External doses to the public from contaminated land

Japan Atomic Energy Agency

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- Motivation of this study
- Simulation methods
- Results and discussion
- Summary
- Activities of ICRP TG90

"Age-dependent dose conversion coefficients for external exposure to radioactive cesium in soil",
D. Satoh, T. Furuta, F. Takahashi, A. Endo, C. Lee and W.E. Bolch, Journal of Nuclear Science and Technology, Vol. 53, No. 1, 69-81, 2016.

"Simulation study of personal dose equivalent for external exposure to radioactive cesium distributed in soil",
D. Satoh, T. Furuta, F. Takahashi, C. Lee and W.E. Bolch, Journal of Nuclear Science and Technology, Vol. 54, No. 9, 1018-1027, 2017.

Dosimetric quantities used for the external-dose assessment after the Fukushima I NPP accident

Air kerma, *K*, (Gy)
Absorbed dose, *D*, (Gy)
in a monitoring instrument

This study aims …
- Construction of a database of conversion coefficients
- Investigation of the relationships of the quantities

Protection quantities
Operational quantities
Physical quantities

Related with calibration

Compared

Personal dose equivalent,
*H*p(10), (Sv)
- Individual monitoring
- Personal dosimeter

Compared

Ambient dose equivalent,
*H**(10), (Sv)
- Area monitoring
- Survey meter

Compared

Effective dose,
E, (Sv)
- Giving dose limit
- Unmeasurable

Conversion coefficients

Conversion coefficients

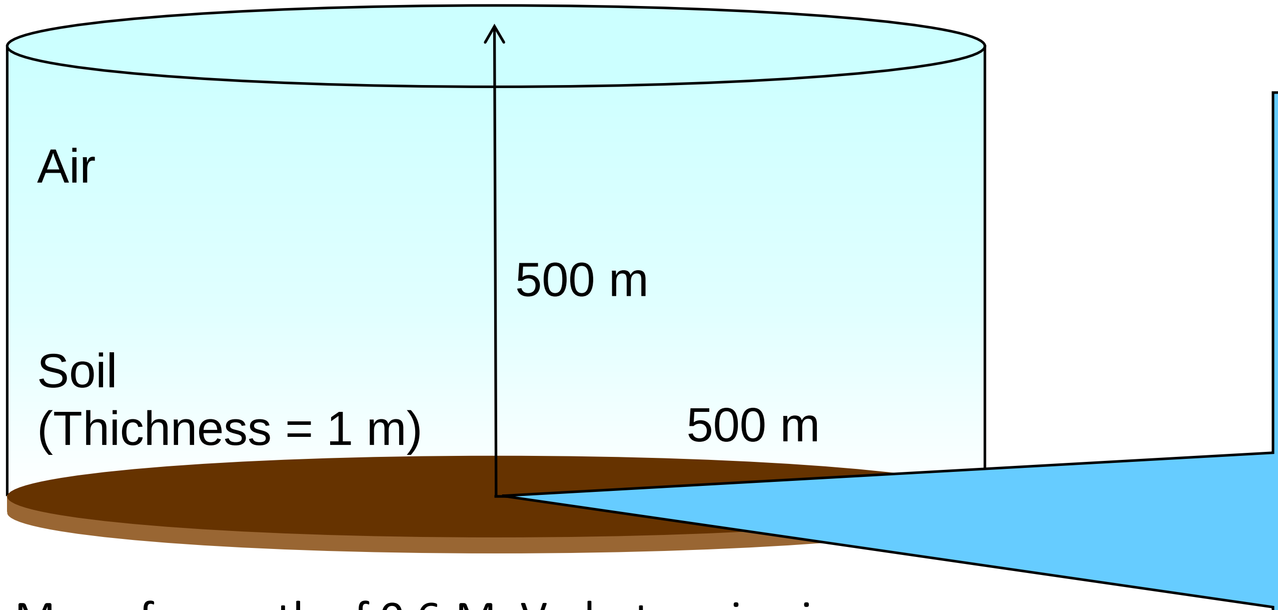
Conversion coefficients

Activity concentration, *A*, (Bq/cm^2)

*Fuji Electric, http://www.fujielectric.co.jp/products/radiation/servy/other.html
†Fukushima City government office, http://www.city.fukushima.fukushima.jp/hkenkou-kanri/bosai/bosaikiki/shinsai/hoshano/hosha/hkenkou-kanri16.html

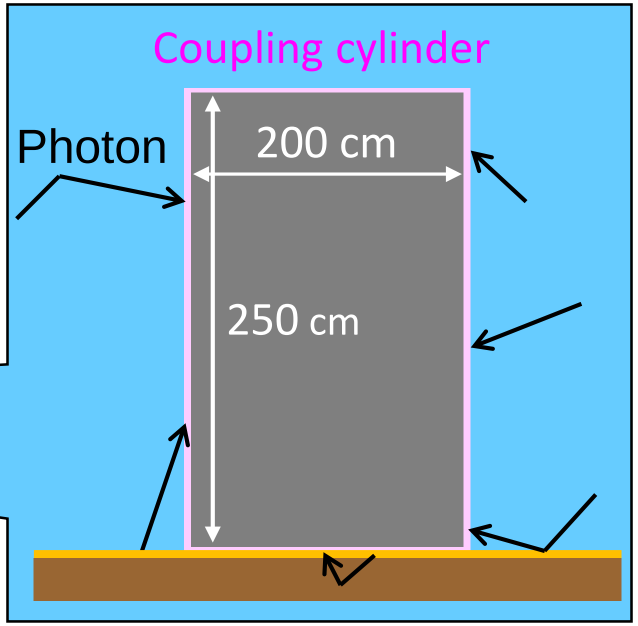
Radiation transport simulation in the contaminated environment

- Radio nuclide : ^{134}Cs and ^{137}Cs
- Distribution form : Uniform planar distribution
- Depth in soil : 0.0, 0.5, 2.5, 10.0, 50.0 g/cm^2
- Radiation transport code : PHITS (version 2.66)
- Atomic data library : MCPLIB04 (photon), EL03 (electron)
- Simulation geometry:



Mean free path of 0.6-MeV photons in air is approximately 100 m

Radio nuclide	Half-life (year)	Photon energy (MeV)	Emission rate (1/decay)
^{134}Cs	2.0648	0.563	0.084
		0.569	0.154
		0.605	0.976
		0.796	0.855
		0.802	0.087
		1.365	0.030
^{137}Cs (^{137m}Ba)	30.1671	0.662	0.851



- Spatial coordinate
- Momentum
- Kinetic energy
- Monte Carlo weight

were recorded for photons that reach the surface of the coupling cylinder.

Computation of age-dependent effective doses in the environmental radiation field

Effective dose, E, (Sv)

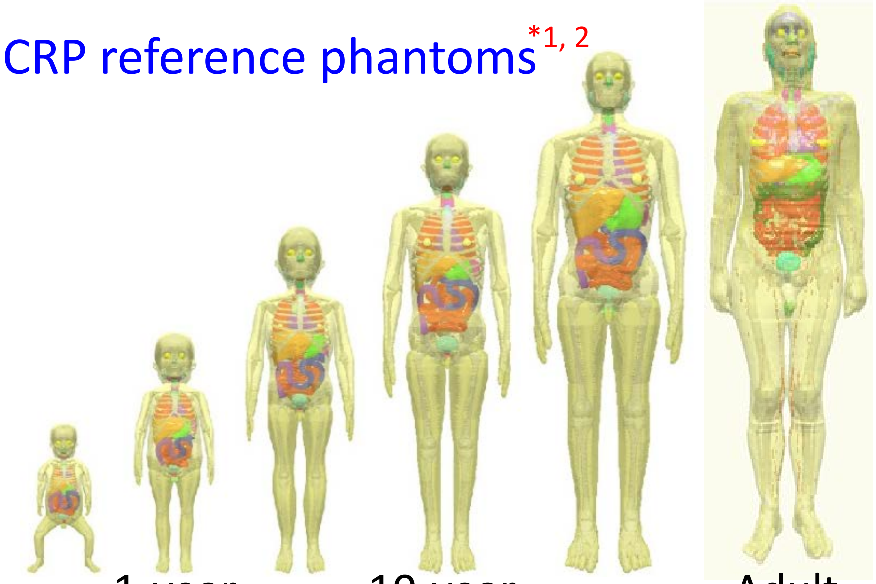
$$E = \sum_{T} w_T \sum_{R} w_R D_{T,R}$$

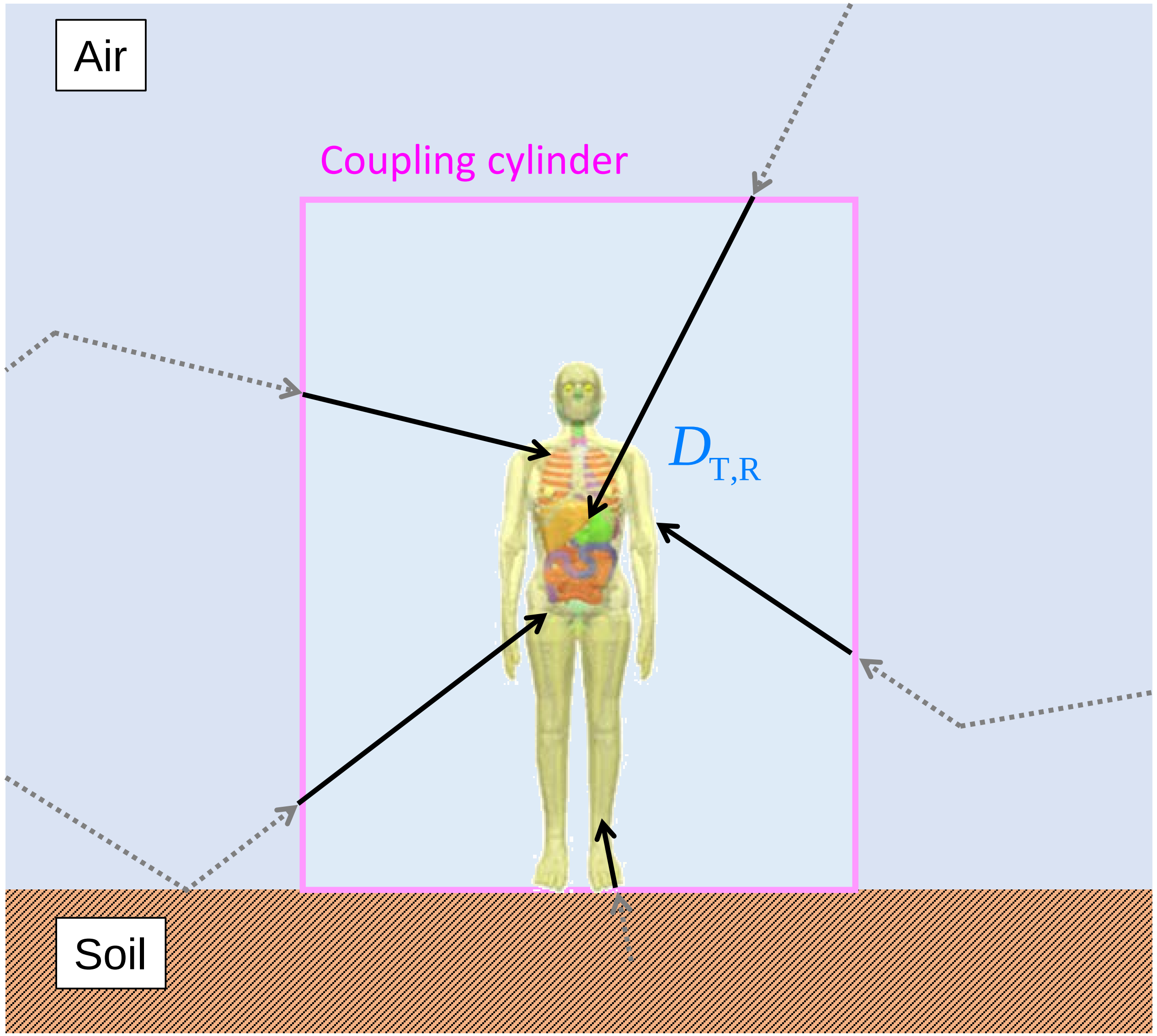
$D_{T,R}$: mean absorbed dose in an organ or tissue T from radiation type R, (Gy)

w_R : radiation weighting factor

w_T : tissue weighting factor

- ICRP reference phantoms*1, 2





*1; "Adult Reference Computational Phantoms", ICRP, Publication 110 (2008).

*2; "The UF family of reference hybrid phantoms for computational radiation dosimetry", C. Lee, D. Lodwick, J. Hurtado et al., Phys. Med. Biol., 55 (2010).

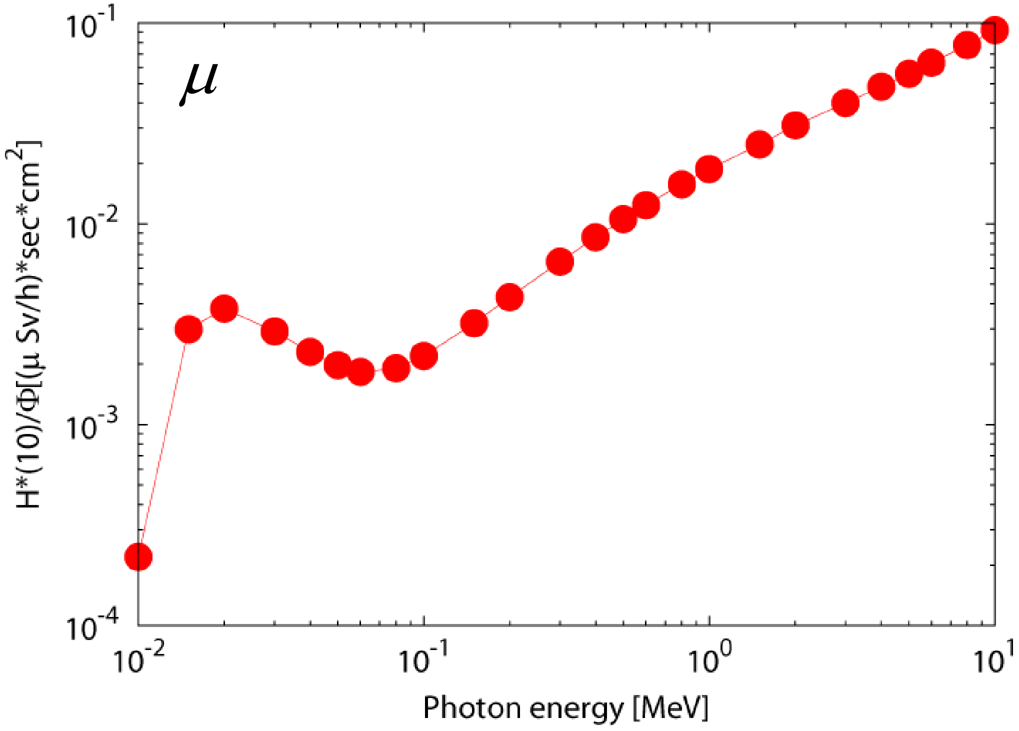
Ambient dose equivalent, *H**(10), at a height of 1 m above ground

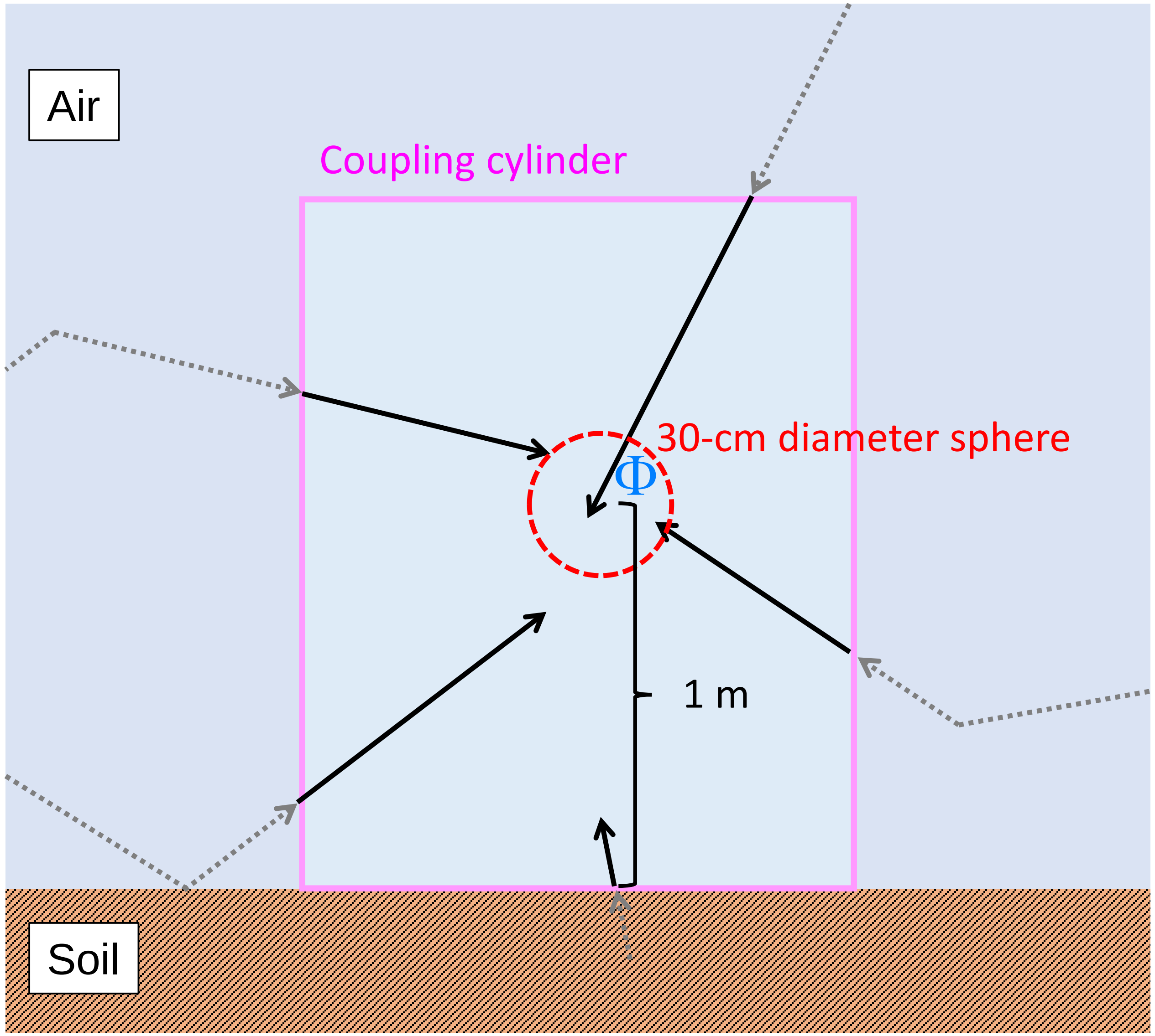
Ambient dose equivalent, *H**(10), (Sv)

$$H^*(10) = \sum \Phi(E) \cdot \mu(E)$$

Φ : photon fluence ($1/cm^2$)

μ : conversion coefficient* for ambient dose equivalent from photon fluence ($pSv\ cm^2$)





*"Conversion coefficients for use in radiological protection against external radiation", ICRP, Publication 74 (1996).

Age-dependent personal dose equivalent, *H*p(10), monitored using a dosimeter

Personal dose equivalent, *H*p(10), (Sv)
monitored using a calibrated dosimeter

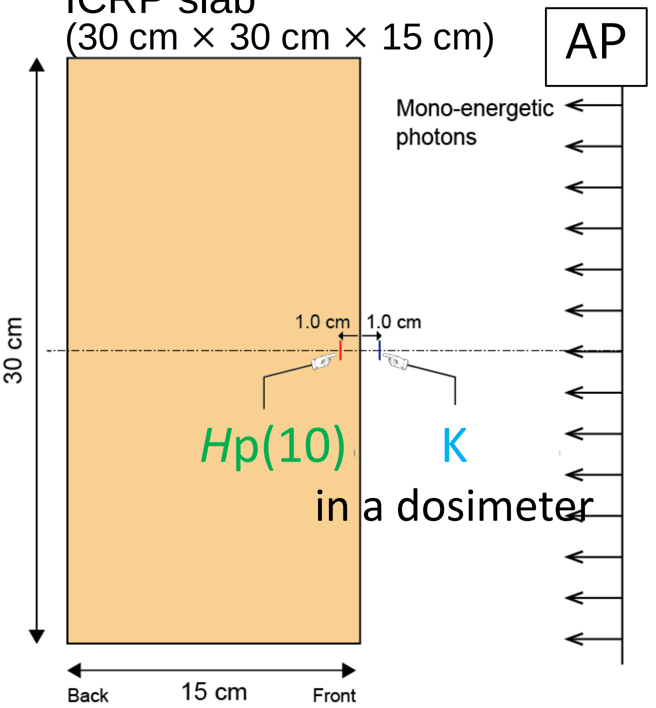
$$H_{\mathrm{p}}(10) = K \cdot \alpha(\mathrm{AP})$$

K : air kerma free in air (Gy)

$\alpha(\mathrm{AP})$: calibration factor to convert air kerma in a dosimeter to personal dose equivalent (Sv/Gy)

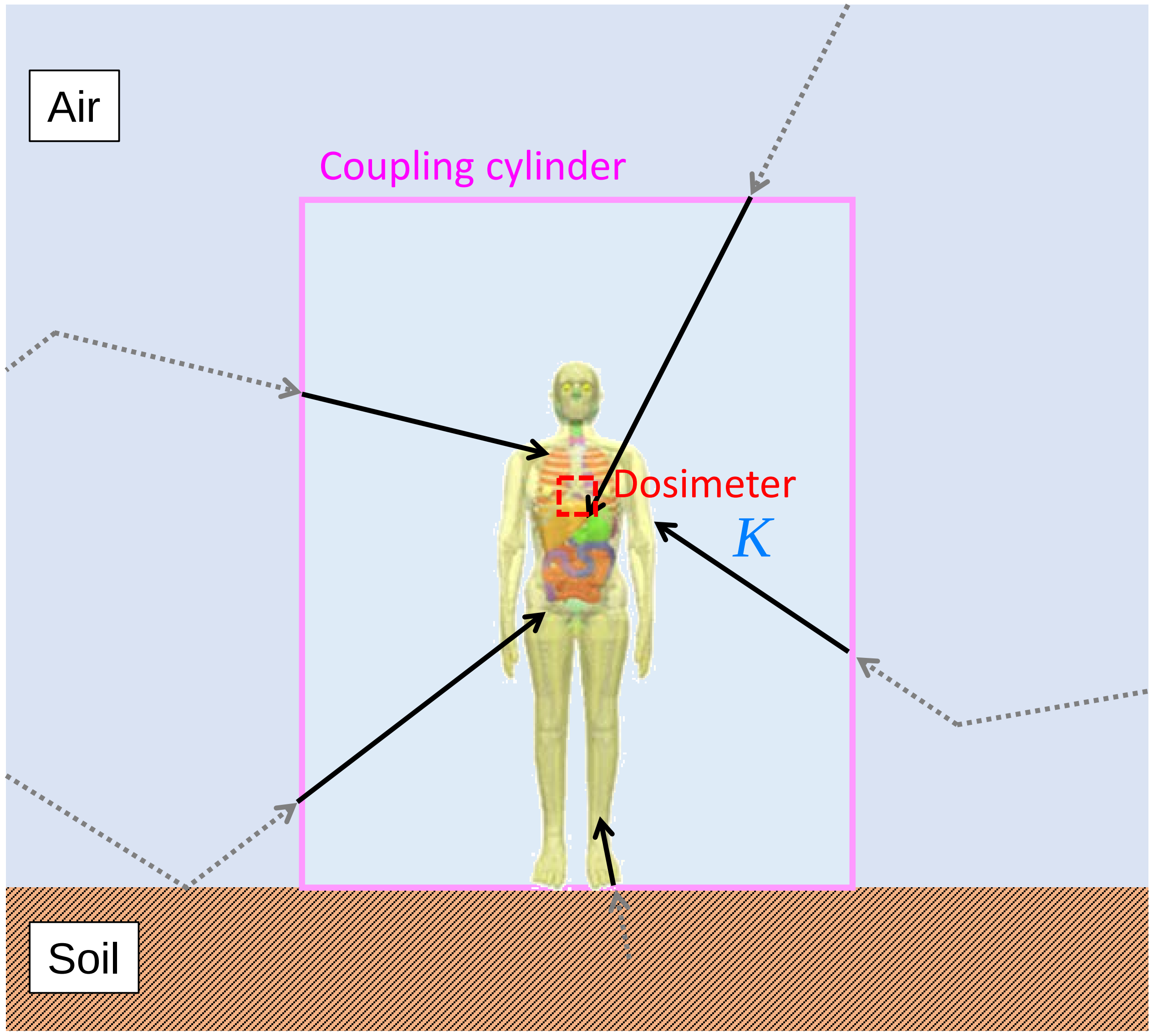
- Simulation of calibration factor

ICRP slab
(30 cm × 30 cm × 15 cm)



$$\alpha(\mathrm{AP}) = \frac{H_{\mathrm{p}}(10)}{K} = 1.12$$

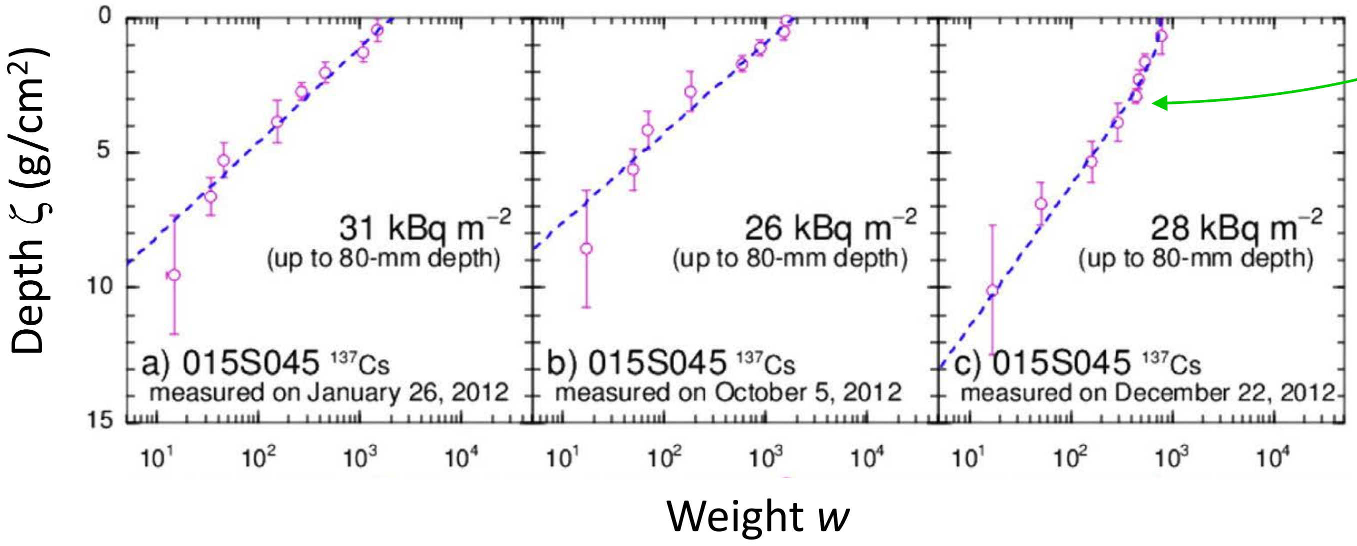
for standard radiation source of ^{137}Cs



Estimation of doses due to the Fukushima I NPP accident

- Conversion coefficients for a volumetric source

Depth profile*



Exponential function:

$$w(\zeta) = \alpha \cdot \exp\left(-\frac{\zeta}{\beta}\right)$$

$w(\zeta)$: weight regarding a radioactivity concentration distribution along a depth ζ

β : relaxation mass per unit area (g/cm^2)

Weighted-integral method

$$C_V = \frac{1}{W}\int C_P(\zeta)\cdot w(\zeta)\,d\zeta,$$

$$W = \int w(\zeta)\,d\zeta.$$

C_V : conversion coefficient for a volumetric source

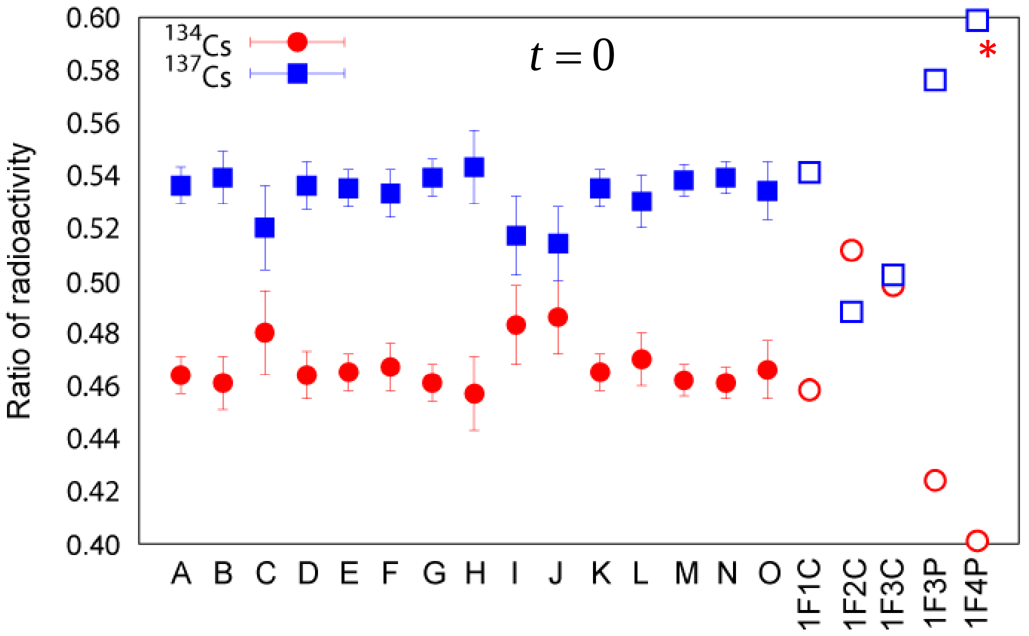
C_P : conversion coefficient for planar sources at specific depths of 0.0, 0.5 2.5, 5.0, 10.0 and 50.0 g/cm^2

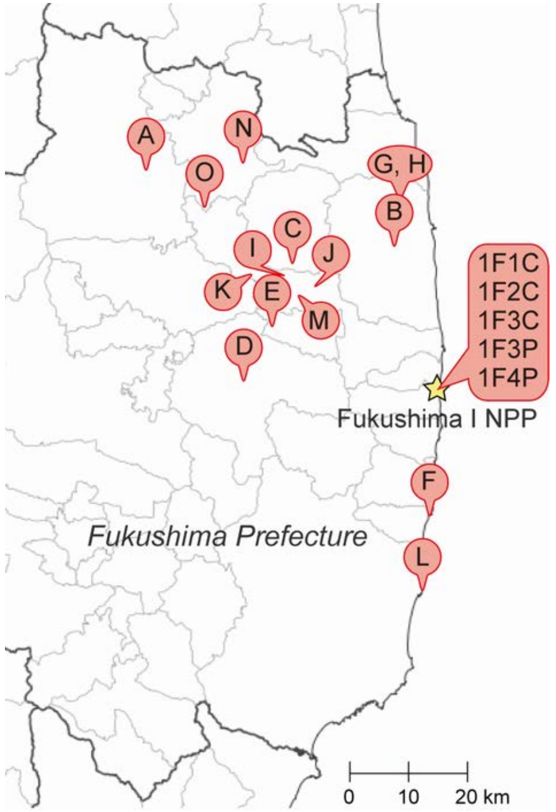
*"Depth profiles of radioactive cesium in soil using a scraper plate over a wide are surrounding the Fukushima Dai-ichi Nuclear Power Plant, Japan", N. Matsuda, et al., Journal of Environmental Radioactivity, 139, 427-434, 2015.

Estimation of doses due to the Fukushima I NPP accident

- Conversion coefficients considering physical decay effect

	Half-life, T, (year)
^{134}Cs	2.0648
^{137}Cs	30.1671





Initial condition:

$$\frac{A^{134}(t=0)}{A^{137}(t=0)} = 1.0$$

$A^{134}(t=0)$: radioactivity of ^{134}Cs at the time of the accident

$A^{137}(t=0)$: radioactivity of ^{137}Cs at the time of the accident

$$C(t) = \frac{C^{134}\cdot\exp(-\lambda^{134}\cdot t)+C^{137}\cdot\exp(-\lambda^{137}\cdot t)}{\exp(-\lambda^{134}\cdot t)+\exp(-\lambda^{137}\cdot t)},$$

$$\lambda^{134} = \frac{\ln 2}{T^{134}}, \lambda^{137} = \frac{\ln 2}{T^{137}}.$$

$C(t)$: conversion coefficients at time t from the accident occurrence

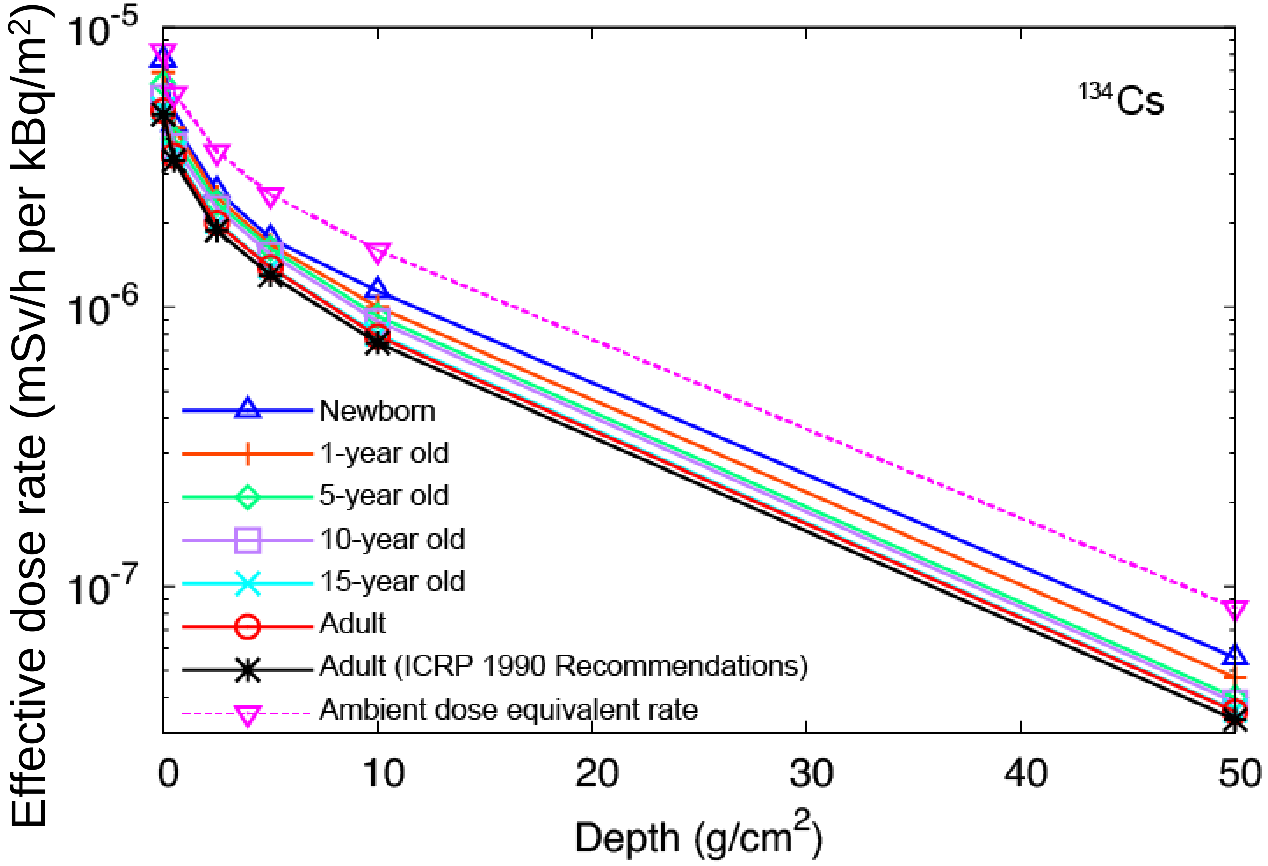
C^{134} : conversion coefficient for ^{134}Cs

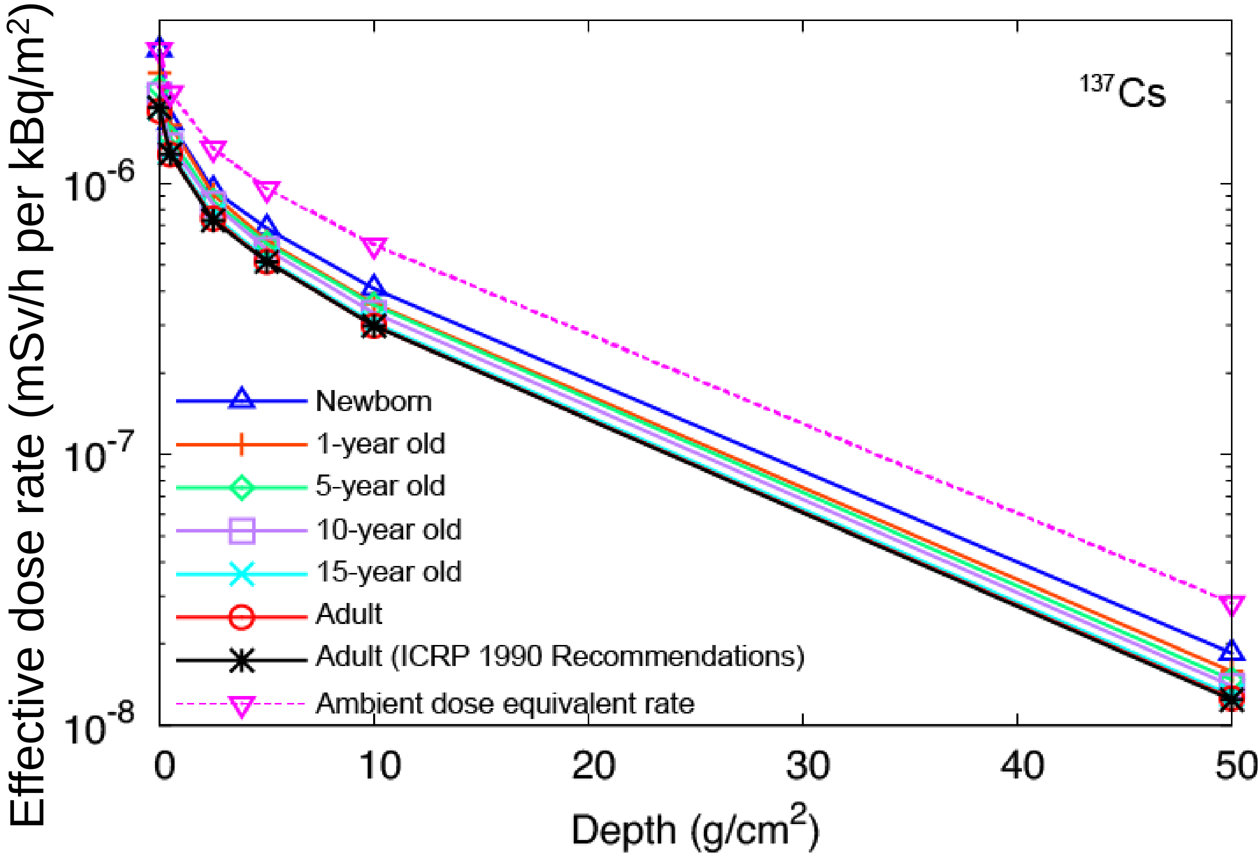
C^{137} : conversion coefficient for ^{137}Cs

*"Development of a calculation system for the estimation of decontamination effects ", D. Satoh, et al., Journal of Nuclear Science and Technology, 51, 5, 656-670, 2014.

Age-dependent conversion coefficients of effective dose rate

Conversion coefficients to convert activity concentration to effective dose rate at each age for uniform planar sources of ^{134}Cs and ^{137}Cs located at the specific depth in soil.

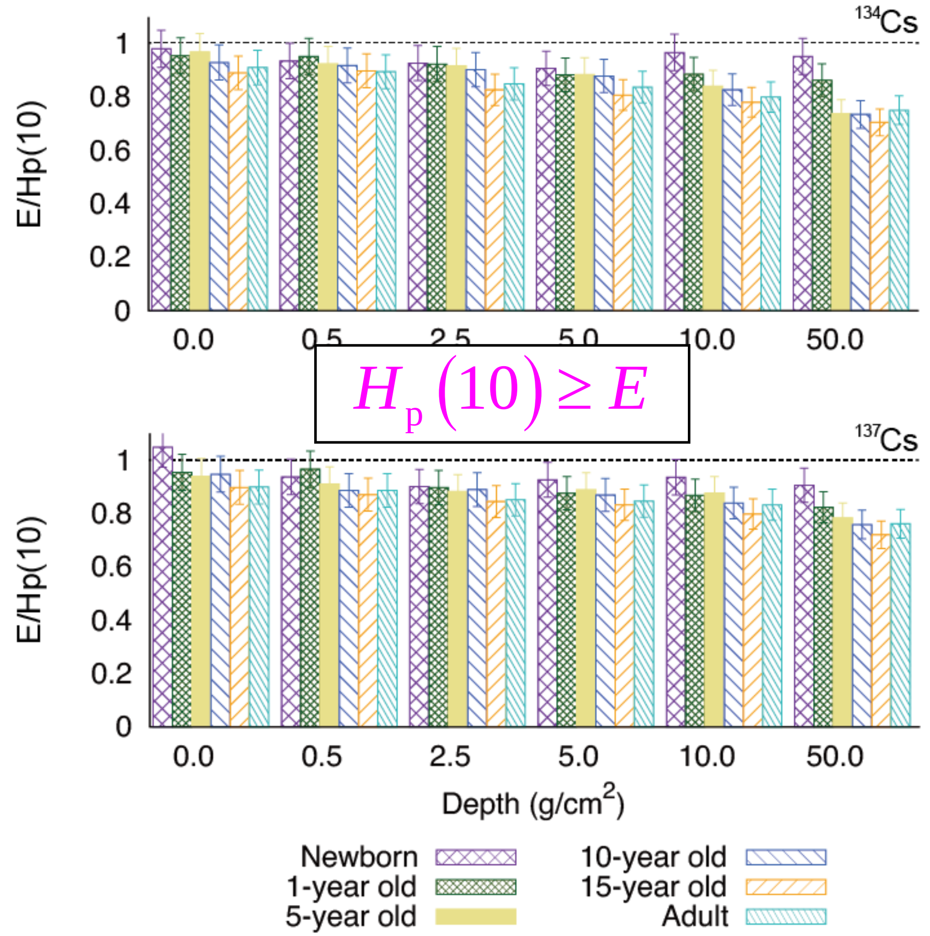




- Radiation control based on the ambient dose equivalent rate gives a conservative estimate for all ages of the dose limits defined by the effective dose
- Update of the dosimetry system does not cause an undesirable confusion for estimating doses

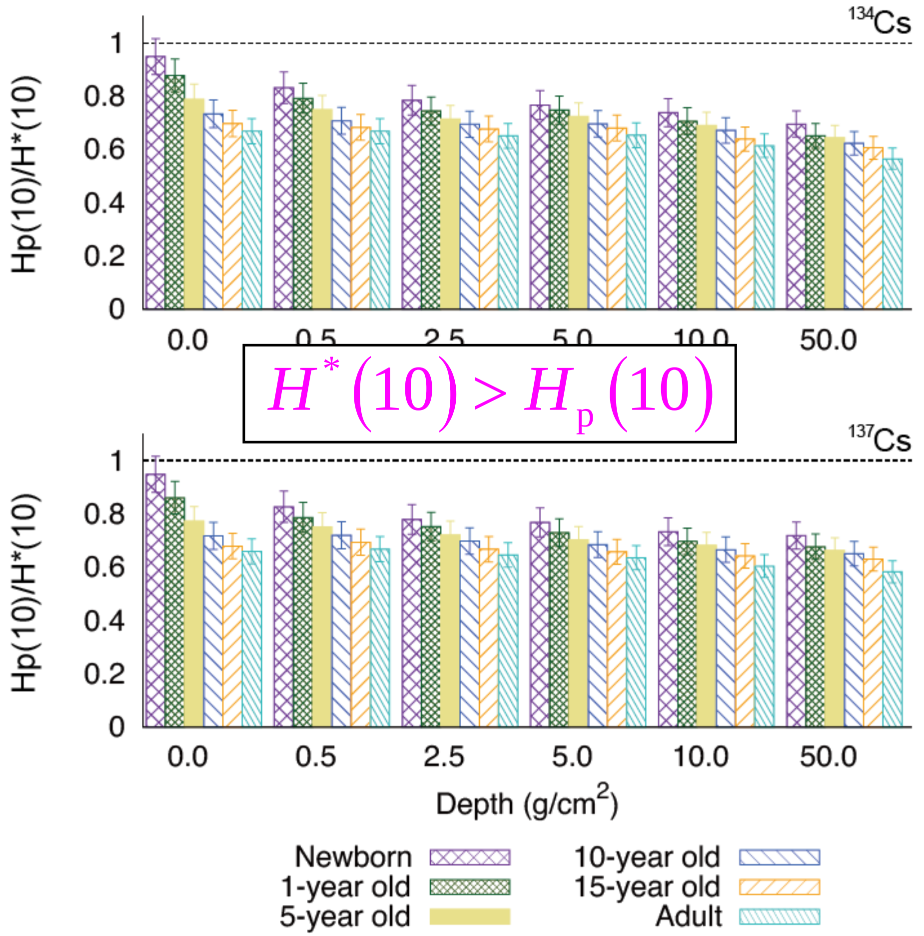
Relationships between effective dose, personal dose equivalent, and ambient dose equivalent

Effective dose, *E*, to personal dose equivalent, *H*p(10), ratio for planar sources of ^{134}Cs and ^{137}Cs distributed at various depths



$$H_{\mathrm{p}}(10) \geq E$$

Personal dose equivalent, *H*p(10), to ambient dose equivalent, *H**(10), ratio for planar sources of ^{134}Cs and ^{137}Cs distributed at various depths



$$H^{*}(10) > H_{\mathrm{p}}(10)$$

- Personal dose equivalent provides a good estimate regarding the effective dose in a contaminated environment and does not exceed the ambient dose equivalent

Comparison with the data measured in Fukushima

- Date of dose estimation : September 2013 (t=2.5years)
- Radiation source : mixed source of ^{134}Cs and ^{137}Cs
- Depth profile : Exponential distribution (β = 2.5 g/cm^2)

Age	Simulation $\frac{H_p(10)}{H^*(10)}$	Measurement* $\frac{H_{p,Meas.}(10)}{H^*_{Meas.}(10)}$	Evaluation† $\frac{H_{p,Eval.}(10)}{H^*_{Meas.}(10)}$
Newborn	0.83	-	0.85
1-year old	0.78	-	0.85
5-year old	0.74	-	0.8
10-year old	0.71	-	0.8
15-year old	0.68	-	0.8
Adult	0.66	0.66 (0.6～0.7)	0.7

- The present simulation methods was validated
- The simulation method can be applied to the prediction of external doses in Fukushima

*"Researches on the characteristics of personal doses after the accident of TEPCO Fukushima Daiichi Nuclear Power Station", Joint task group of National Institute of Radiological Sciences and Japan Atomic Energy Agency, 2014. Japanese.

†"Additional researches on the characteristics of personal doses after the accident of TEPCO Fukushima Daiichi Nuclear Power Station", Joint task group of National Institute of Radiological Sciences and Japan Atomic Energy Agency, 2015. Japanese.

Summary

Air kerma, *K*, (Gy)
Absorbed dose, *D*, (Gy)
in a monitoring instrument

- External doses for the public can be readily estimated using the conversion coefficients
- Rationality of the system of radiological protection based on radiation monitoring has been ensured even for the environmental exposure

Related with calibration

$H_p(10) \geq E$
Compared

Personal dose equivalent,
*H*p(10), (Sv)
- Individual monitoring
- Personal dosimeter

Compared
$H^*(10) > H_p(10)$

Ambient dose equivalent,
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- Area monitoring
- Survey meter

Compared
$H^*(10) > E$

Effective dose,
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Conversion coefficients

Conversion coefficients

Conversion coefficients

Activity concentration, *A*, (Bq/cm^2)

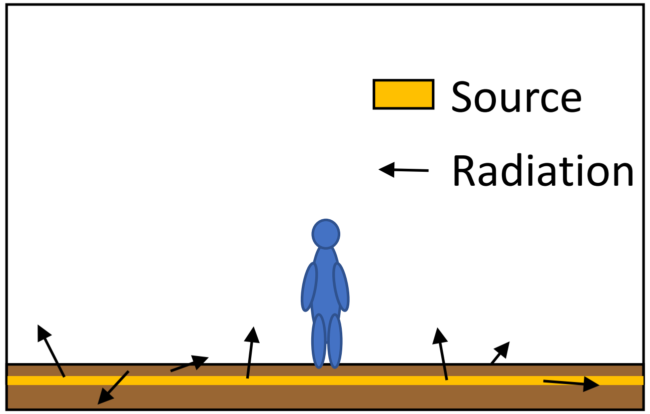
ICRP TG90 activities

Task Group 90: Age-dependent Dose Conversion Coefficients for External Exposures to Environmental Sources

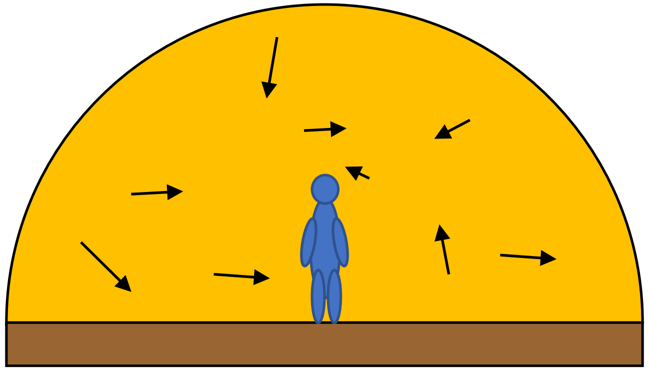
http://www.icrp.org/icrp_group.asp?id=81

Purpose is to evaluate nuclide-specific effective and organ dose coefficients for members of the public due to environmental exposures to photons and electrons, calculated using the ICRP adult and pediatric male and female reference computational phantoms, representing adults, newborn, 1, 5, 10 and 15 year old individuals.

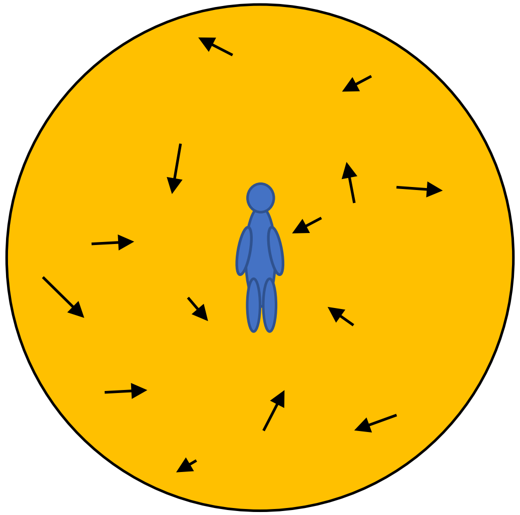
Soil contamination



Air submersion



Water immersion



- Radiation Source : 1252 radionuclides of 97 elements compiled in the *ICRP Publication 107*
- Phantom : ICRP reference phantoms (newborn, 1-year, 5-year, 10-year, 15-year children, adults)
- Primary calculation : PHITS
- Spot check calculation : Geant4, EGSnrc, MCNPX, MCNP6, VMC

ICRP publication is expected to appear end of 2018