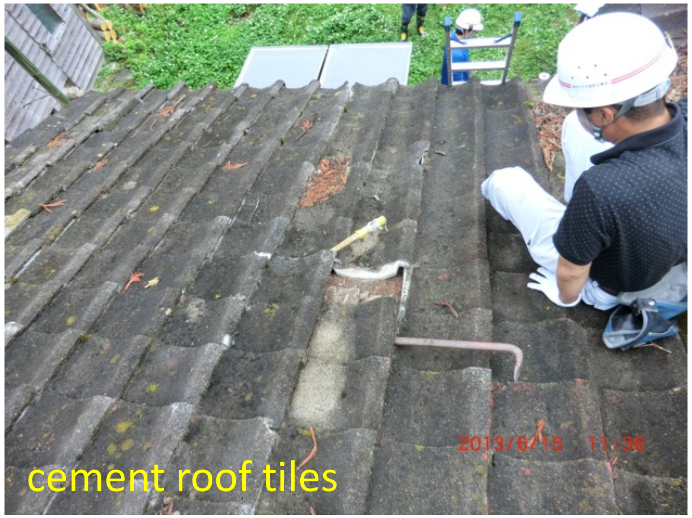


Estimation of an effect of contaminated roofs on indoor air dose

- Cement roof tiles were collected from the roof of a house.
- The highest concentrations of ^{134}Cs and ^{137}Cs ; 3,162 ± 23 and 6,756 ± 30 Bq/kg, respectively.
  (using a high-purity germanium (HPGe) detector)
- Assuming that the roof is a surface source containing the highest concentrations of ^{134}Cs and ^{137}Cs observed, the dose rate at a height of 1 m above the floor in the room was calculated using a Monte Carlo method.
- Approximately 30% of the indoor dose rate came from the roof.

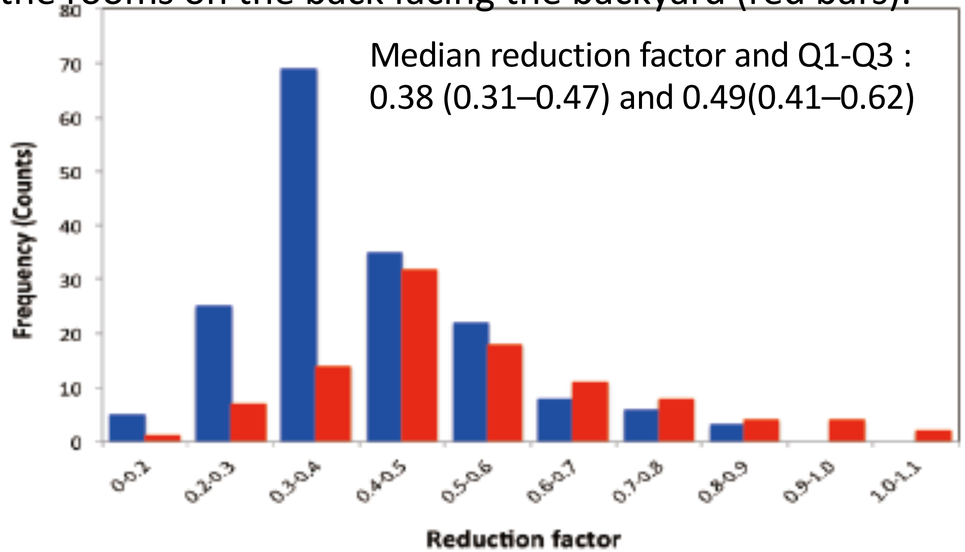


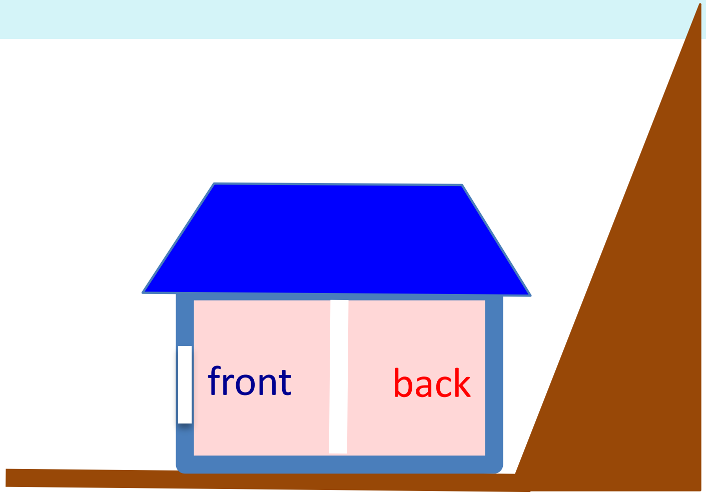
Autoradiography of a cement tile roof



Location of the room in the house and area topography affect RF.

the rooms (located on the front side of the house) (blue bars) and the rooms on the back facing the backyard (red bars).





Some rooms facing a steep upward slope of a hill or a mountain.

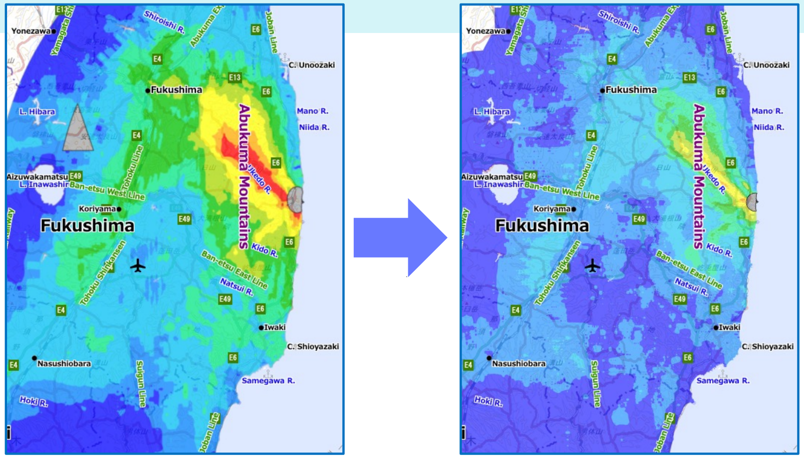
The contaminated top layer of soil has slid down the slope.

Change of reduction factors over the years after the accident

- Air dose values has been dropping rapidly in the affected areas.

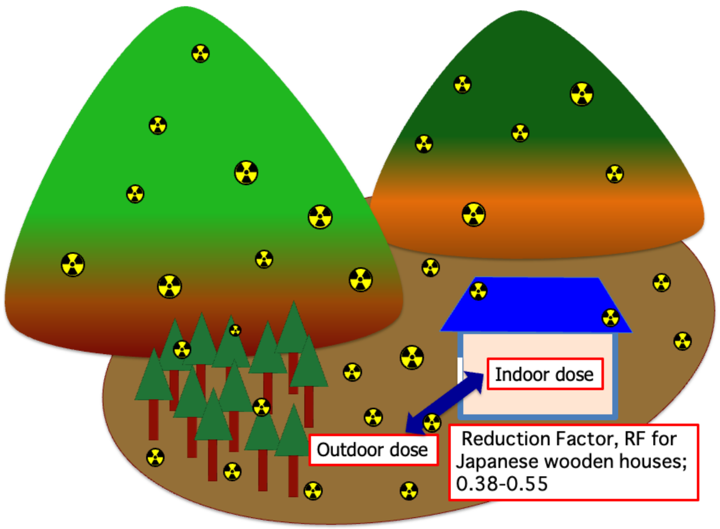
- How have the air dose rates inside and outside of dwellings and the reduction factors changed six to seven years after decontamination?
Effects of decontamination, physical decay, environmental decay.

- How long can we use the RF value of 0.4 ?

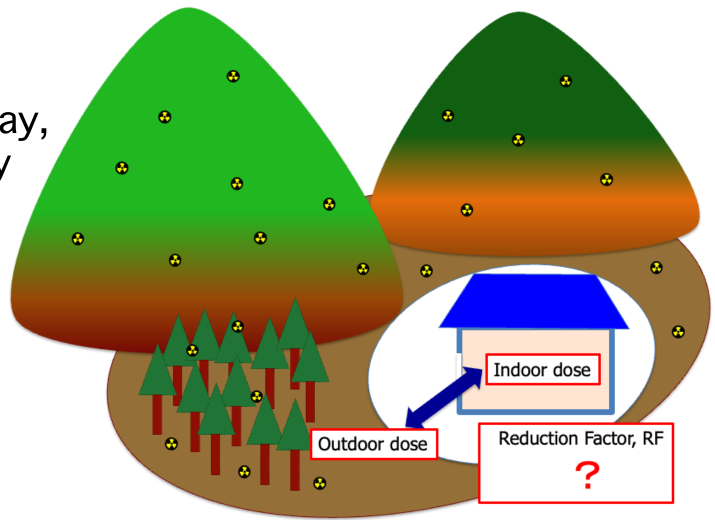


As of 26 May, 2011   As of 29 Oct, 2020

Cited from the NRA website

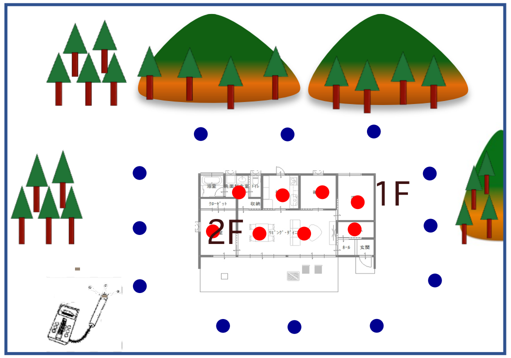


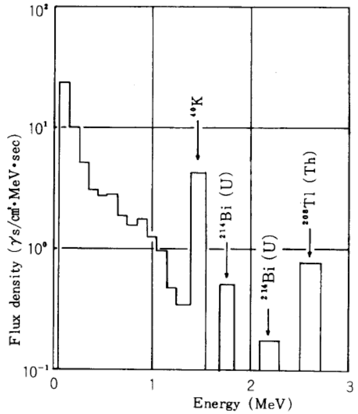
～After 7 to 8 years
Decontamination, physical decay, effects of environmental decay



Remeasurements of the indoor and outdoor dose

In situ measurements were conducted again (2019, 2020) for wooden houses measured before decontamination (2012-2015). Approximately 150 houses in Iitate-village, Odaka-ku, Minamisoma, Namie town, Tomioka town, Okuma town, and Futaba town were measured.





The Reduction factor, Rf:

$$Rf = H^*(10)_{in} / H^*(10)_{out} \quad (1)$$

using NaI (Tl) scintillation survey meter

$H^*(10)_{in}$; Collected from all rooms.
$H^*(10)_{out}$; 5 to 6 m from the exterior wall of the house building.

Gamma Ray Spectrum Data Analysis

using the 3”φ x 3” NaI (Tl) scintillation spectrometer

- The gamma ray energy spectra were measured indoors and outdoors.
- Pulse height distribution was unfolded with the 22 x 22, 49x49 response matrix method ,Energy range 50keV- 3.2 MeV
- Dose rates for K, U, and Th due to environmental radiation sources were estimated and subtracted from total flux densities.

Dose rates due to natural radiation sources in the environment

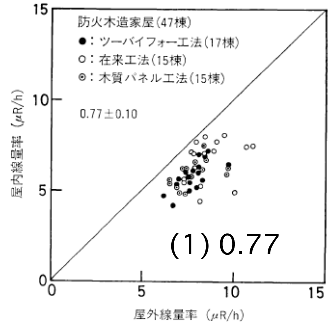
Outdoor and indoor dose rates due to natural radiation sources
(Iitate Village and Odaka-ku, Minamisoma City)

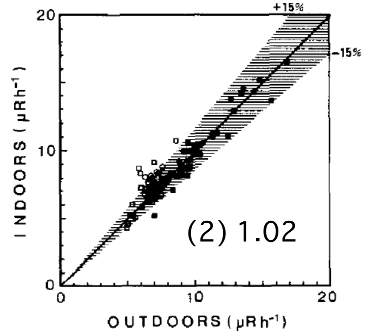
No significant change before and after decontamination and in 2019,2020 for both outdoor and indoor.

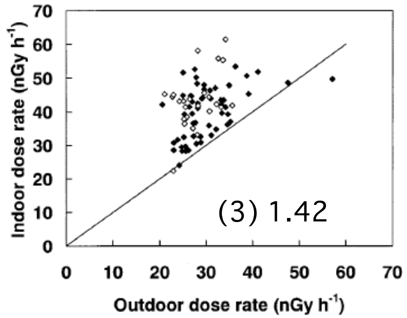
- ■ Values in 69 houses measured before decontamination
- ▲ Values from 33 houses measured immediately after decontamination
- ◆ Values for 67 houses measured in 2019-20221

indoor/outdoor ratios from natural radiation sources are 0.86,0.87,0.85, respectively,
almost the same values

Indoor/outdoor dose ratio in Japanese wooden houses in the previous studies

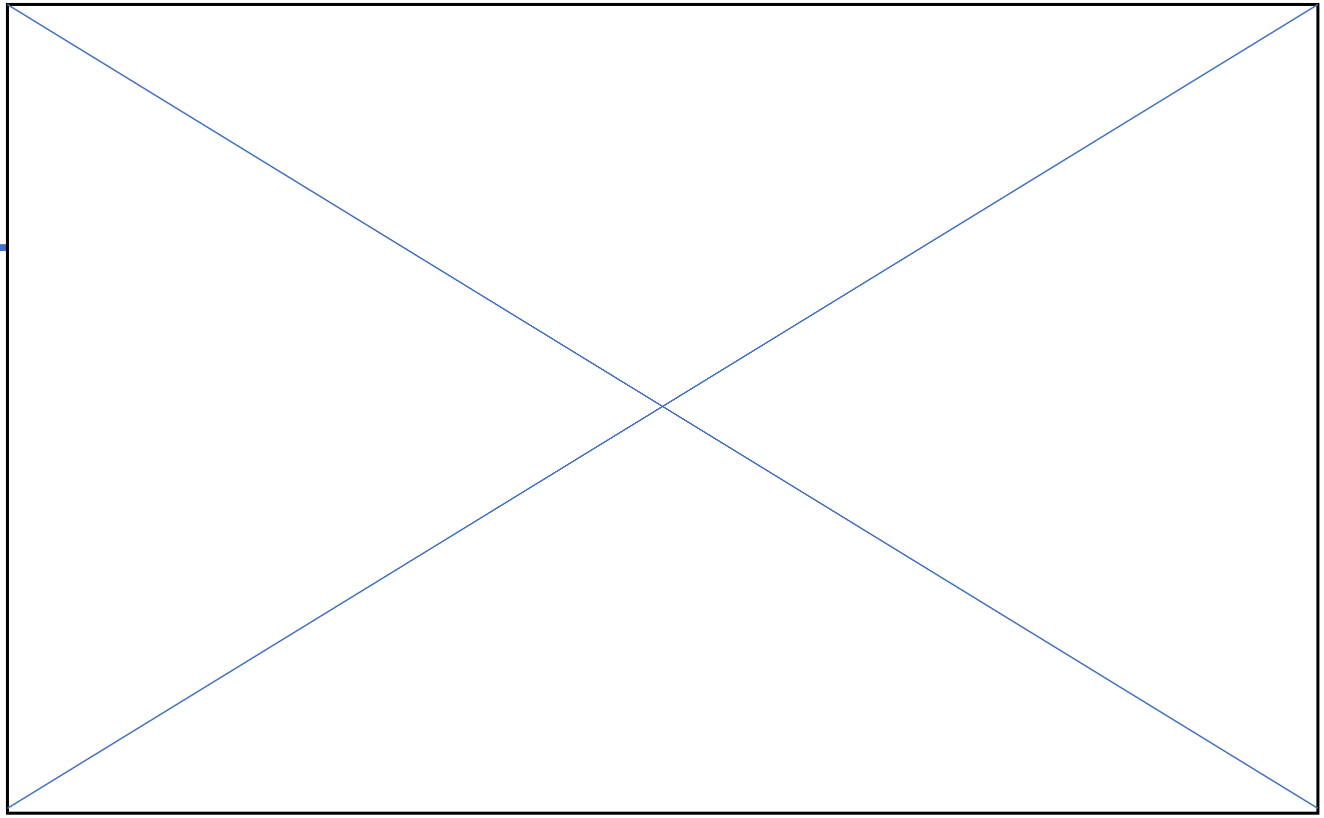






1) Matsuda, H., et al. Jpn. J. Health Phys. (1990).
2) Abe, S., et al. Rad.Protec.Dosim.(1984).
3)Iyogi, T. et al. Health. Phys. (2002).

Relationship between RF and outdoor air dose rate

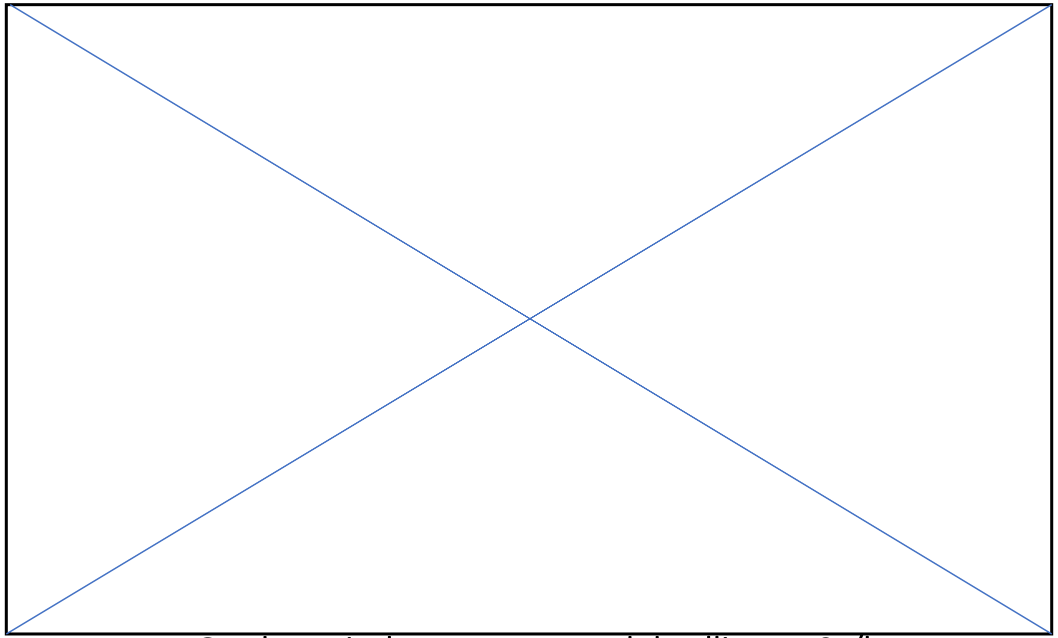


indoor/outdoor ratios from natural radiation sources：0.85～0.87

- at around 0.5 μSv/h and above, 0.4 is reasonable to use as a representative value of RF.
- Reduction factors increase as outdoor air dose rates decrease.
- lower than around 0.5 μSv/h, RF increases rapidly and approaches 0.85-0.87. inappropriate to use 0.4

Relationship between RF and outdoor air dose rate lower than around 0.5 µSv/h

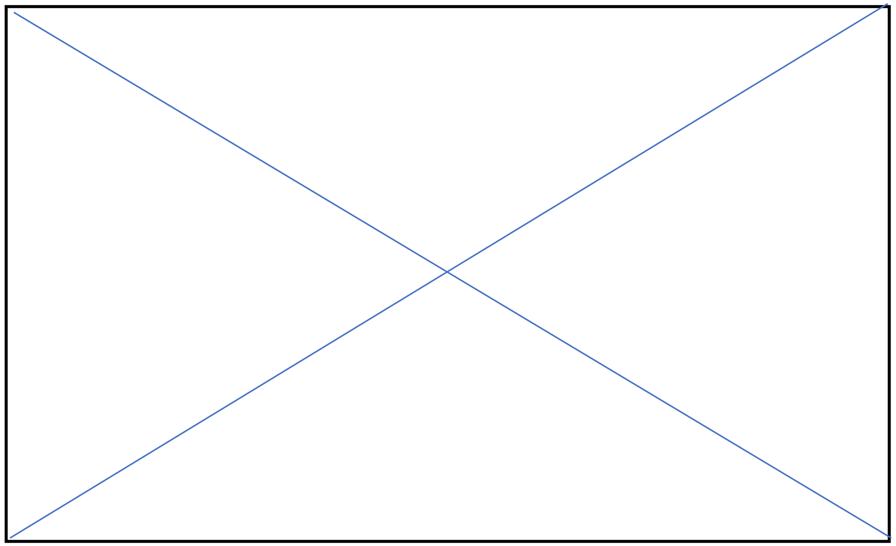
- Time passed after decontamination. As the outdoor air dose rate decreases, what value of RF is appropriate to use?



Outdoor air dose rate, around dwellings, µSv/h

Relationship between RF and outdoor air dose rate lower than around 0.5 µSv/h

RF of wooden houses per outdoor air dose rate



Convey results of a survey to residents ; Engagement with the residents

- Residents spend the most time inside their homes. Radiation level there has been one of their high concerns.
  - very little information on indoor measurements after a nuclear accident in the past studies.
  - less information on the actual measured data that has been continuously measured over the years.

- For each indoor measurement, residents returned to their homes in the exclusion areas. We explained the results of the measurements to the residents each time. The residents will not be convinced if they are simply told general information. The actual values measured in the survey became a useful “tool” for dialogue. Through repeated surveys, we have deepened our engagement with the residents.

- Engagement with the residents allowed us to provide advice on their concerns about returning to their homes. During the recovery period, the situation will continue to be more difficult and complex than ever before, and "science” alone cannot solve it.

- Engagement with the residents will be a key to help them better understand radiation and its risks.

Summary

- It was confirmed that using RF of 0.4 is appropriate as the representative value for Japanese wooden houses in the early stage after the nuclear power plant accident.

- We conducted a survey focusing on residential houses that had been surveyed in the past study, re-evaluated reduction factors for wooden houses, and found that 0.4 is appropriate when the air dose rate around the residential houses exceeds 0.5 μSv/h, but when the value is below 0.5 μSv/h, 0.4 is not appropriate. We determined representative RF values and representative RF ranges for each air dose rate around the residential houses when the air dose rate around houses is below 0.5 μSv/h.

- The results of this study will contribute to the residents and local governments who are considering returning to their homes.

This work was partly supported by Research project on the Health Effects of Radiation organized by Ministry of the Environment, Japan.

Thank you for your kind attention!

A photo of Shiki-zakura (four seasons cherry blossoms) was taken by H Yoshida in Okuma town in Jan 2023.