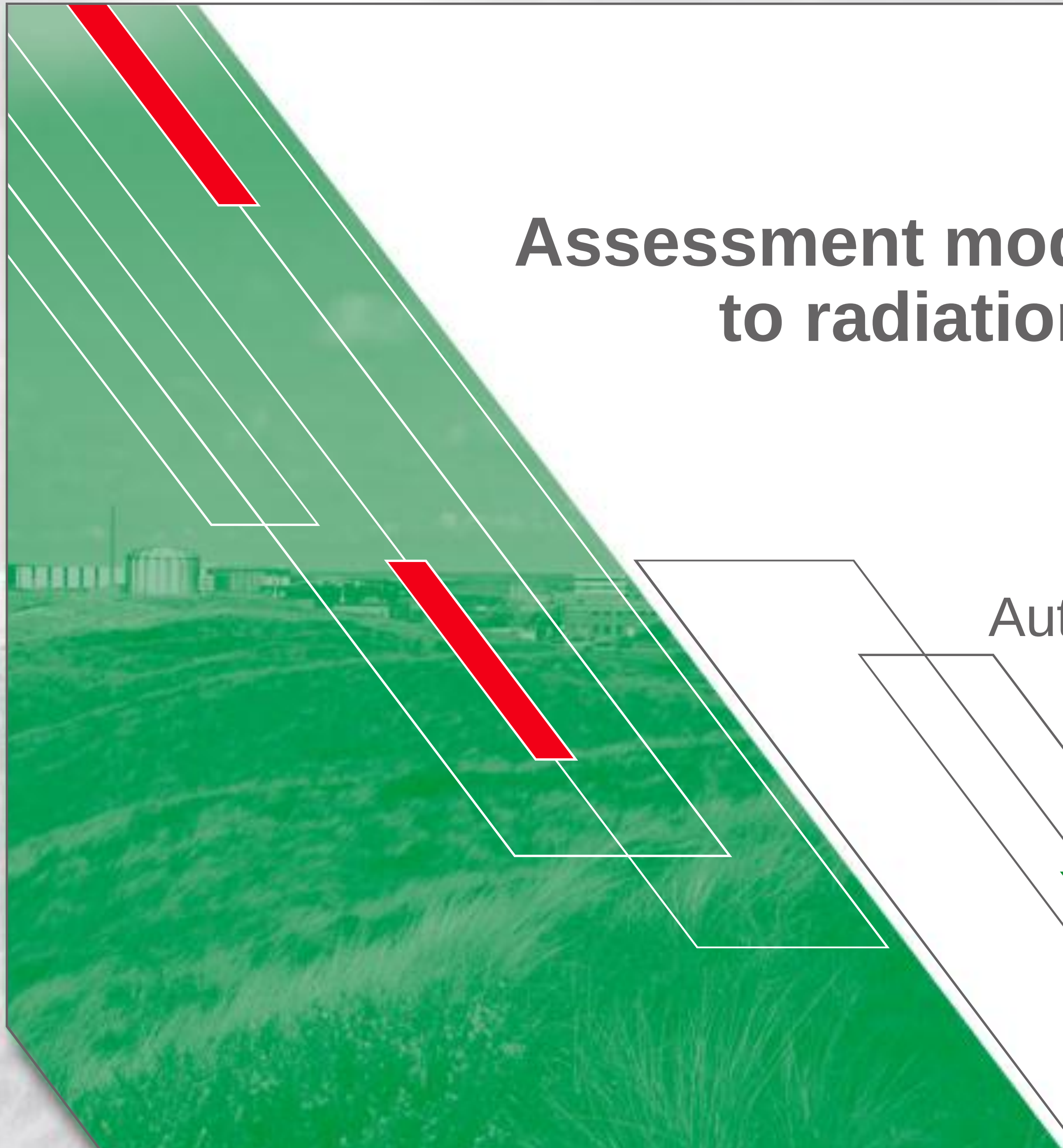
Assessment model of exposure to radiation from building materials



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1.1 Introduction

- Calculation procedure for assessment of both external and internal radiation exposure are laid down in a NEN standard
- The NEN standard is not actively used as its use not enforced through national legislation
- Calculation procedures for assessment to radiation exposure from thoron have been developed recently within NRG

2.1 Radiation performance standard

- This draft decree (Radiation Performance Standard) was supposed to apply to new dwellings.
- The decree aims at limiting and restricting the exposure of residents to radon and external radiation in the dwellings, from the building materials and emissions from underground.
- The radiation performance index is a value for the annual mean radiation exposure that the inhabitant can receive from external and internal radiation.
- The decree never came into force, due to the introduction of the stand-still agreement between goverment and industry.

2.2 Limit values for the radiation performance index

- Radiation levels from radon and external radiation together and calculated in accordance with NEN 7181 at the level of communal rooms and communal areas should not exceed the following limiting values:

  communal area 1,1 mSv/y,

  communal room 0,65 mSv/y.

- For dwellings at ground-floor level, a maximum permitted radon supply into the dwelling from the ground applies in certain situations max 0,0033 Bq-s.m2.

2.3 NEN standards for determining the performance index

- The radiation exposure is determined using the NEN 7181: Stralingsprestatie van een woonfunctie
- The standard provides calculation take account of building materials, ventilation and other building specific factors.
- With NEN 5697 (activity concentration) and NEN 5699 (radonexhalation) the required parameters can be determined.
- Both standard are suitable for mineral based building materials

2.4 Principles of the method

- **Radiation performance**
  - RP_i is the radiation performance (Sv/y), $\Delta C_{Rn;i}$ is the radon concentration diff., DCC is the dose conversion coefficient and $E_{ext;i}$ is the effective dose rate from external radiation.

Performance index: $RP_i = \Delta C_{Rn;i} * DCC + E_{ext;i}$

2.5 Calculation of the effective dose

- **Radon concentration**
  - $\Delta C_{Rn;i}$ is the radon concentration difference between indoor and outdoor. S_i is the source term (Bq/s), A_i is the floor area, ΣA_j and S_{or} are the terms for the other room and Q_i is the ventilation flow.

Radon: $\Delta C_{Rn;i} = (S_i + A_i / \Sigma A_j * S_{or}) / 0.5 * Q_i$

- A database with the exhalation rate for various materials is available
- Correction factors for age, moisture and place are available
- Alternatively the source term can be computed from available experimental data

2.6 Principles of the method

- **External radiation**
  - $E_{ect,i}$ is the external radiation exposure (Sv/y), A_n is the surface area (m^2), m is the mass per m^2 and $c_{l\text{-}eff}$ is conversion from dose rate to effective dose rate (Sv/Gy).

External: $E_{ext,i} = \Sigma(A_n * m_n / m_{ref} * F_{dose}) / \Sigma A_n * c_{l\text{-}eff}$

- Dose factor needs to be computed for each substructure

$$F_{dose} = (k_{Ra\text{-}226} * a_{Ra\text{-}226} + k_{Ra\text{-}228} * a_{Ra\text{-}228} + k_{K\text{-}40} * a_{K\text{-}40})\ \rho / \rho_0$$

- Correction for density is included.
- Nuclide specific conversion coefficients to compute the dose factor at reference density are provided.

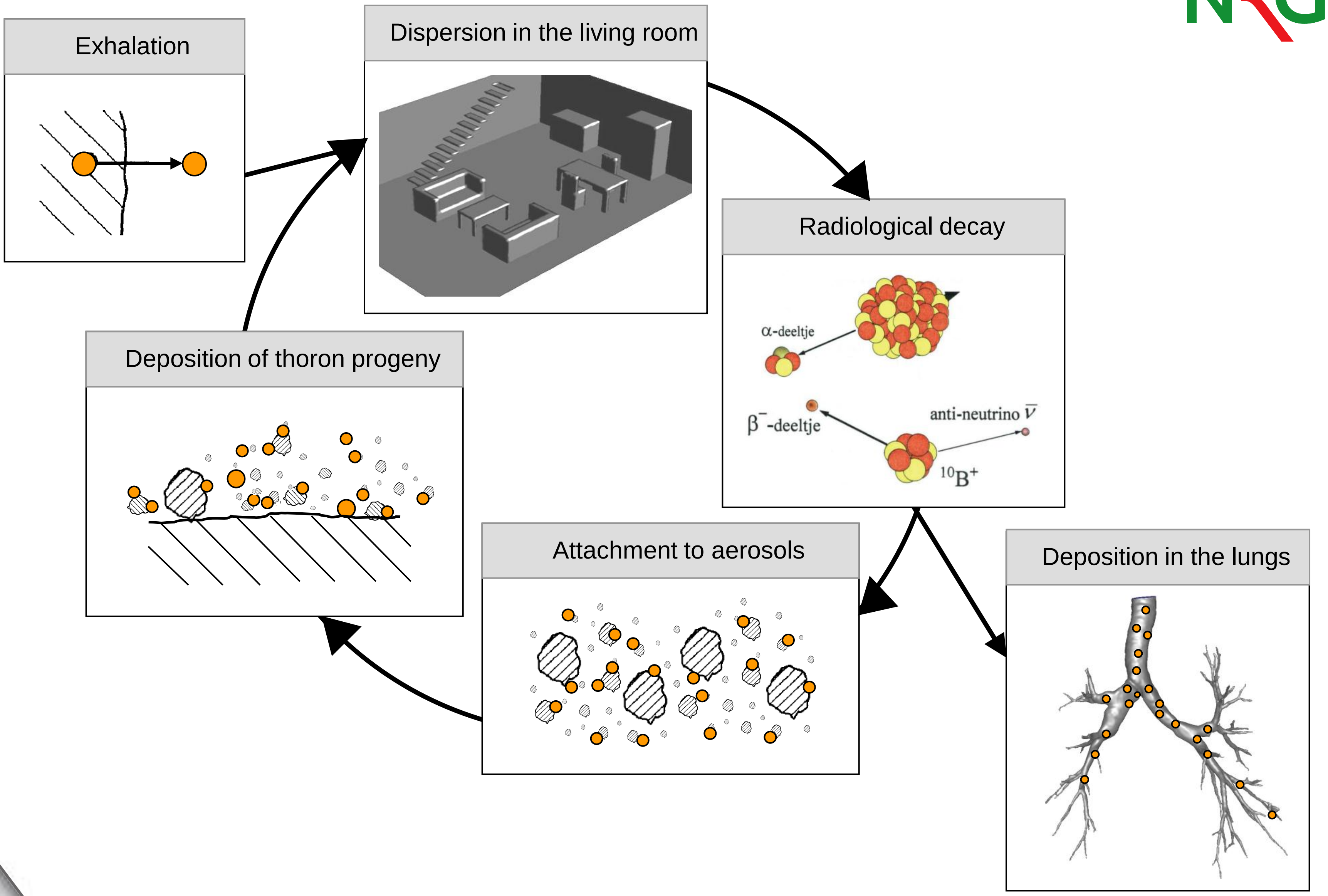
2.7 Features and limitations

- Radon exposure is based on the assumption that there is uniform distribution
- Calculation procedures for external radiation are based on results from multi-purpose Monte-Carlo (MC) codes.
- MC codes are laborious and execution of the computation is time consuming
- These alternative methods then make corrections for parameters like thickness, density, with certain codes also adjustments for dimensions of the construction and radon release are feasible.

3.1 Assessment method for thoron

- Crude estimates suggest that exposure to thoron may well exceed that of radon.
- The thoron source comes from the stone-based building materials in the house.
- Contrary to radon the thoron concentration in the living room varies due to its short half-life.
- Due to thoron's non-uniform concentration an effective dose from thoron progeny is difficult to establish.
- The aim of this study is to establish the thoron progeny concentrations in a typical Dutch house using computer simulation.

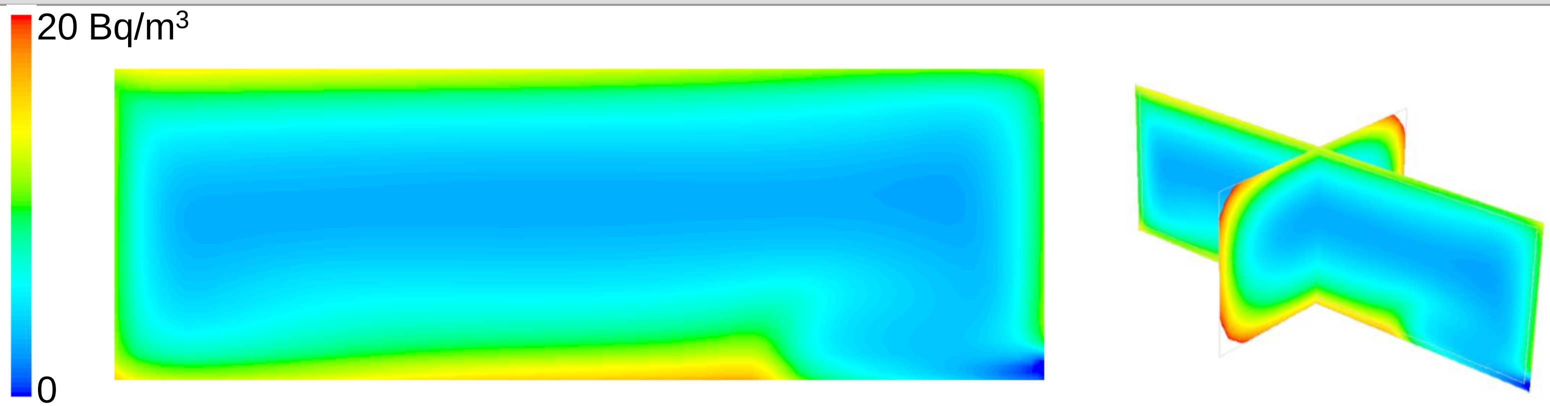
2.1 From thoron exhalation to radiological dose



3.2 Radon versus Thoron

Radon ^{222}Rn

Thoron ^{220}Rn



3.4 Relative contribution from the thoron progeny

Nuclide	PAE per atom (10^{-12} J)	PAE per Bq (10^{-9} J/Bq)	Relative contribution
^{216}Po	2,33	0	0.000
^{212}Pb	1.24	68	0.913
^{212}Bi	1.24	6	0.087
^{212}Po	1.41	0	0.000
^{208}Tl	0.00	0	0.000

Large contribution

Small contribution

3.3 Calculation of the effective dose

- **Radon ^{222}Rn**
  - F_{Rn} is the equilibrium factor of 0.4 and DCC is the Dose Conversion Coefficient of 9 nSv/(Bq·h·m^{-3}).

Radon: $E_{Rn} = {}^{222}Rn * F_{Rn} * DCC_{Rn}$

- **Thoron ^{220}Rn**
  - DCC is the Dose Conversion Coefficient of 40 nSv/(Bq·h·m^{-3}).

Thoron: $E_{Tn} = (0.913\ C_4 + 0.087\ C_5) * DCC_{Tn}$

2.16 Equilibrium Eq. Concentration and Equilibrium factor

- Equilibrium Equivalent Concentration (EEC).
  - Weighted accumulation of the progeny concentrations as a measure for the potential alpha-energy concentration (Bq/m3).

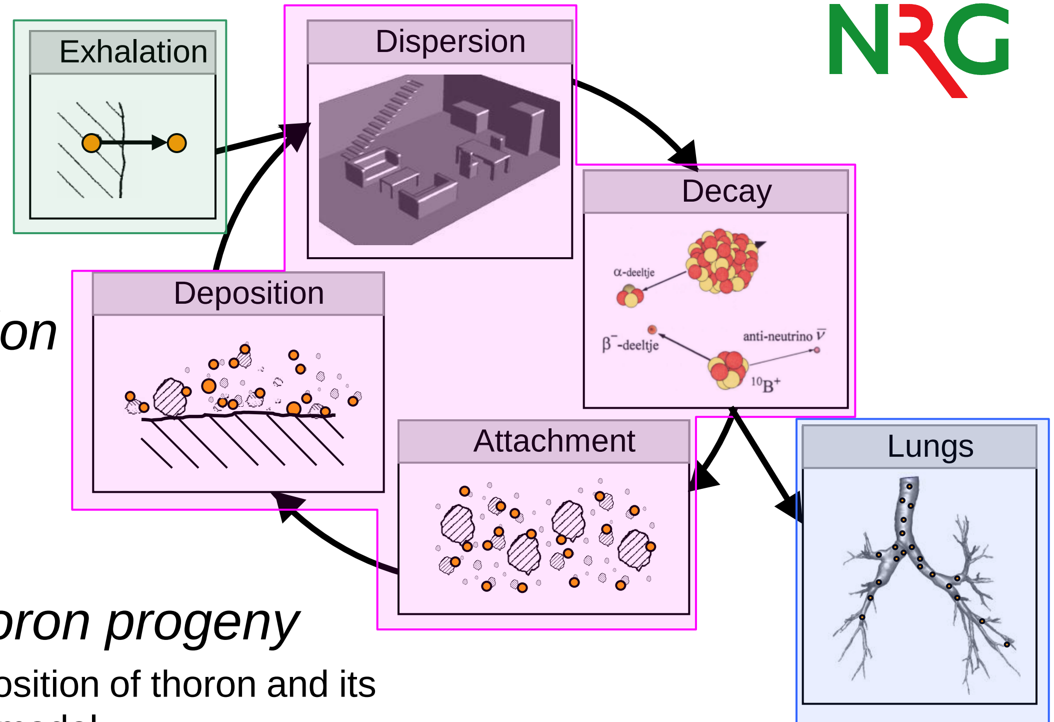
Radon: $EEC = 0.105\,C_1 + 0.515\,C_2 + 0.380\,C_3$

Thoron: $EEC = 0.913\,C_4 + 0.087\,C_5$

^{218}Po (C_1), ^{214}Pb (C_2), ^{214}Bi (C_3), ^{212}Pb (C_4), ^{212}Bi (C_5)

- C_1 to C_1 are the concentrations of the various progeny products in Bq/m3
- Equilibrium factor
  - The ratio between EEC and gas concentration.
  - The equilibrium factor for radon in the indoor environment is estimated to be around 0.4.

2.2 Simulation methodology



Estimate thoron exhalation

The thoron exhalation is derived theoreticallly.

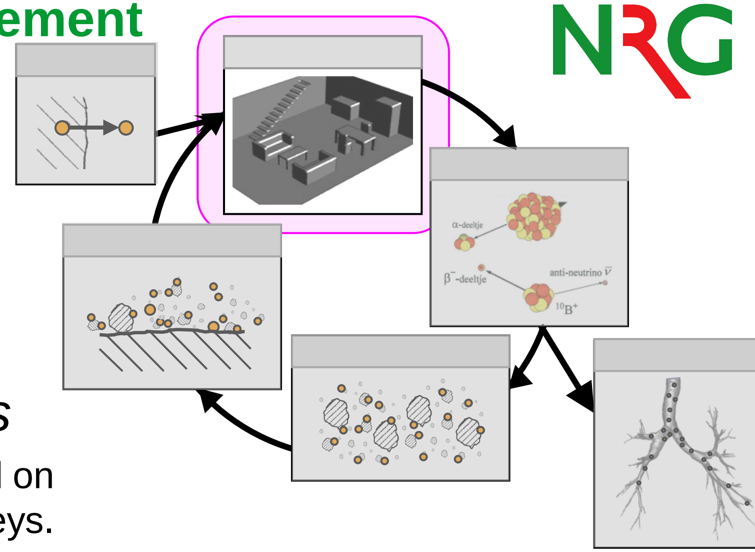
Modelling thoron and thoron progeny

The dispersion, formation and deposition of thoron and its progeny is simulated using a CFD model.

Calculation effective dose

The dose is calculated using the simulated progeny concentrations and the dose conversion coefficients as published in UNSCEAR.

2.3 CFD simulation of the indoor air movement



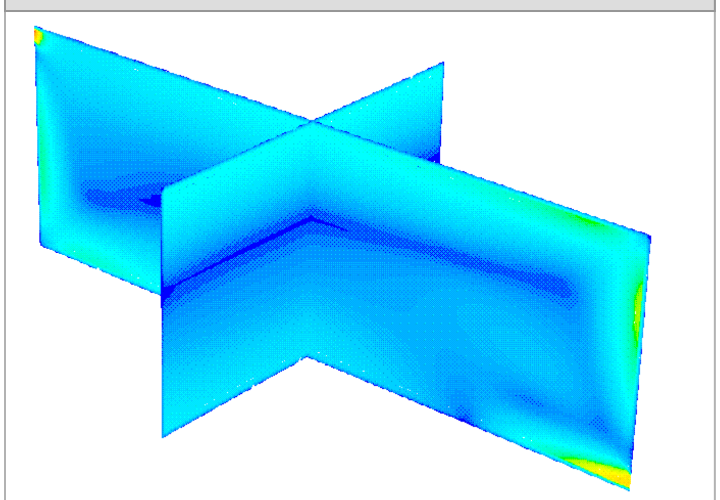
1. *CFD simulation*

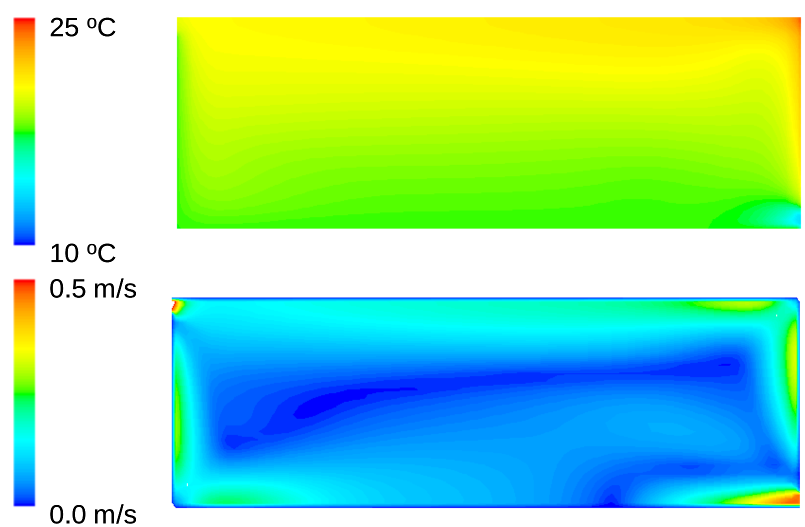
   The CFD software FLUENT© is used as a framework for the simulation.

2. *Geometry and boundary conditions*

   The geometry and boundary conditions are based on information from a number of Dutch building surveys.

Contourplot of the airflow pattern

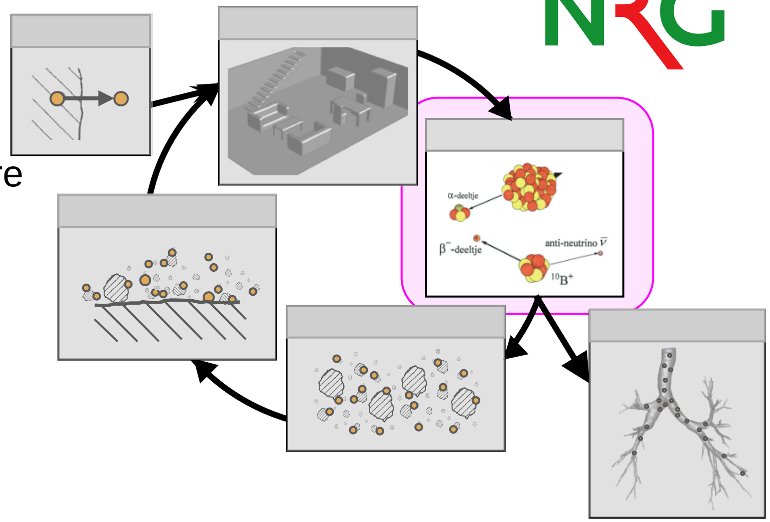


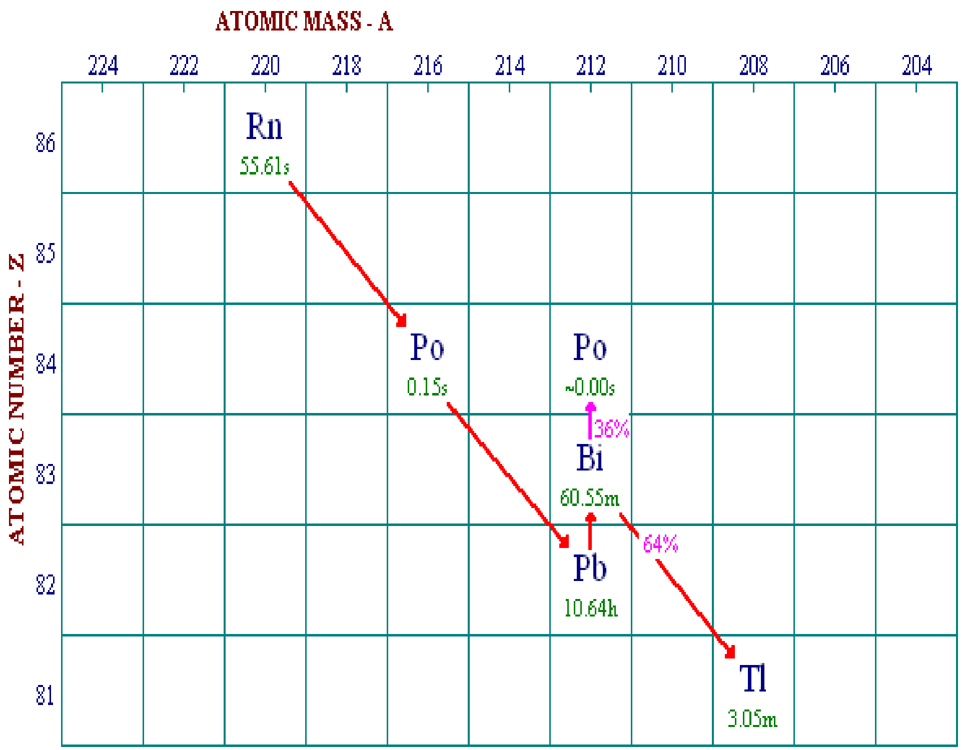


2.4 Nuclear decay

Thoron decay chain

The most important isotopes from the thoron decay chain are incorporated in the CFD software.

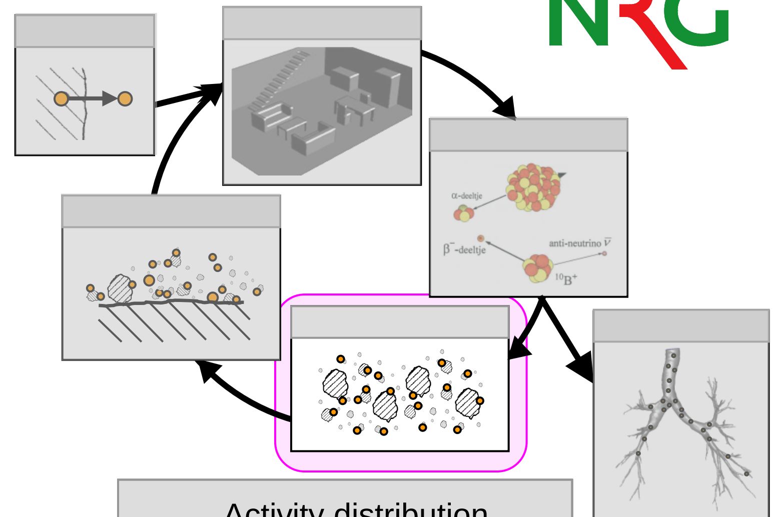




The nuclear decay:

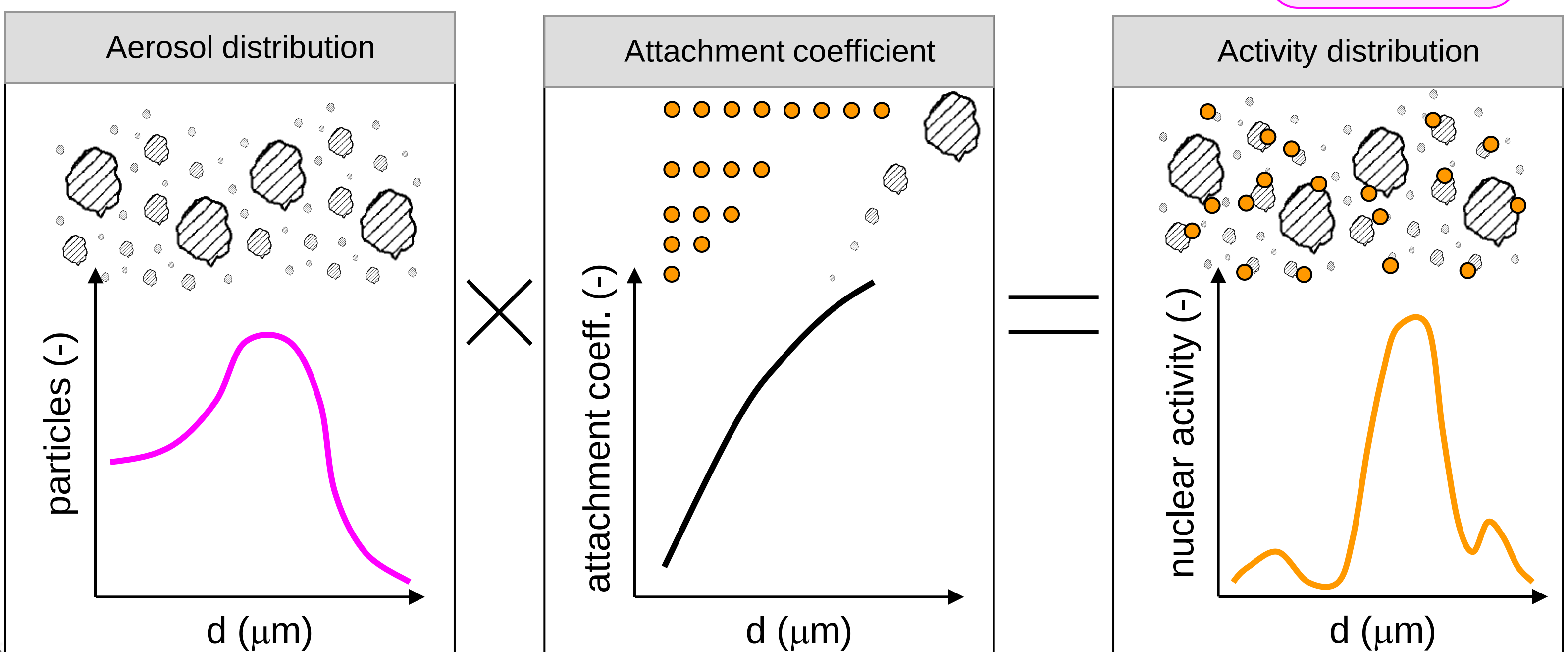
1. The decay of progeny products is incorporated as a extra sink.
2. The production of progeny products is incorporated as a extra source.

2.5 Attachment of nuclides to aerosols

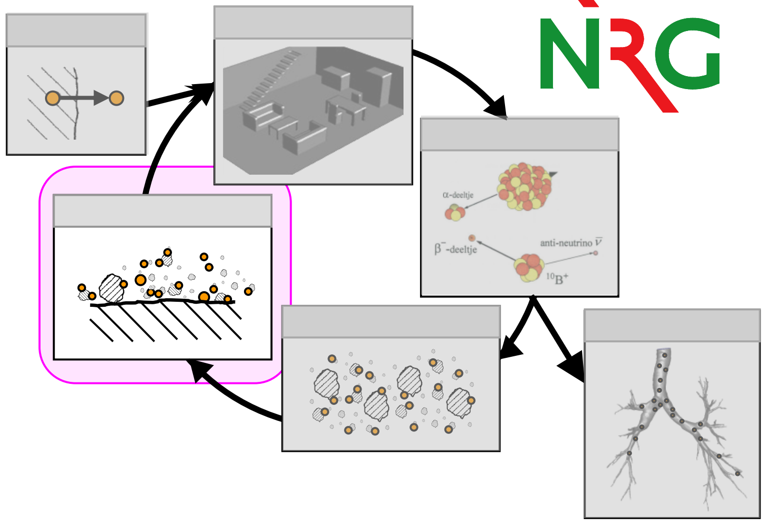


Aerosol concentration

The presence of airborne aerosols is an important parameter in the attachment of nuclides, and is strongly influenced by human activity.



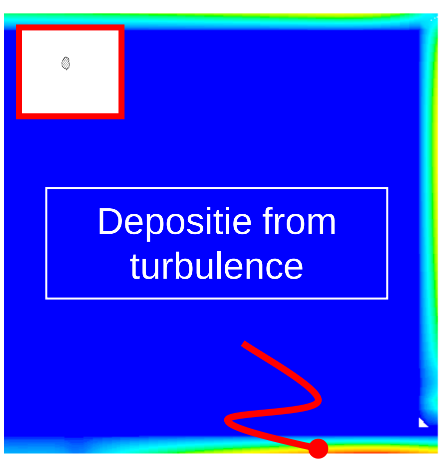
2.6 Deposition of progeny products

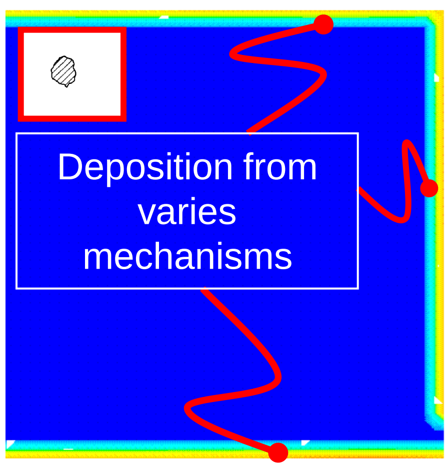


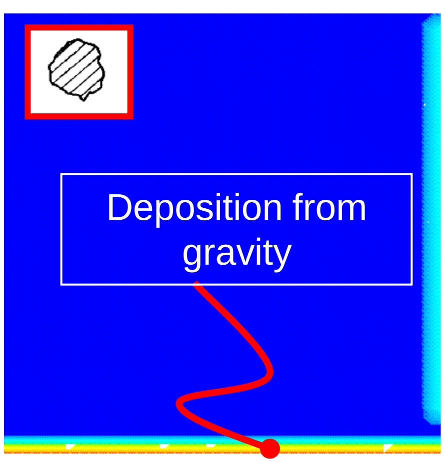
Deposition mechanism

1. *Deposition from gravity*
2. *Deposition from turbulence near the wall*
3. *Deposition from Brownian motion*

Depositie velocity on the floor, walls and ceiling		
Small size aerosol	Middle size aerosol	Large aerosol

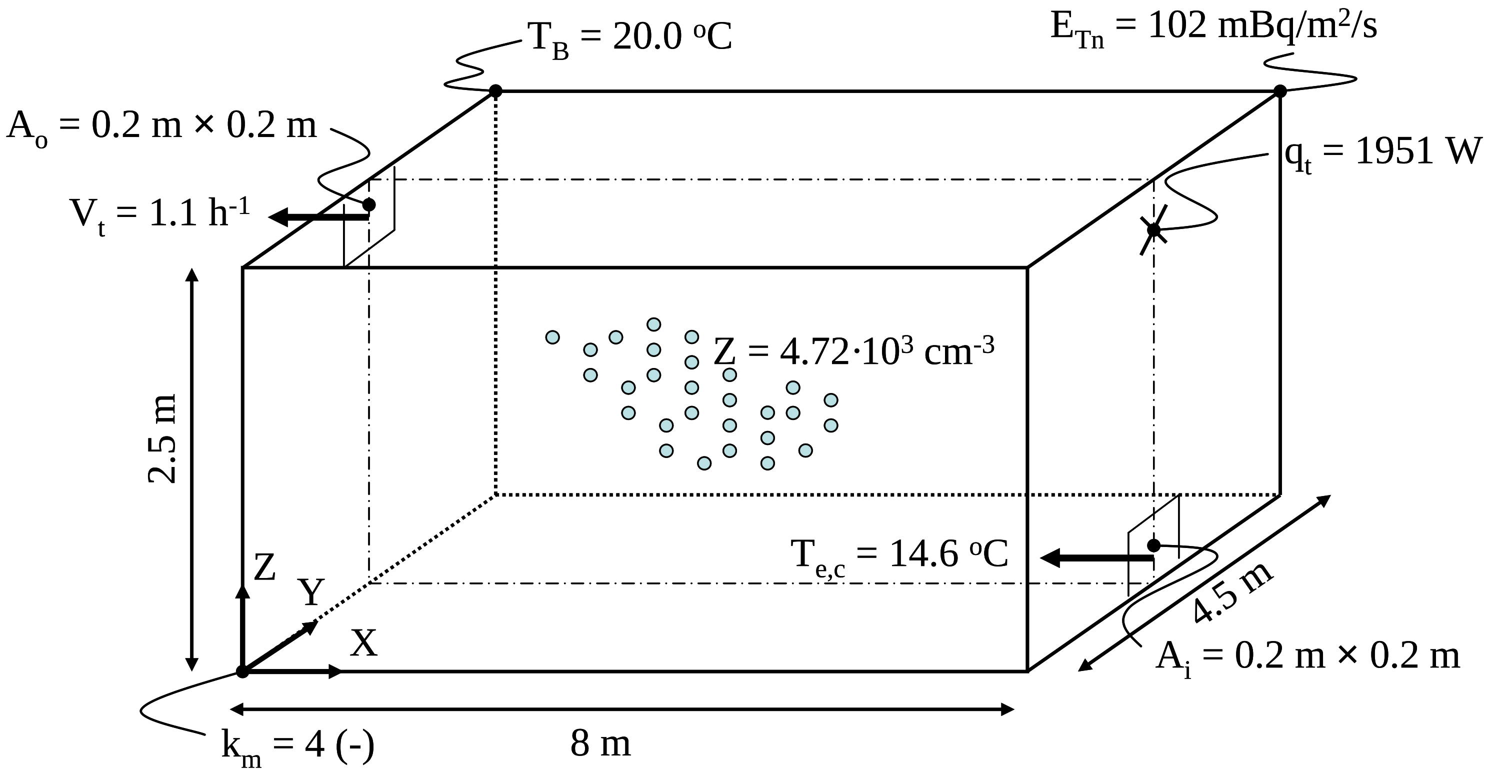




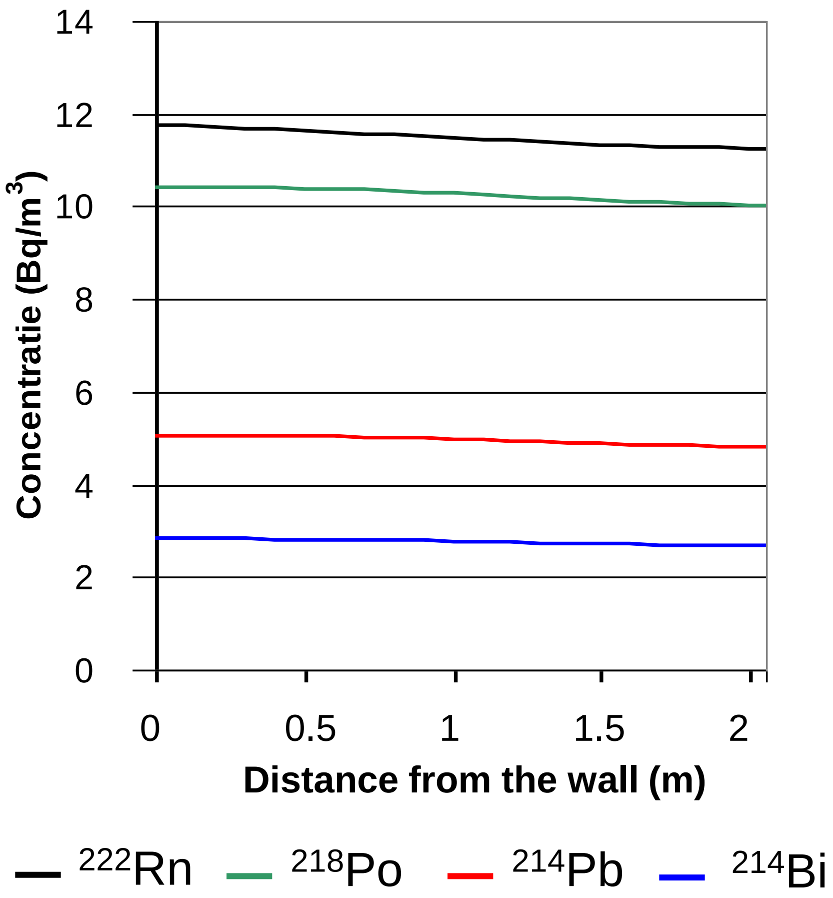


3.1 Details of the model setup

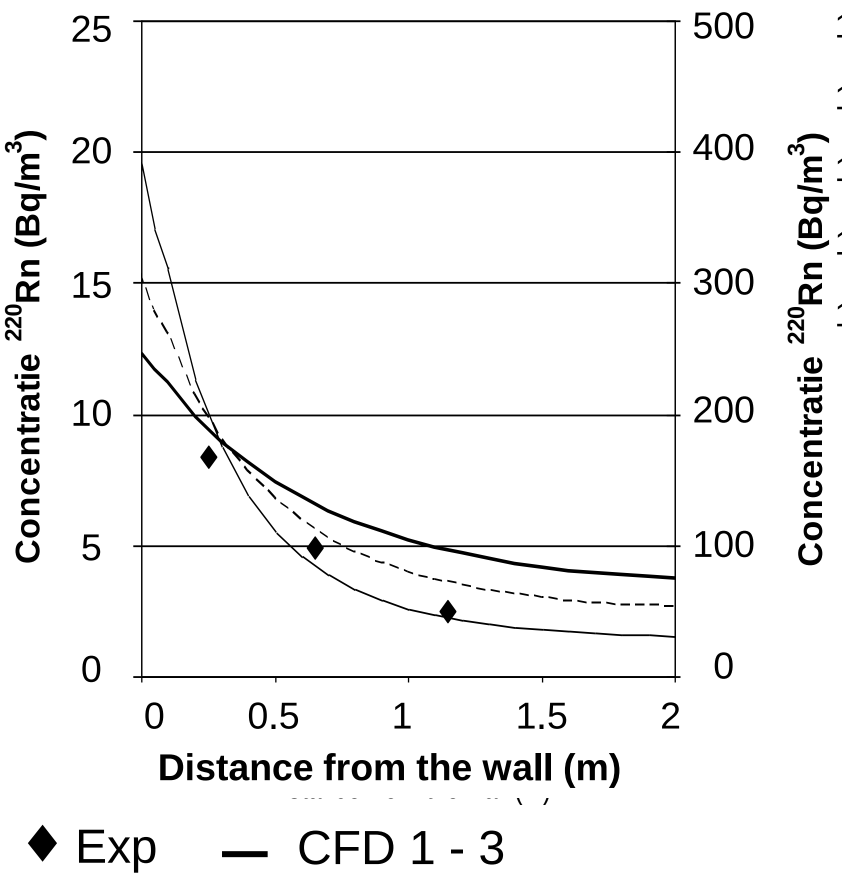
Simulation model



3.3 Radon & radon progeny concentrations

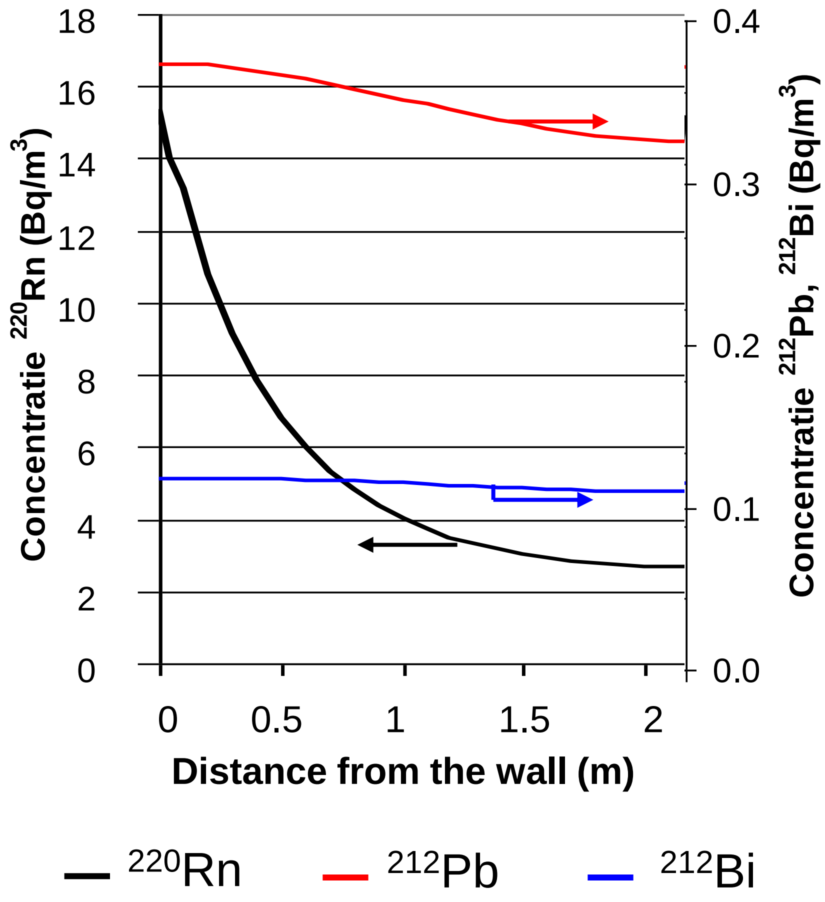
Radon	Summary
	- *The radon concentration and its progeny is nearly uniform.* - *The mean radon concentration is around 12 Bq/m^3.* - *The radon equivalent factor F_{Radon} is 0.4.*

3.4 Thoron concentrations

Thoron	Summary
	- *The thoron concentration profile is comparable with experimental data.* - *The concentration profile depends on the air movement in the room as reflected in the diffusion coefficient.*

3.5 Thoron & thoron progeny concentrations

Thoron & thoron progeny



Summary

- *The thoron progeny concentrations are uniform.*
- *The EEC from thoron is 0.33 Bq/m^3*
- *The EEC depends on a range of variables including: deposition surface & ventilation.*

4.1 Calculation of the effective dose

Radon dose versus thoron dose

The dose from thoron is roughly 25% of the total dose from radon isotopes.

Radon ^{222}Rn

^{222}Rn (Bq/m^3)	F_{Rn} (-)	DCC_{Rn} (nSv/(Bq·h·m^{-3}))	E_{Rn} (mSv/yr)
12,2	0,4	9	0,29

Thoron ^{220}Rn

^{212}Pb (Bq/m^3)	^{212}Bi (Bq/m^3)	EEC (Bq/m^3)	DCC_{Tn} (nSv/(Bq·h·m^{-3}))	E_{Tn} (mSv/yr)
0,35	0,11	0,33	40	0,09

4.2 Calculation *worst-case* scenario

1. Assumptions

   The thoron source term is based on a 10 mm thick layer of plaster material with a ^{224}Ra concentration of 240 Bq/kg applied on all walls and ceiling.

2. Thoron source term

   Consequently, the source term is 24 times higher than under normal circumstances; as a result the effective dose increases with a factor of 24.

Thoron ^{220}Rn

^{212}Pb (Bq/m^3)	^{212}Bi (Bq/m^3)	EEC (Bq/m^3)	DCC_{Tn} (nSv/(Bq·h·m^{-3})	E_{Tn} (mSv/yr)
8,25	2,59	0,33	40	2,12

Is 0,09 mSv under normal circumstances!

5.1 Conclusions

- A number of models for assessing the radiation exposure are available in the Netherlands
- The exposure from radon in The Netherlands is around 0.29 mSv
- A new generic assessment model for thoron exposure is developed recently
- The estimated effective dose from thoron is 0,09 mSv
- The thoron dose can reach as much as 2 mSv

END