Sources of radiation doses in contaminated environment

- External radiation direct from cloud
- Internal dose from inhalation of radioactive materials in the air
- External dose direct from radioactive materials deposited on the ground
- Internal dose from eating and drinking radioactive materials in food and water
Cumulative thyroid dose of a 10 year old child in Fukushima prefecture

WHO Report WN 665, 2012

→ External irradiation is main source of radiation dose a few months after accident
Historical overview

- Dillman, Health Physics 1974: Dose-depth values for reference adult (MIRD-type) in radioactive cloud
ICRP task group: establishment of reference dose coefficients

- Conversion coefficients:
  measured activity $\rightarrow$ organ and effective dose rate

- Three different scenarios
  - Air submersion
  - Ground contamination
  - Water immersion

- ICRP reference human models
  - Reference adults (ICRP 110)
  - Upcoming reference paediatric models

- For gamma and beta emitters
ICRP Reference virtual human models

Adults

Paediatric

Share identical anatomy except gender organs

Newborn 1-year 5-year 10-year 15-year male 15-year female
Quality assurance

- Primary calculations by JAEA
- Spot checks by ICRP task group 90 members
- Comparison with previous calculations for photons in air and soil
- Comparison with draft “Federal Guidance Report 15” of the US Environmental Protection Agency
Simulation setup (air)

Step 1: Scoring at coupling cylinder

Semi-sphere:
Radius = 5.0 mean free paths (e.g. 656m for 1 MeV photon)
Soil thickness = 100 cm

Step 2: Organ DC calculation

Coupling cylinder:
diameter= 60 cm,
height 200 cm
Step 1: Scoring at coupling cylinder

Semi-sphere:
Radius: 5 mean free paths (MFP)
Height: 3 mean free paths
Soil thickness between 2 and 5 MFP

5 source depths:
0, 0.2, 1.0, 2.5 and 4 mean free paths

Step 2: Organ DC calculation

Coupling cylinder:
diameter = 60 cm,
height 200 cm
Volumetric ground sources

Figure 8. Energy spectra for environmental photons from volumetric source of $^{137}$Cs with exponential distribution with $\beta = 1.0$.
Note: Stars represent the results calculated directly by PHITS from the volumetric source, and line indicates the results reconstructed by using data for planar sources.

Air submersion: angular field

Photons, 100 keV

\[ \frac{N_j}{N} \]

\( \sin \theta \)

\( \frac{N_j}{N} \)

downwards  upwards
Results: soil contamination

Effective dose rates per activity (Adult)
Effective dose rates per activity (Adult)

Ground contamination at 2.5 MFP (photon source)

Energy [MeV] vs. Effective dose rate per activity [Sv/(Bq*s/m²)]
Results: air submersion

Skin - Air submersion (photon source)

Absorbed dose / disintegration density (pGy/m³)

Energy (MeV)

- JAEA 2015 (EGSnrc)
- JAEA 2015 (PHITS)
- JAERI/HMGU 1990 (EGS)
- FGR-12
Results: air submersion

Liver - Air submersion (photon source)

Absorbed dose / disintegration density (pGy/m³)

Energy (MeV)

JAEA 2015 (EGSnrc) +
JAEA 2015 (PHITS)
JAERI/HMGU 1990 (EGS) *
FGR-12
Results: water immersion

Water immersion (photon source)

Effective dose rate per $\mathbf{\mathcal{V}}/\mathbf{Bq} \times \mathbf{s/m}^3$

Energy [MeV]

10^{-2} 10^{-1} 10^{0} 10^{1}

10^{-15} 10^{-16} 10^{-17} 10^{-18} 10^{-19} 10^{-20} 10^{-21}

Adults
15-year old
10-year old
05-year old
01-year old
Newborn
$^{137}$Cs source in ground

Effective dose rate per activity

Source depth
- $0.0 \text{ g/cm}^2$
- $0.5 \text{ g/cm}^2$
- $2.5 \text{ g/cm}^2$
- $5.0 \text{ g/cm}^2$


1y old: dose at most 35% higher than for adult
Effective dose rate per activity

$^{137}$Cs source in ground

1-year-old:
Ambient dose at least 15\% higher than effective dose

Summary

- Establishment of reference dose coefficients for air submersion, ground contamination and water immersion
- Application of ICRP adult and paediatric reference models
- Quality control by international members of ICRP task group 90
- Ambient dose rate is conservative effective-dose rate estimator for adults, children and infants