Improving European decision support reliability and robustness to manage scenarios involving contamination of inhabited areas

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Decision support system application includes:

- Rough early phase risk prognoses (when reliable measurements have not yet been made)
- Estimation of doses received in a contaminated area over time (recovery justification)
- Estimation of possible implications of recovery countermeasures (including residual doses)
- Preparedness exercises, drills and training (including evaluation of current preparedness)

Requirements in most of these cases (ERMIN dose model):

- Estimation of deposition velocities / relations on different surfaces of different contaminants in different types of weather
- Estimation of resultant dose rate in different locations in different types of inhabited environments from different contaminants (gamma energies)
- Estimation of likely behaviour pattern of inhabitants in an inhabited area (occupancy factors)
- Estimation of natural decline in contamination / dose rate level of different contaminants on different surfaces over time
- Estimation of countermeasures effectiveness for a given contamination and time and surface type

Parameter uncertainties?

Extensive work has been done in the EU H2020 (CONCERT) project CONFIDENCE (**CO**ping with u**N**certainties **F**or **I**mproved modelling and **DE**cision making in **N**uclear emergen**C**i**E**s) to quantify and where possible minimise important modelling uncertainties.

Example below: dry deposition relative to that on a well-defined reference surface (based on knowledge from actual measurements).

Surface	Elemental iodine		AMAD < 2 µm		AMAD 2-5 µm		AMAD 5-10 µm		AMAD 10-20 µm	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Short grass*	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.
Bare soil	0.6	0.4	0.3	0.15	0.3	0.15	0.17	0.10	0.23	0.12
Soil and short grass*	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-
Small plants*	0.8	0.5	1.4	0.7	1.6	0.8	1.0	0.5	1.2	0.7
Trees and shrubs*	0.4	0.25	2.5	1.2	4.3	2.5	1.7	1.2	1.5	1.1
Paved area	0.2	0.1	0.25	0.15	0.75	0.35	0.3	0.15	0.3	0.25
Clay tile roof	1.5	0.3	0.8	0.1	3.0	0.8	1.9	0.5	1.5	0.4
Concrete tile roof	1.8	0.4	1.0	0.2	4.0	1.0	2.2	0.6	1.6	0.4
Fibre cement roof	1.6	0.3	0.9	0.1	3.6	0.9	2.1	0.5	1.6	0.4
Silicon covered fibre cement roof	1.0	0.2	0.7	0.1	2.5	0.6	1.7	0.4	1.4	0.4
Glass roof	0.5	0.1	0.4	0.1	1.4	0.4	1.5	0.4	1.3	0.3
Smooth metal roof	0.7	0.1	0.5	0.1	1.6	0.4	1.6	0.4	1.3	0.3
External walls	0.15	0.1	0.03	0.02	0.07	0.04	0.1	0.07	0.05	0.03

*Values given per area of ground covered by the vegetation.
Note: typical dry deposition velocities to ref. surface (unit: 10-4 m/s) are respectively (left to right): 20, 4, 7, 30 and 130.

Similar data compilations made for other types of weather including rain (table below).

Surface	Elemental iodine		Cationic caesium		Other contaminants		Elemental iodine		Cationic caesium		Other contaminants	
	Rel. deposition		Rel. deposition		Rel. deposition		Runoff fraction		Runoff fraction		Runoff fraction	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Short grass*	1	-	1	-	1	-	0.9	0.1	0.8	0.1	1	0.2
Bare soil	1	-	1	-	1	-	0	-	0	-	0	-
Soil and short grass*	1	Ref. surf.	1	Ref. surf.	1	Ref. surf.	0	-	0	-	0	-
Small plants*	1	-	1	-	1	-	0.99	0.01	0.7	0.2	0.8	0.2
Trees and shrubs*	1	-	1	-	1	-	0.99	0.01	0.5	0.3	0.8	0.2
Paved area	1	-	1	-	1	-	0.97	0.03	0.55	0.15	0.55	0.15
Clay tile roof	0.8	0.2	0.8	0.2	0.8	0.2	0.99	0.01	0.3	0.04	0.35	0.05
Concrete tile roof	0.8	0.2	0.8	0.2	0.8	0.2	0.99	0.01	0.4	0.05	0.45	0.06
Fibre cement roof	0.8	0.2	0.8	0.2	0.8	0.2	0.99	0.01	0.15	0.02	0.18	0.02
Silicon covered fibre cement roof	0.8	0.2	0.8	0.2	0.8	0.2	0.99	0.01	0.8	0.1	0.9	0.1
Glass roof	0.8	0.2	0.8	0.2	0.8	0.2	0.99	0.01	0.95	0.05	0.95	0.05
Smooth metal roof	0.8	0.2	0.8	0.2	0.8	0.2	0.99	0.01	0.9	0.07	0.9	0.07
External walls	0.01	0.01	0.01	0.01	0.01	0.01	0	-	0	-	0	-

*Values given per area of ground covered by the vegetation.

Modelling of migration of contaminants in soil in ERMIN (RODOS/ARGOS):

Vertical migration described by one dimensional convective-dispersive, local equilibrium mass transport model, as suggested by Bunzl et al (2000). The crucial parameters are D_s and v_s, defined respectively as

$$D_s = \frac{D}{1 + K_d \frac{\rho}{\varepsilon}}$$

and

$$v_s = \frac{v_w}{1 + K_d \frac{\rho}{\varepsilon}}$$

Values of the parameters in the soil model

Quantity	Value	unit	uncertainty
Parameter D_s	0.6	cm^2 $year^{-1}$	uniform distribution from 0.2 – 1
Parameter v_s	0.15	cm $year^{-1}$	uniform distribution from 0 – 0.3

Applying locally representative soil type dependent values in preparing for recovery can greatly reduce uncertainty.

where

D is the dispersion coefficient, v_w is the mean pore water velocity,

K_d is the distribution coefficient of the contaminant in the soil

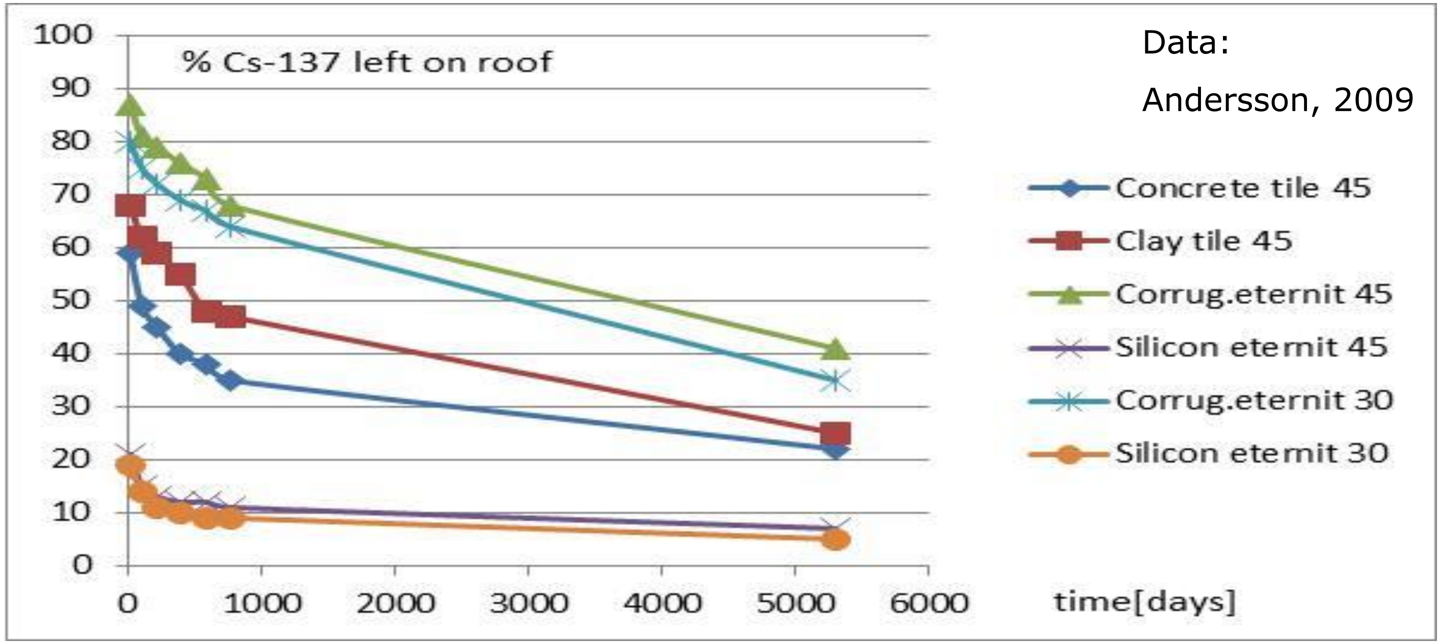
ρ is the bulk soil density, ε is the soil porosity

Results of a review of values of K_d for 3 important elements by soil type in different types of soil, based on hundreds (for Cs and I) of field assessments (in units of L/kg = cm^3/g).

Soil group	GM	GSD	AM	SD	Min	Max
Contaminant: Cs						
All soils	1.2E3	7	6.1E3	2.1E4	4.3	3.8E5
Clay/Loam	5.5E3	4	2.2E4	6.7E4	5.7E2	3.8E5
Sand	5.3E2	6	2.2E3	5.0E3	1.0E1	3.5E4
Organic	2.7E2	7	3.0E3	1.2E4	4.3	9.5E4
Unspecified	1.7E3	5	6.7E3	1.5E4	4.0E1	5.5E4
Contaminant: I						
All soils	5.4	6	2.5E1	7.0E1	1.0E-2	5.8E2
Clay/Loam	6.8	6	2.1E1	3.0E1	1.0	1.2E2
Sand	3.6	8	1.3E1	2.0E1	1.0E-2	1.3E2
Organic	3.6E1	4	9.3E1	1.8E2	8.5	5.8E2
Unspecified	2.6	6	2.0E1	7.0E1	1.0E-1	3.7E2
Contaminant: Ru						
All soils	2.7E2	8	4.7E3	1.7E4	5.0	6.6E4
Clay/Loam	5.0E2	2	6.0E2	3.6E2	2.0E2	9.9E2
Sand	3.6E1	6	7.7E1	9.0E1	5.0	6.6E4
Organic	-	-	6.6E4	-	-	-
Unspecified	1.4E2	3	2.3E2	2.1E2	3.4E1	4.9E2

GM: geometric mean; GSD: geometric standard deviation; AM: arithmetic mean; SD: arithmetic standard deviation.

Natural weathering processes on roof surfaces



Early retention against rain:

Corrugated Eternit >

Clay tile >

Concrete tile >

Silicon treated eternit

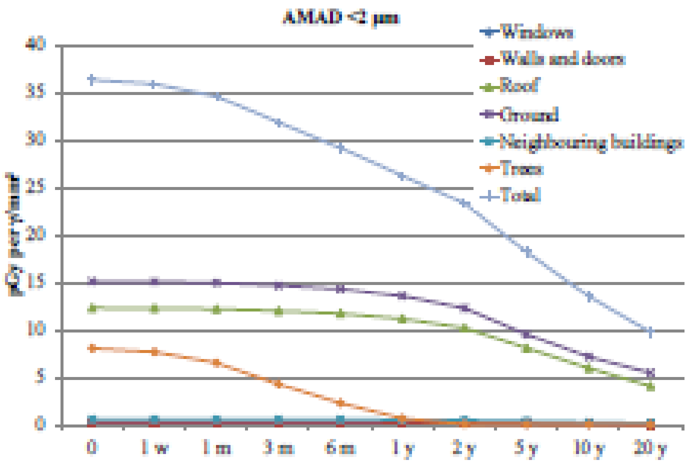
Initial retention increases with material roughness / open porosity.

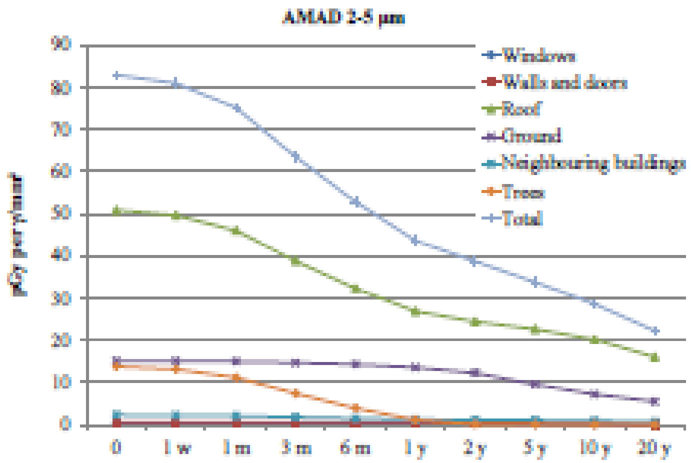
The retention after deposition process is over 15 years for all these materials: 37 % +/- 6 % (independent measurements made in different countries: Denmark, Germany, UK)

Material specification can lead to difference in early retention by a factor of 4-5, although all these materials contain large numbers of intact micaceous minerals with caesium traps.

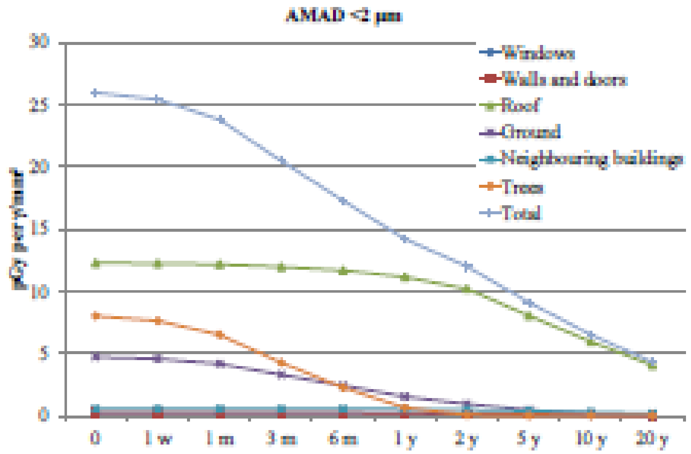
For example on a glass roof, the weathering process has been found to have a half-life of 95 +/- 30 days. Similar figures for a metal roof. On a clay tile half of the contamination is removed with a half-life of 35 +/- 7 years.

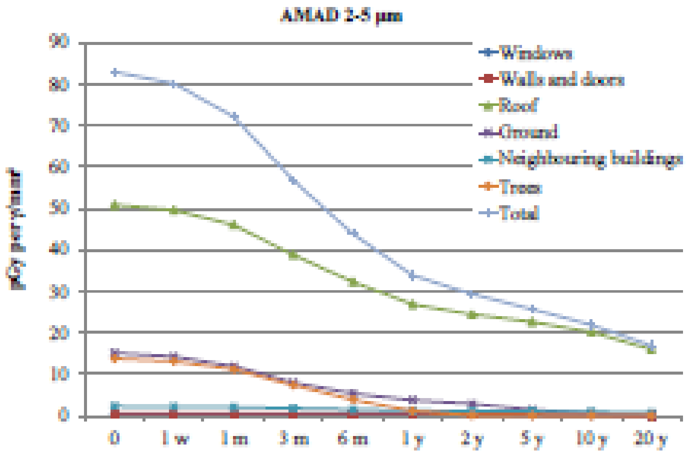
Dry deposition example





Natural decline with time in kerma contributions from different ^{137}Cs contaminated surface types per gamma initially emitted from the contamination on the reference surface per unit area. The detection point is here located on the ground floor of a two-storey brick building with clay tile roof and all ground areas are assumed to be grassed. The physical half-life of ^{137}Cs is here not included in the calculations.



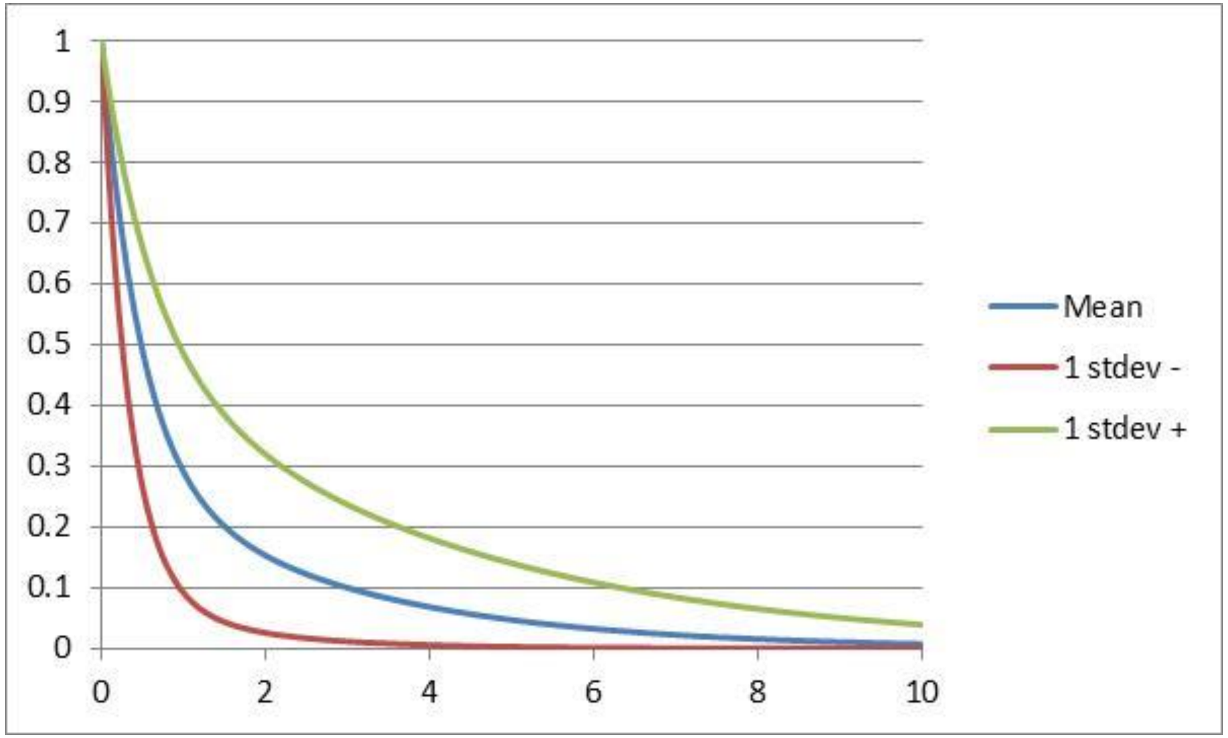


Natural decline with time in kerma contributions from different ^{137}Cs contaminated surface types per gamma initially emitted from the contamination on the reference surface per unit area. The detection point is here located on the ground floor of a two-storey brick building with clay tile roof and all ground areas are assumed to be paved. The physical half-life of ^{137}Cs is here not included in the calculations.

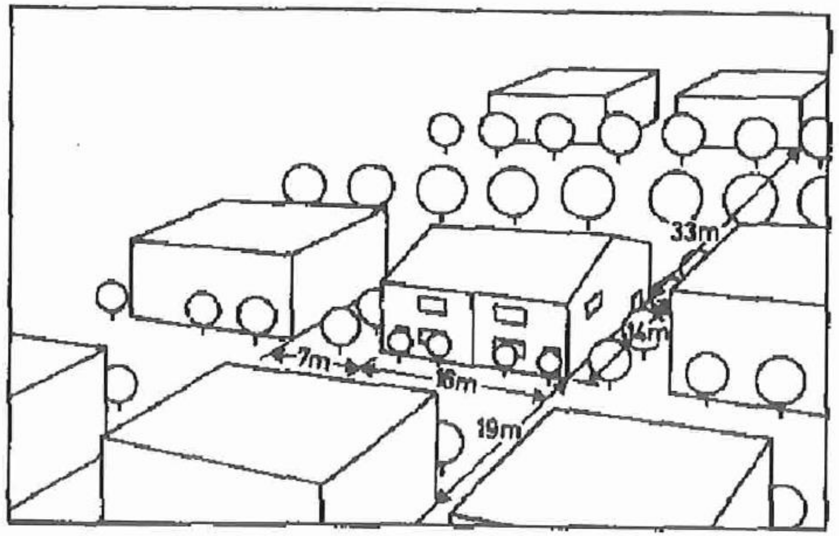
On average, European inhabitants spend 13 +/- 2 % of the time outdoors (Andersson, 2013).

While outdoors, the kerma or dose rate contribution from the ground areas will be some 10 times higher (Meckbach et al., 1988), and the time-averaged dose rate will thus in more cases be dominated by the contributions from the ground.

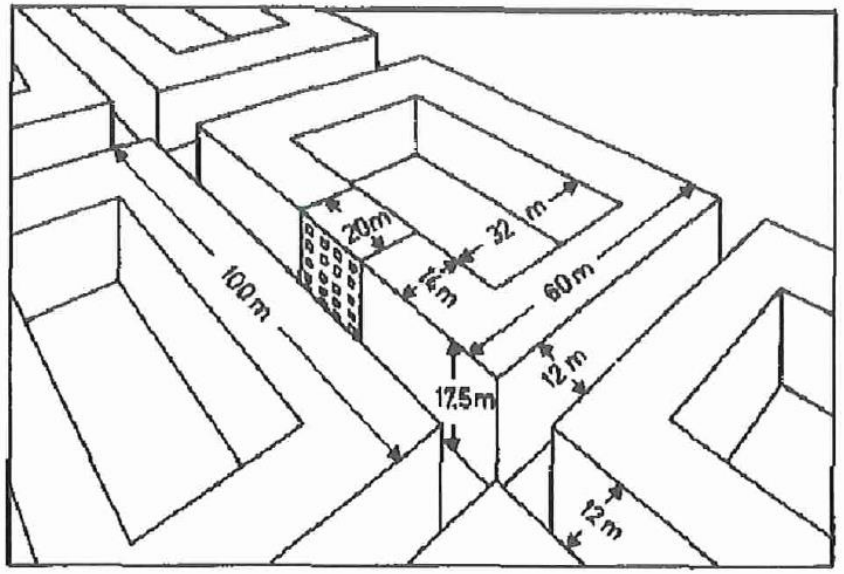
However, if the ground is paved, the contamination level declines very fast:



Natural decline in Cs-137 contamination on street as a function of time in years (based on measurements in Sweden and Germany)



Note: In the assumed Meckbach (GSF, 1987) scenario, about 80% is unpaved ground)



Note: Even in the most ‘urbanised’ Meckbach scenario, unpaved ground is >30%

London (2019)

New Monte Carlo photon transport calculations using MCNP

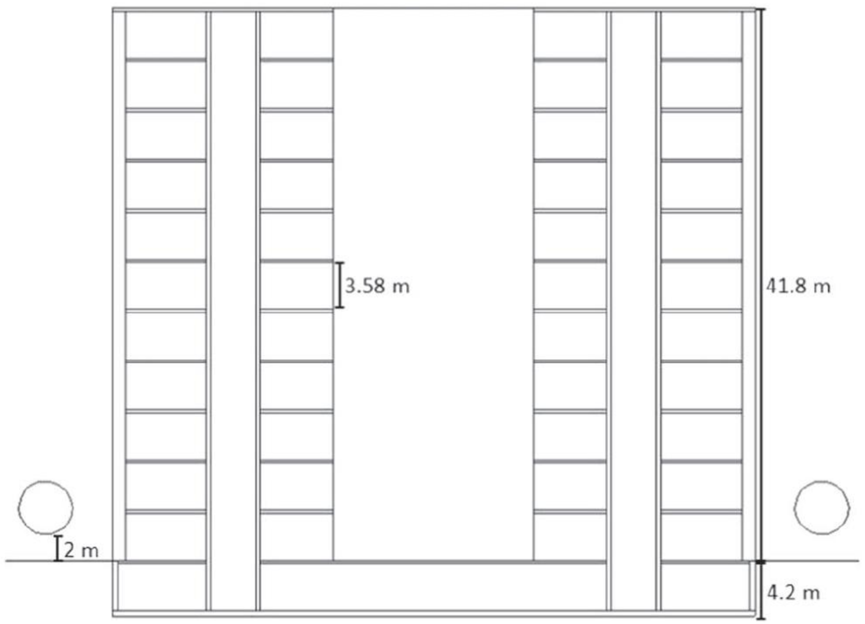


Figure 2. Vertical cut of the glass building for the largest height of eleven storeys.

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Kerma conversion factors for modern glass buildings in radioactively contaminated areas

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Abstract

To improve the estimation of external gamma irradiation from deposited radioactivity in urban environments a model of a modern office or residential building with glass facades was set up with eleven different building heights. Kerma conversion factors for the floors inside the building from contamination on different types of surfaces were determined by using the Monte Carlo code MCNP6 for the primary gamma energies 0.3 , 0.662 and 3.0 MeV and for three different environmental scenarios. The kerma conversion factors were expressed as formulas for each possible deposition area for contaminants. The importance of the determined factors was shown by comparing them to previously generally used factors for multistorey house blocks.

Conclusions:

Good models with reliable parameters are required to calculate e.g. residual doses expected after a recovery strategy in inhabited areas (justification and optimisation of intervention).

This work in CONFIDENCE can extend the ERMIN model with parameters for use in determining endpoint prediction uncertainty ranges.

Further, new methods have been introduced that considerably improve predictions for specific materials (soil types, roof covers, etc.) and specific contaminants.

Tom Charnock (PHE) will elaborate Thursday afternoon on the implications for ERMIN dose estimation of the new work in CONFIDENCE, on the basis of the standard environments currently considered in the European DSS.

It is proposed to expand the current standard inhabited environments with more options with less unpaved areas.

Dose calculations for an additional standard environment with a modern glass front urban house have been made and published – parameters could be included in ERMIN.