Annex XII of Technical Volume 4
CALCULATIONS USED IN THE ASSESSMENT OF DOSES TO NON-HUMAN BIOTA

XII–1. CALCULATION OF ABSORBED DOSE RATES FROM ACTIVITY CONCENTRATION DATA

The basic underlying expressions used to derive internal (D_{int}) and external (D_{ext}) absorbed dose rates (in units of µGy/h) from activity concentration data are given in equations below. The total absorbed dose rate is the sum of these components, through the application of dose conversion coefficients (DCCs):

$$\dot{D}^{b}_{\mathrm{int}} = \sum_{i} C^{b}_{i} * DCC^{b}_{\mathrm{int},i}$$

where:

C^{b}_{i} is the average concentration of radionuclide *i* in the reference organism *b* (Bq/kg fresh weight),

$DCC^{b}_{\mathrm{int},i}$ is the radionuclide specific dose conversion coefficient (DCC) for internal exposure defined as the ratio between the average activity concentration of radionuclide *i* in the organism *j* and the dose rate to the organism b (µGy/h per Bq/kg fresh weight).

$$\dot{\mathrm{D}}^{\mathrm{b}}_{\mathrm{ext}} = \sum_{\mathrm{z}} \mathrm{v}_{\mathrm{z}} \sum_{\mathrm{i}} \mathrm{C}^{\mathrm{ref}}_{\mathrm{zi}} * \mathrm{DCC}^{\mathrm{b}}_{\mathrm{ext,zi}}$$

where:

v_z is the occupancy factor, i.e. fraction of the time that the organism *b* spends at a specified position *z* in its habitat.

C_{zi}^{ref} is the average concentration of radionuclide *i* in the reference media of a given location *z* (Bq kg^{-1} fresh weight or dry weight (soil or sediment) or Bq/L (water)).

$DCC^{j}_{ext,zi}$ is the dose conversion coefficient for external exposure defined as the ratio between the average activity concentration of radionuclide *i* in the reference media corresponding to the location *z* and the dose rate to organism *b* (µGy/h per Bq/kg fresh weight or Bq/L).

The DCCs used correspond to those reported in ICRP (2008) [XII–1]. Occupancy factors for organisms have been selected such that they might characterize simplified, yet realistic exposure geometries (Table XII–1).

TABLE XII–1. SUMMARY OF SOURCE TARGET EXPOSURE GEOMETRY FOR SELECTED ORGANISMS

Organism	Exposure geometry assumption
Earthworm	In soil, volumetric source
Wild grass	On soil, volumetric source
Duck	1. On soil, volumetric source 2. At water air interface, aquatic source
Trout	In water column, aquatic source
Rat	In soil, volumetric source
Pine tree	On soil, volumetric source
Frog	1. On soil, volumetric source 2. In water column, aquatic source
Flatfish	At water sediment interface, aquatic source
Bee	On soil, volumetric source
Deer	On soil, volumetric source
Brown seaweed	At water sediment interface, aquatic source
Crab	At water sediment interface, aquatic source

The results from these calculations are expressed as absorbed total dose rates (in µGy/h).

The dosimetric calculations underpinning the derivation of DCCs are dealt with in detail elsewhere [XII–2, XII–3]. Radionuclide decay chains were truncated at the first long lived radionuclide, i.e. with a half-life greater than ten days, and the resulting DCCs of radioactive progeny were included in the DCC of their long lived parent. DCCs for internal exposure were derived assuming a homogeneous distribution of the radionuclide in the organism; the error introduced by this assumption is, in view of the assessment goals, considered to be of minor significance [XII–4].

XII–2. EXAMPLES OF CALCULATIONS OF CONCENTRATION RATIOS FROM BIOTA IN DIFFERENT ENVIRONMENTS

For terrestrial biota the whole body concentration ratio, CR_{wo}, is defined as in the following equation

$$CR_{wo} = \frac{A_{b,r}^{biota}}{A_{r}^{soil}}$$

where:

$A_{b,r}^{biota}$ = activity concentration of radionuclide ‘r’ in the whole organism of biota ‘b’ (Bq/kg fresh weight (fw));

A_{r}^{soil} = activity concentration of radionuclide ‘r’ in soil (Bq/kg dry weight (dw)).

XII–3. CALCULATION OF ACTIVITY CONCENTRATIONS IN VEGETATION AND IN SOIL FROM TOTAL DEPOSITION

In case of an acute deposition the radionuclide content on vegetation at time *t*, accumulated via direct deposition from the air, can be calculated as:

$$C_{veg,r} = \alpha \cdot D_{tot,r} \cdot [e^{(-(\lambda_{veg,r}+\lambda_r)\cdot t)}]$$

where

$C_{veg,r}$ = radionuclide activity concentration in vegetation from air deposition (Bq/kg fw).

α = fraction of deposited activity intercepted by vegetation per unit mass (mass interception factor, Bq/kg per Bq/m^2, or m^2/kg; considered in fresh weight for vegetation).

$D_{tot,r}$ = total deposition of radionuclide ‘r’ (Bq/m^2).

$\lambda_{veg,r}$ = weathering constant for a given vegetation for radionuclide r (per d).

λ_r = decay constant for radionuclide r (per d^{-1}).

t = time (d).

For the same acute deposition, at time *t*, there is also a component of contamination that becomes associated with soil

$$C_{Soil,r} = \left[\frac{D_{tot,r} \cdot \left[(1 - f_{veg}) + f_{veg} \cdot (1 - e^{-\lambda_{veg,r} t})\right] \cdot e^{-\lambda_r t}}{\rho_{soil} \cdot d_{soil}} \right]$$

where

ρ_{soil} = dry soil density (kg/m^3 dry mass).

d_{soil} = depth of soil within which radionuclide r has become mixed (m).

f_{veg} = interception fraction for a given vegetation (dimensionless).

All other parameters have been defined above.

Parameters for herbaceous vegetation (wild grass) and trees (pine trees) are given in Table XII–2.

TABLE XII–2. PARAMETERS USED IN TERRESTRIAL DEPOSITION MODEL

Parameter, symbol	Value	Units *and notes*
Mass interception fraction for herbaceous vegetation, α_{herb}; *(interception fraction — f_{herb})*	0.75 *(0.05)*	m^2/kg, *3 m^2/kg dry weight (animal feed, forage, pasture) converted to fw using a factor of 0.25* [XII–5]
Mass interception fraction for trees, α_{tree}; *(interception fraction — f_{tree})*	0.167 *(0.5)*	m^2/kg, *ca. 5 kg tree canopy per m^2, 60 % canopy mass, 0.5 interception fraction*
Weathering loss coefficient herbaceous vegetation, $\lambda_{herb,r}$	0.05	per d, *pertains to all radionuclides*
Weathering loss coefficient tree, $\lambda_{tree,r}$	6.9×10^{-3}	per d, *from information in IAEA Technical Reports Series No. 472 [XII–6]: pertains to all radionuclides*

It should be noted that the time of deposition was before the main growing season — the interception for herbaceous vegetation is therefore indicative only for general types of vegetation present at ground level at the time of deposition.

Soil activity concentrations with time (to allow derivation of external dose rates and application of CR values) are also required for exposure estimates. The method of calculating the component of deposited radioactivity which becomes associated with soil is set out in above.

A dry soil density of 1300 kg/m^3 and sampling depth of 5 cm have been used in the above calculation. The time integrated activity concentration in vegetation and soil is calculated for 0-30 days and 31–90 day periods. The radionuclide concentrations in soil at 1 year was determined for the late period exposure calculations.

Concentrations for terrestrial RAPs are derived from soil concentrations using CRs for terrestrial RAPs (Table XII–3). Thereafter, doses for all biota are derived using the methodology described above. There are likely to be larger uncertainties associated with the results of the calculations for biota (e.g. pine) in ecosystems that require longer than a period of 90 days to reach equilibrium.

TABLE XII–3. CONCENTRATION RATIOS (CRs) FOR TERRESTRIAL RAPS (ICRP, 2009) [XII–7].

Element	Organism	CR (Bq/kg fw per Bq/kg dw)
Cs	Bee	4.7×10^{-3}
I	Bee	2.8×10^{-1}
Cs	Earthworm	4.8×10^{-2}
I	Earthworm	1.4×10^{-1}
Cs	Rat	2.2×10^{-1}
I	Rat	4.0×10^{-1}
Cs	Deer	1.6×10^{0}
I	Deer	4.0×10^{-1}
Cs	Duck	2.2×10^{-1}
I	Duck	4.0×10^{-1}
Cs	Frog	2.8×10^{-2}
I	Frog	4.0×10^{-1}

The highest activity of ^{137}Cs found in the soil survey covering Fukushima Prefecture and adjacent areas, conducted by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), was at a location in Okuma Town [XII–8]. This value was used to provide an indication of exposures to the most highly exposed individuals in animal and plant populations for the contaminated region as a whole. This approach was also applied in the assessment by UNSCEAR [XII–9].

It was considered more appropriate to take average values of deposition as these corresponded to areas that would be more closely linked to populations of organisms than single points. A further modification was required for the input data set to account for ^{131}I levels.

TABLE XII–4. RADIONUCLIDE DEPOSITION DATA FOR OKUMA TOWN FOR 15 MARCH 2011 (RADIOCAESIUM DERIVED FROM DATA IN UNSCEAR, 2014 [XII–9])

	Cs-134	Cs-137	I-131
Arithmetic mean deposition (Bq/m^2)	2.8E+06	2.8E+06	2.8E+07*

* Derived from the ^{131}I:^{134}Cs ratios provided in Torii et al. (2013) [XII–10]

XII–4. CALCULATION OF ACTIVITY CONCENTRATIONS IN SEA WATER

The total (activity) concentration of a specified radionuclide in sea water, $C_W(j)$ (in Bq/L), is given by:

$$C_w(j) = (1 + K_d(j)\,S)\,C_{DW}(j)$$

where:

S = suspended sediment concentration (kg/L).

K_d(j) = distribution coefficient (L/kg) for radionuclide *j*.

C_{DW}(j) = activity concentration of radionuclide *j* in filtered seawater (Bq/L);

For radionuclides which behave conservatively in sea water, i.e. with a relatively low K_d, and where suspended sediment concentrations are not substantially elevated above normal oceanic levels, $C_W \approx C_{DW}$. These conditions are met for the radionuclides and coastal environments considered in this assessment removing the requirement to specify K_ds and suspended sediment concentrations.

The concentration ratios applied for the marine ecosystem are presented in Table XI–5.

TABLE XII–5. CONCENTRATION RATIOS FOR MARINE ECOSYSTEMS FROM ICRP (2009) [XII–7]

Element	Organism	CR (Bq/kg^{-} fw per Bq/L)
Cs	Flatfish/benthic fish	3.6×10^1
I	Flatfish/benthic fish	9.0×10^0
Cs	Crab/crustacean	1.4×10^1
I	Crab/crustacean	3.0×10^0
Cs	Brown seaweed/macroalgae	1.2×10^1
I	Brown seaweed/macroalgae	1.4×10^3

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