Dose rate from gamma radiation in dwellings – a modelling approach

Jonas Högberg & Mats Isaksson

Department of radiation physics
University of Gothenburg

www.gratisfoton.com

Conclusions

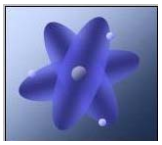
- When predicting the dose rate in a room with structures of low-density concrete the dose rate from adjacent rooms should always be considered
- Considering a centrally located room on the 3rd floor in a 5-storey building, the dose rate in a construction of light weight concrete was found to be nearly ten times the dose rate in a concrete building
- The contribution from the air inside the room can be neglected compared to gamma radiation from the building material

Background and aims

- In Sweden (and in many other countries) the effective dose from gamma radiation is determined by the indoor radiation environment
- The fraction of time spent indoors is about 90 % in Sweden
- Therefore it is interesting to
  - calculate the dose rate in a standard room, taking into account the gamma radiation emitted from the walls, floor and ceiling as well as from the air volume inside the room
  - consider also the contribution from adjacent rooms when estimating the dose rate in a certain room at a given position in a building

The simulation tool

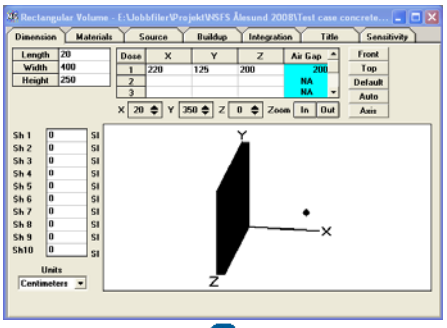
MicroShield 6.20



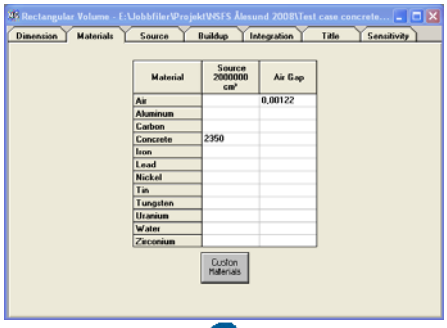
Basics of the calculations

- The photon fluence at a “dose point” is calculated assuming a source of given geometry, radionuclide and activity
- A slab source is modelled by assuming a uniform distribution of radionuclides in a slab of homogeneous composition and summing the contribution from a large number of point sources within the slab
- The specified materials between each point source and the dose point will absorb and scatter the photons, and the attenuation and build-up is calculated
- Both total (with buildup included) and primary photon fluence is calculated but in this work only total fluence has been used for the dose estimations

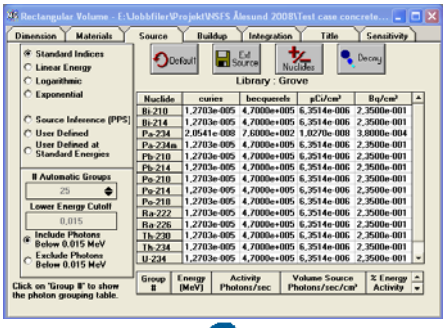
Choice of geometry



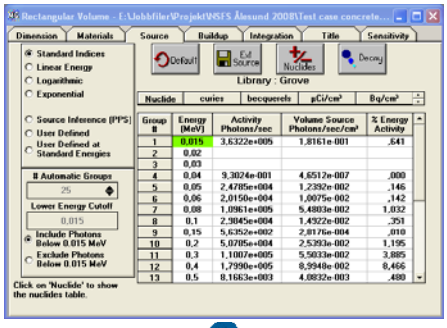
Choice of materials and densities



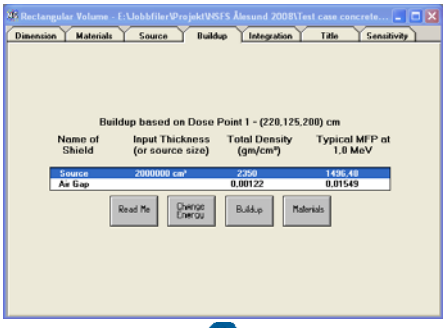
Choice of radionuclides and activities



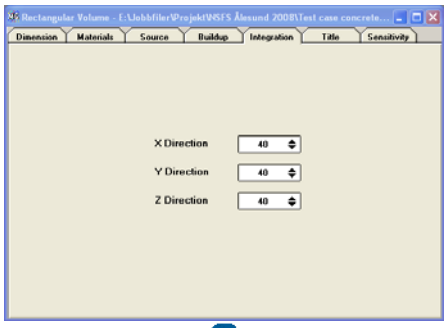
Grouping of photons



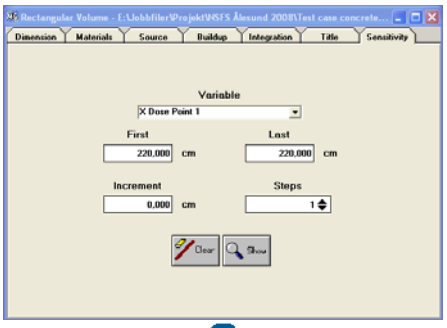
Choice of buildup material



Choice of number of mesh points for integration



Sensitivity analysis for several variables



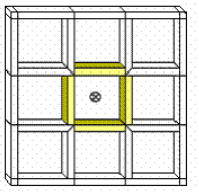
Output – radiation doses

Results (Summed over energies)	Units	Without Buildup	With Buildup
Photon Fluence Rate (flux)	Photons/cm²/sec	1,217e-004	5,778e-004
Photon Energy Fluence Rate	MeV/cm²/sec	1,671e-004	6,207e-004
Exposure and Dose Rates:			
Exposure Rate in Air	mR/hr	2,764e-007	1,061e-006
Absorbed Dose Rate in Air	mGy/hr	2,413e-009	9,259e-009
"	mrad/hr	2,413e-007	9,259e-007
Deep Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2,754e-009	1,069e-008
o Opposed	"	2,394e-009	9,089e-009
o Rotational	"	2,394e-009	9,089e-009
o Isotropic	"	2,148e-009	8,132e-009
Shallow Dose Equivalent Rate	(ICRP 51 - 1987)		
o Parallel Geometry	mSv/hr	2,897e-009	1,126e-008
o Opposed	"	2,801e-009	1,083e-008
o Rotational	"	2,801e-009	1,083e-008
o Isotropic	"	2,252e-009	8,565e-009
Effective Dose Equivalent Rate	(ICRP 51 - 1987)		
o Anterior/Posterior Geometry	mSv/hr	2,476e-009	9,568e-009
o Posterior/Anterior	"	2,293e-009	8,795e-009
o Lateral	"	1,856e-009	6,944e-009
o Rotational	"	2,074e-009	7,892e-009
o Isotropic	"	1,847e-009	6,961e-009

Output – radiation field quantities

Group #	Energy (MeV)	Activity photons/sec	Fluence Rate photons/cm²/sec	Energy Fluence MeV/cm²/sec	Exposure Rate mR/hr
1	0,015	3,632e+005	4,673e-027	7,009e-029	6,012e-030
4	0,04	9,302e-001	8,495e-020	3,382e-021	1,496e-023
5	0,05	2,478e+004	2,573e-011	1,287e-012	3,428e-015
6	0,06	2,015e+004	1,706e-009	1,024e-010	2,033e-013
7	0,08	1,096e+005	4,242e-007	3,393e-008	5,370e-011
8	0,1	2,984e+004	5,867e-007	5,867e-008	8,976e-011
9	0,15	5,635e+002	5,180e-008	7,768e-009	1,279e-011
10	0,2	5,079e+004	8,557e-006	1,711e-006	3,021e-009
11	0,3	1,101e+005	3,199e-005	9,596e-006	1,820e-008
12	0,4	1,799e+005	6,878e-005	2,751e-005	5,361e-008
13	0,5	8,166e+003	3,728e-006	1,864e-006	3,659e-009
14	0,6	2,269e+005	1,177e-004	7,063e-005	1,379e-007
15	0,8	4,598e+004	2,870e-005	2,296e-005	4,367e-008
16	1,0	1,522e+005	1,083e-004	1,083e-004	1,997e-007
17	1,5	8,959e+004	7,959e-005	1,194e-004	2,009e-007
18	2,0	1,258e+005	1,293e-004	2,586e-004	3,989e-007
	TOTALS:	1,537e+006	5,778e-004	6,207e-004	1,061e-006

Conceptual model and assumptions



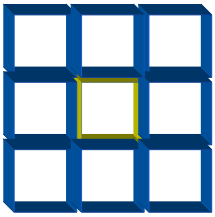
Standard room geometry

- The room was modelled by wall slabs (400×250×20 cm³) and slabs representing the floor/ceiling (400×400×20 cm³)
- The dose point was placed in the middle of the room, with a shortest point-to-source distance of 125 cm
- The total dose rate inside a detached room was modelled by summing the dose rate contributions from all six delimiting slabs
- During the integration process, each slab segment was divided in 40 slices in each spatial dimension (giving a total of 64 000 point sources in each slab)
- The photon fluence at the dose point was thus calculated from 384 000 point sources within the slabs

Activity and radionuclides

- Source: ^{238}U-series elements in equilibrium
- The photons were grouped into 25 groups (15 keV – 2.0 MeV); photons belonging to a given group handled as having the mean energy of the group
- The activity per unit mass of the building materials was chosen to resemble common levels in Sweden:
  - concrete
    - 2350 kg/m³
    - 100 Bq/kg ^{238}U
  - light weight concrete (alum shale)
    - 800 kg/m³
    - 1000 Bq/kg ^{238}U

Collecting the pieces



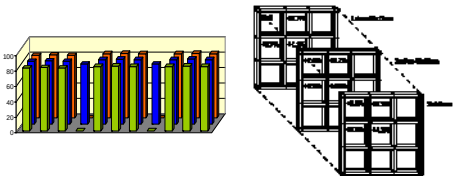
Building model 1

- The quadratic room model was used to create different macro structures in order to compare the dose rates in rooms located in different parts of a block of flats
- Building heights from 1 to 5 floors (ground floor considered equivalent with top floor since the outdoor environment was excluded)
- Three different horizontal positions: corner, semi-centric and central position

Building model 2

- With this modelling approach where the influence from very remote rooms is neglected will:
  - buildings with more than 5 floors be equivalent to a 5-storey building regarding the two bottom floors and the two top floors
  - all the other floors be equivalent to the 3rd floor in the 5-storey building model
- Due to limitations in MicroShield, only shields parallel with the source slabs could be included; in reality, the oblique angles will increase the effective slab thickness and lead to an overestimation of the calculated dose rate

Results



Detached standard room

- The dose rate increases with increasing thickness of building material until saturation is reached and 90 % (54 %) of the saturated dose rate was reached using a thickness of 20 cm concrete (light weight concrete)
- The calculated dose rate due to building materials was
  - concrete: 78.6 nGy h^{-1}
  - light weight concrete: 434 nGy h^{-1}
- The calculated dose rate due to radionuclides in the indoor air was:
  - concrete: 0.30 nGy h^{-1}
  - light weight concrete: 4.8 nGy h^{-1}

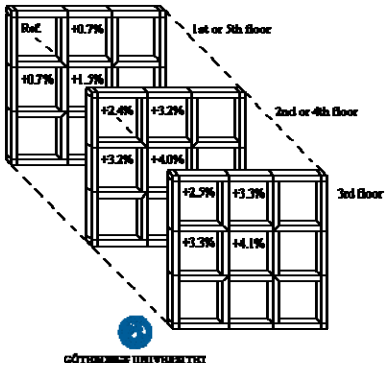
Dose rates in nGy h^{-1} for different locations in a 5-storey building: concrete

- Left: 1st or 5th floor; Middle: 2nd or 4th floor; Right: 3rd floor
- Single bars: detached room, shown for comparison

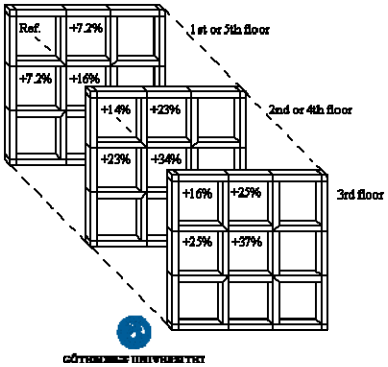
Dose rates in nGy h^{-1} for different locations in a 5-storey building: light weight concrete

- Left: 1st or 5th floor; Middle: 2nd or 4th floor; Right: 3rd floor
- Single bars: detached room, shown for comparison

Relative increase in dose rate: concrete



Relative increase in dose rate: light weight concrete



Thank you!