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The optimalization of calibration procedures for field gamma spectrometers

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Introduction

- Field gamma spectrometry can be complementary method in radon risk mapping.
- Field spectrometers are calibrated using calibration pads, that are designed for single measurement geometry.
- Detailed description of radiation field around these pads can help to expand the options for calibration in existing facilities.

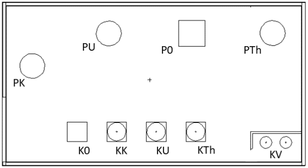
Calibration in field spectrometers

- General principle described in detail in "Radioelement mapping" [IAEA 2010].
- Measurement on 4 calibration standards (pads): 3 with enhanced concentration of K, U, Th and one low activity.
- Original procedure evaluates data in selected windows.
- Alternative methods exist (like Full spectrum analysis).
- MC simulation can be used mainly to estimate correction factors.

Calibration facility Straz pod Ralskem, Czech Republic

- Surface standards
  - PK, PU, P0 a PTh
  - cylinder: ∅ 1.9m, ↕ 0.62m
  - rectangular: P0 2x2x0.8m
- Well logging standards
  - KK, KU, KTh a K0
  - cylinder: ∅ 1.4m, ↕ 1.2m
  - K0 1.5x1.5x1.8m
- Layered well logging
  - set of rings
  - ∅ 0.9m, ↕ 0.1m

Details:
http://www.gammastandard.com/



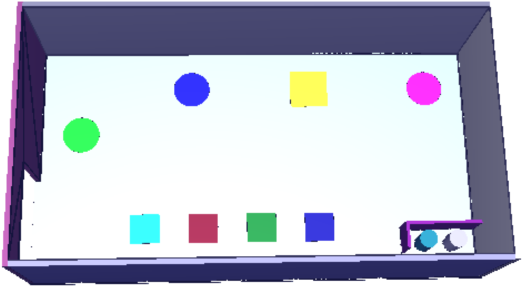
Model: creation and verification

- First version of the model
  - based on literature, on site measurements and taken samples
- First verification measurement (portable HPGe)
  $\Rightarrow$ major adjustments needed
- Step by step adjusting the model to fit the verification measurements
  - major adjustments made in source distribution
  - minor adjustments in building material density
  - minor adjustments in geometry (floor thickness)
- Final verification measurements (scintillation detectors)
  $\Rightarrow$ the model deviates from reality less than 10%

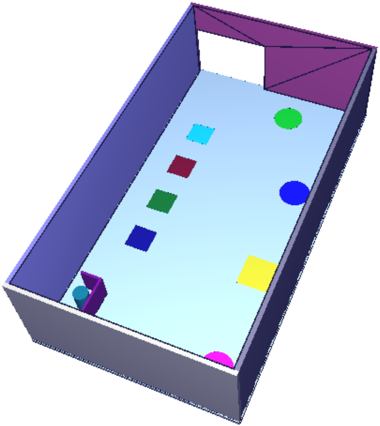
Model: geometry

- Geometry based on literature and on site geometry measurements.
- Density and activity based on literature and samples taken on site (bricks, plaster, ground...)
- Some parameters had to be estimated and later adjusted (density of the calibration pads, activity of the pads...)
- Model includes: walls (divided into brick and plaster) - S, N, W, E; floor, ground, all standards, small shielding wall and air inside.

Model: geometry



Model: geometry



Model: source distribution

- used "Dependent source" function of MCNP
- In one run only one of the three sources (K, U, Th) is generated in the whole model.

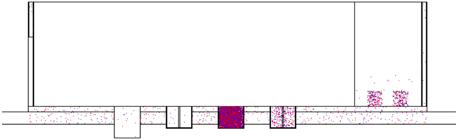


Figure: Uranium distribution in the model (ZY plane)

Model: source distribution

- used "Dependent source" function of MCNP
- In one run one of the three radionuclides (K, U, Th) is generated in the whole model.

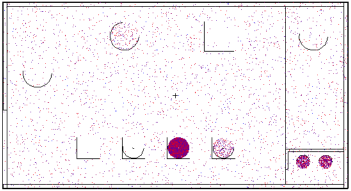


Figure: Uranium source distribution, XY plane.

Model: source distribution

- used "Dependent source" function of MCNP
- In one run only one of the three sources (K, U, Th) is generated in the whole model.

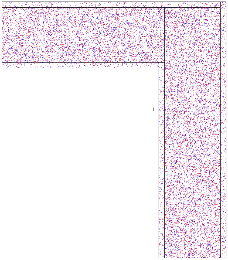


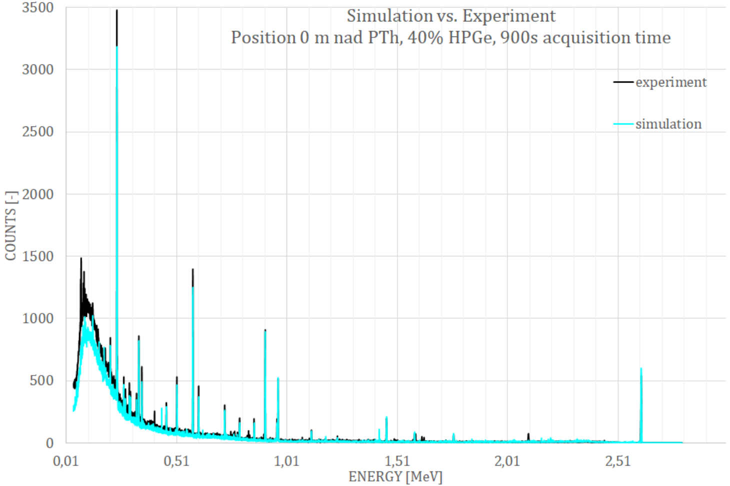
Figure: Thorium source distribution - wall detail.

Initial verification: experimental set up

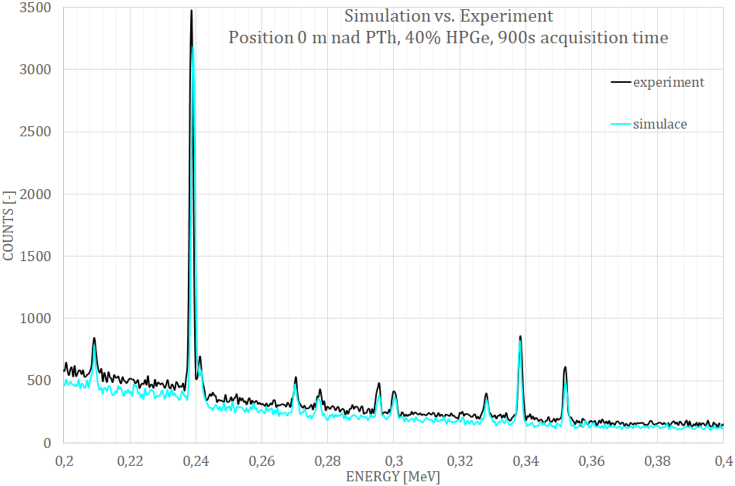
- 15 verification points selected.
- Gamma spectra measured with 40% HPGe portable detector.
- Same situation simulated with previously verified model of the HPGe detector.
- Comparison (model vs. experiment) made for areas of 16 peaks K(1), U(8), Th (7).

^{40}K: 1460,8 keV
^{238}U: 186,2; 295,2; 351,9; 609,3 ; 1120,3; 1238,1; 1764,5; 2204,2 keV
^{232}Th: 238,6; 338,3; 583,2; 727,3; 911,2; 969,0; 2614,5 keV

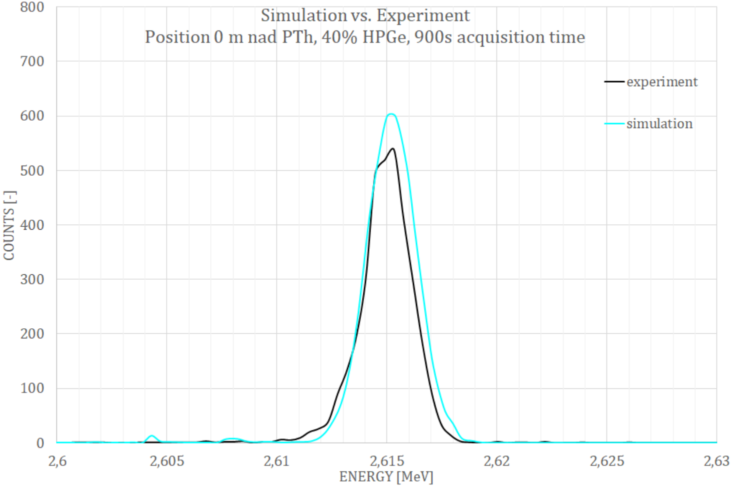
Final version the model: HPGe spectra



Final version the model: HPGe spectra



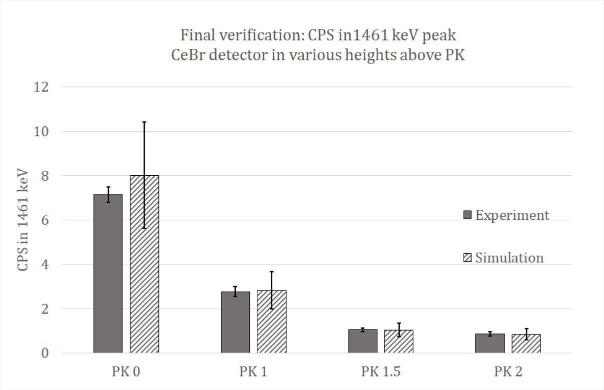
Final version the model: HPGe spectra



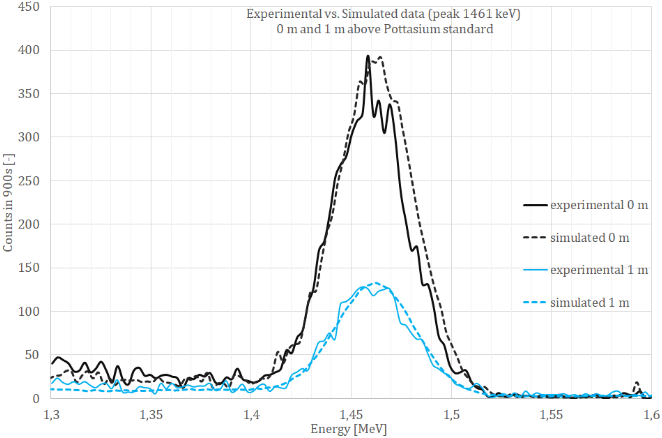
Final verification

- Model accuracy tested inside and also outside previously verified region.
- Scintillation spectrometers used: NaI (3"x3"), CeBr (2"x2"), LaBr (2"x2").
- Same situations simulated with previously verified models of these detectors.

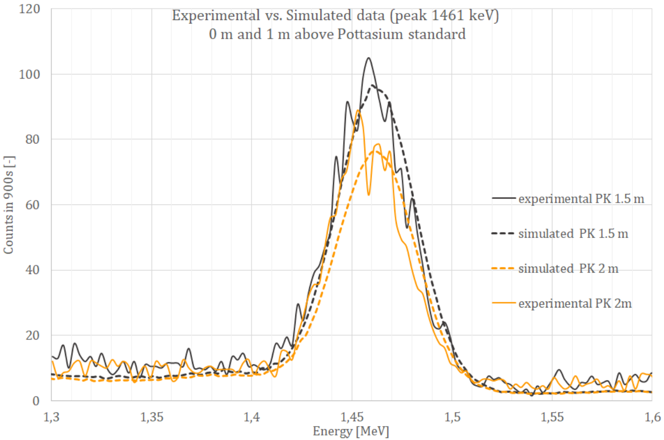
Final verification: Testing the model up to 2 m above surface



Final verification: Testing the model up to 2 m above surface



Final verification: Testing the model up to 2 m above surface



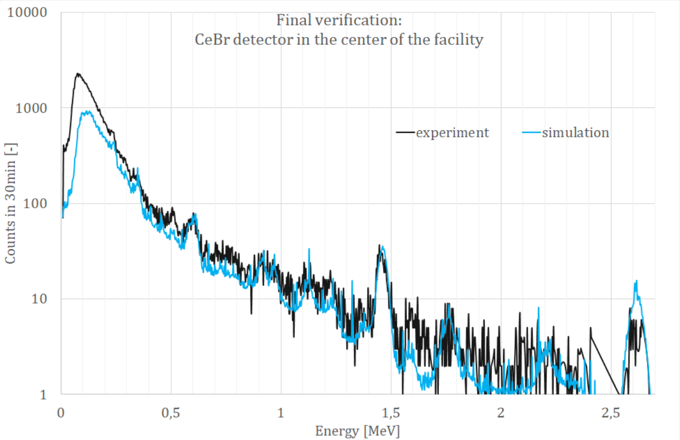
Final verification
Position in the centre of the facility

- CeBr detector on the ground in the centre of the facility.
- Low count rate measurement - 30 minutes spectrum acquisition.

Table: Comparison of CPS for CeBr measurement on the ground in the centre of the facility.

	experiment	model	model/experiment
609 keV	0,518	0,549	1,06
1461 keV	0,277	0,298	0,93
1764 keV	0,033	0,036	1,10

Final verification
Position in the centre of the facility



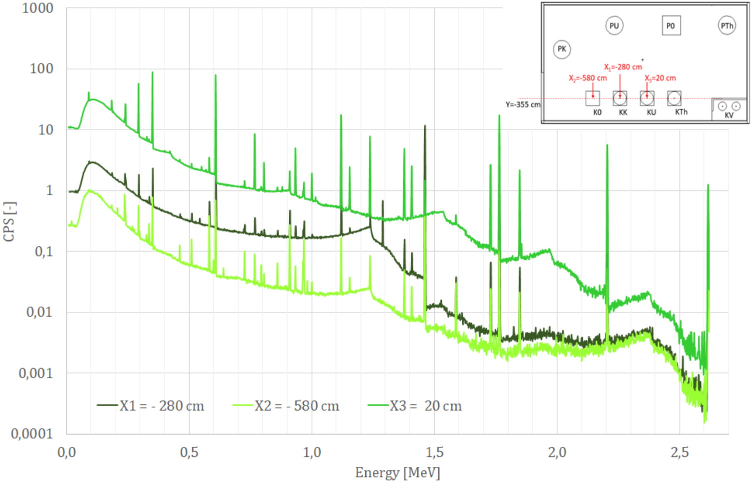
Examples of model application

- Custom detector spectra simulation
- Dose rate in air mapping
- Building structures contribution to measured spectra

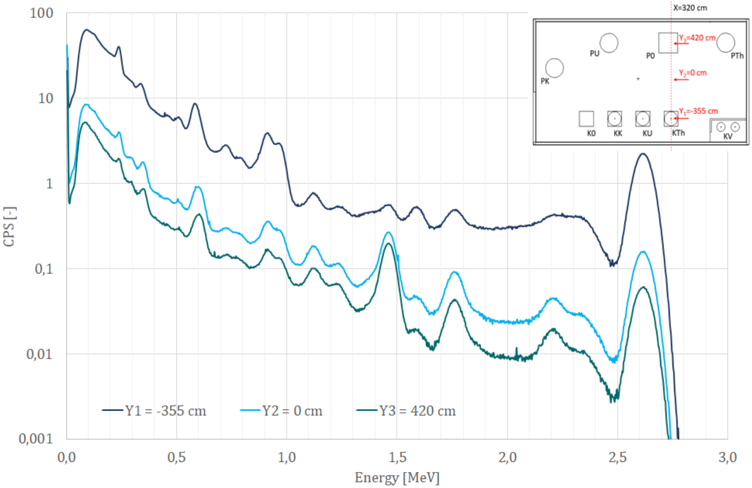
Custom detector spectra simulation

- By adding a model of custom detector, a full gamma spectrum can be simulated in any position.
- Areas with a high field gradient may be prone to positioning error.
- Calculating the spectra can be useful in the preparatory phase of an experiment, e.g. for estimating required time of measurement etc.

Spectrum simulation: HPGe above borehole standards

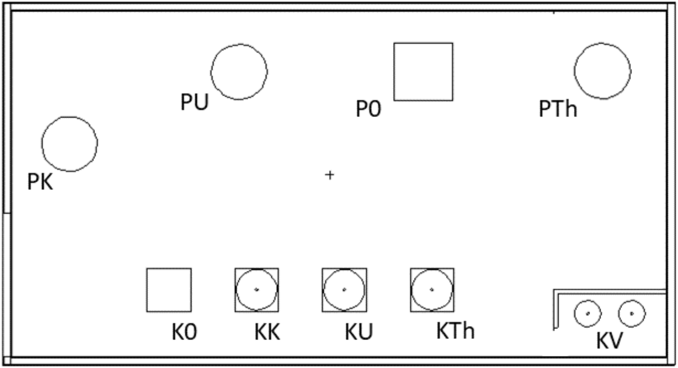


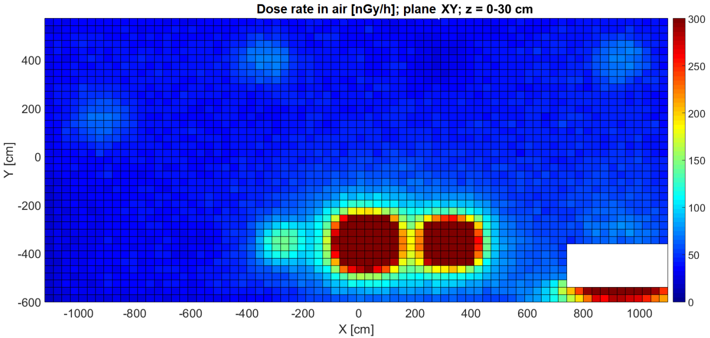
Spectrum simulation: NaI(Tl) at various positions

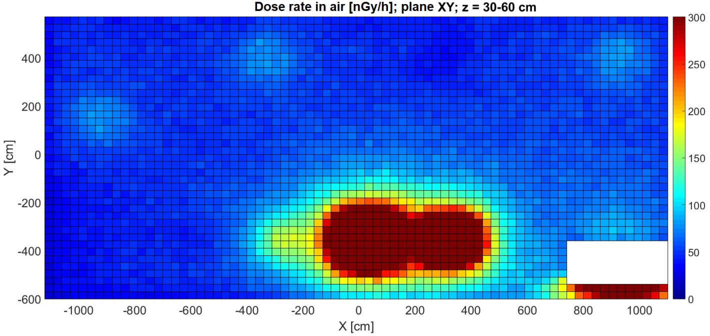


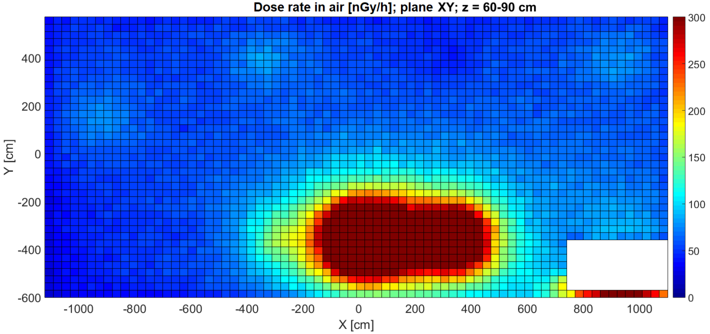
Dose rate in air mapping

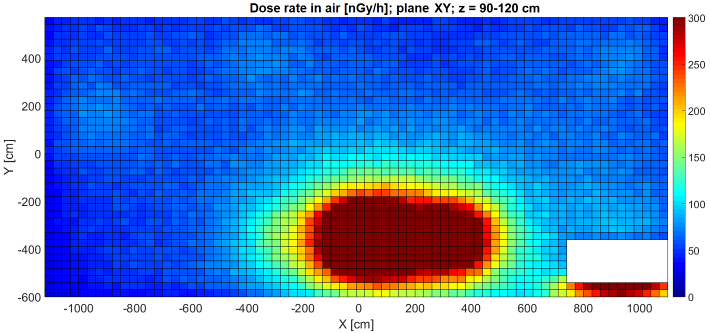
- Using Meshtally option it is possible to calculate **3D matrix of Dose Rate** in air averaged over defined element of mesh (30x30x30 cm in following example).
- This option is good for getting an **overall overview of the radiation field**.
- It is necessary to choose a compromise between spatial resolution and calculation time requirement.

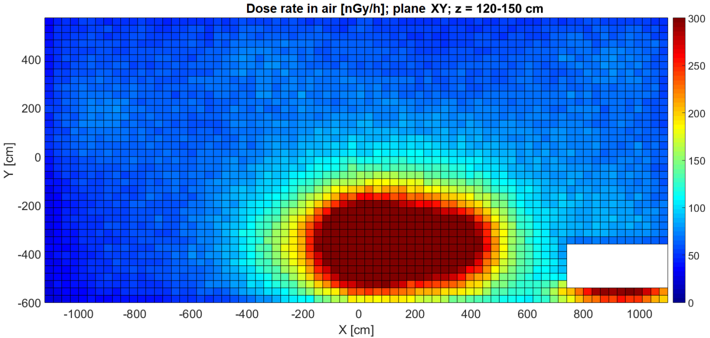

PU
PO
PTh
PK
KO
KK
KU
KTh
KV

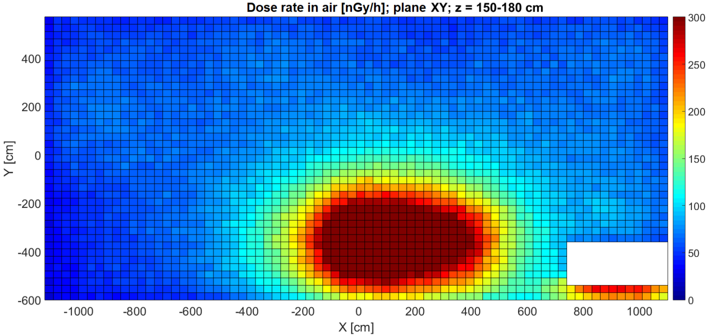

Dose rate in air [nGy/h]; plane XY; z = 0-30 cm
Y [cm]
X [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0

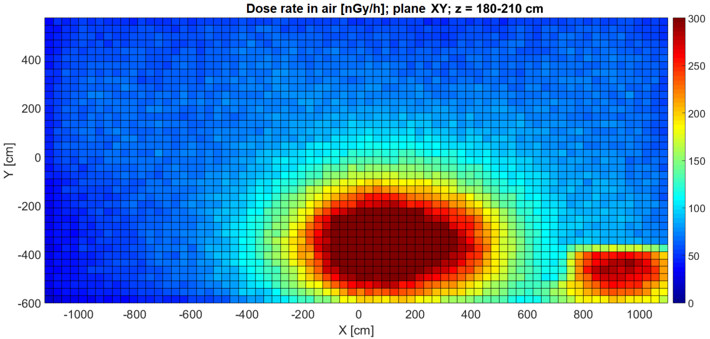

Dose rate in air [nGy/h]; plane XY; z = 30-60 cm
Y [cm]
X [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0

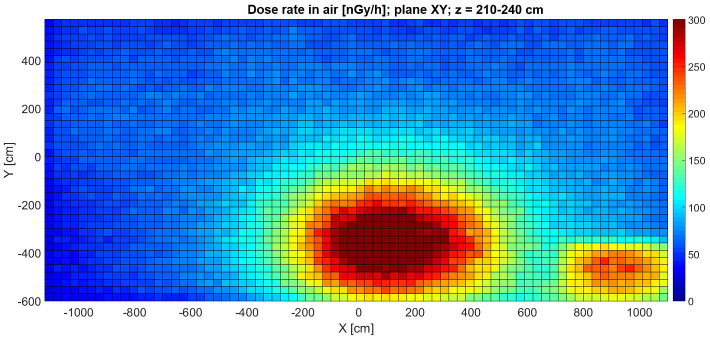

Dose rate in air [nGy/h]; plane XY; z = 60-90 cm
Y [cm]
X [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0

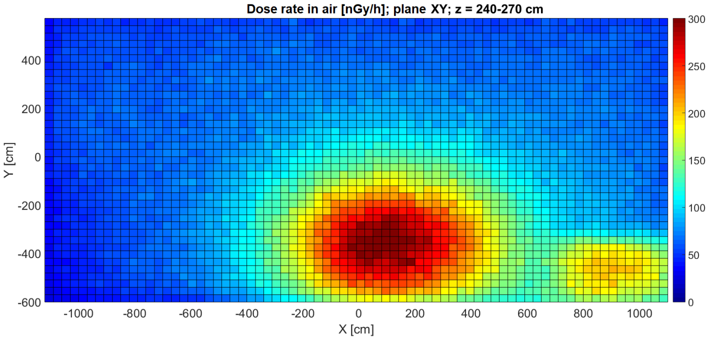

Dose rate in air [nGy/h]; plane XY; z = 90-120 cm
Y [cm]
X [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0

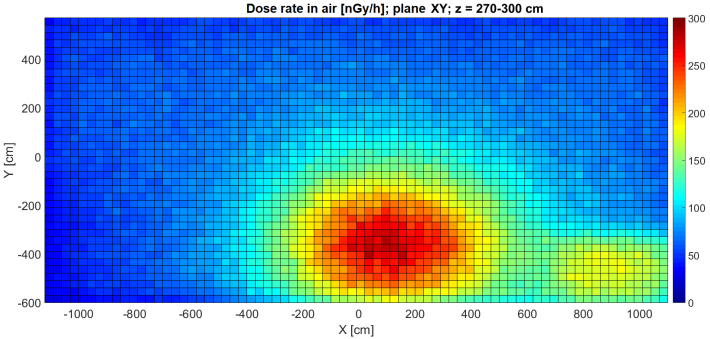

Dose rate in air [nGy/h]; plane XY; z = 120-150 cm
Y [cm]
400
200
0
-200
-400
-600
X [cm]
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0

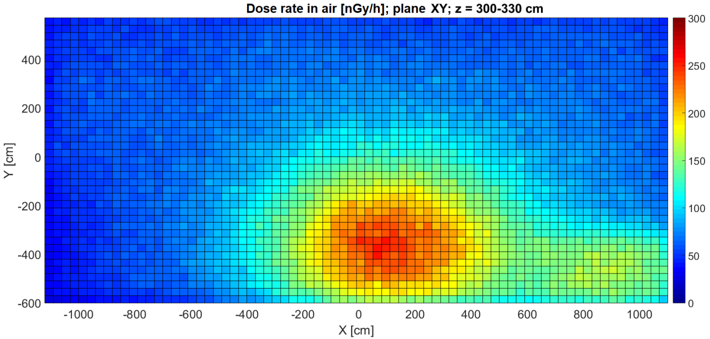

Dose rate in air [nGy/h]; plane XY; z = 150-180 cm
Y [cm]
X [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0

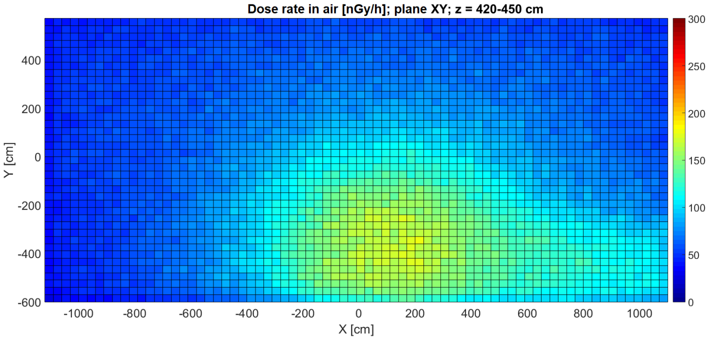

Dose rate in air [nGy/h]; plane XY; z = 180-210 cm
Y [cm]
X [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0

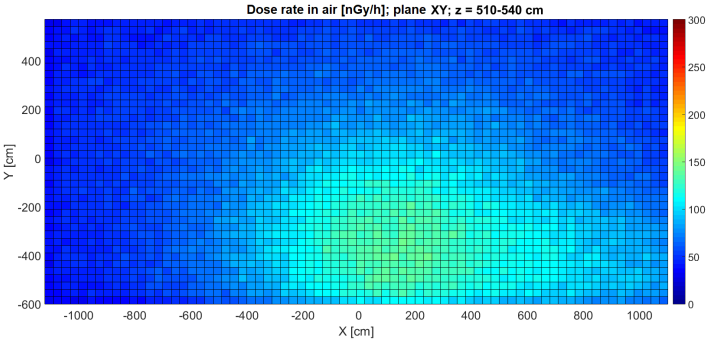

Dose rate in air [nGy/h]; plane XY; z = 210-240 cm
Y [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
X [cm]
300
250
200
150
100
50
0


Dose rate in air [nGy/h]; plane XY; z = 240-270 cm
Y [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
X [cm]
300
250
200
150
100
50
0


Dose rate in air [nGy/h]; plane XY; z = 270-300 cm
Y [cm]
400
200
0
-200
-400
-600
X [cm]
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0


Dose rate in air [nGy/h]; plane XY; z = 300-330 cm
Y [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
X [cm]
300
250
200
150
100
50
0


Dose rate in air [nGy/h]; plane XY; z = 420-450 cm
Y [cm]
X [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
300
250
200
150
100
50
0


Dose rate in air [nGy/h]; plane XY; z = 510-540 cm
Y [cm]
400
200
0
-200
-400
-600
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
X [cm]
300
250
200
150
100
50
0

Building structures contribution to measured spectra

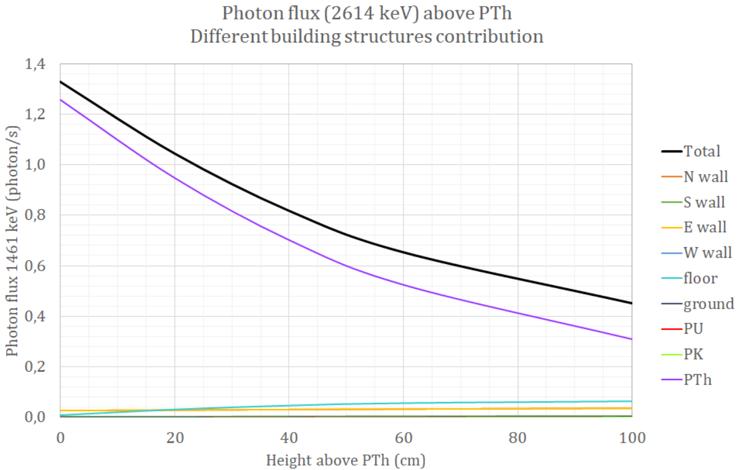
Function ICD on FT card (MCNP)

- allows to sort scored values based on source cell
- F5 tallies only
- source cells defined in custom bins

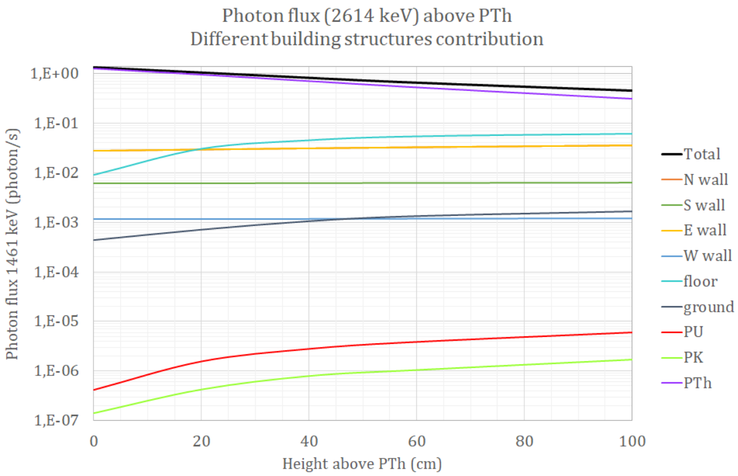
Example of definition: point detector 1m above PTh standard:

```
f5:p 920 400 104 0
ft ICD
fu5 20 22 23 24 17 25 111 11 112 121 12 122 ...
```

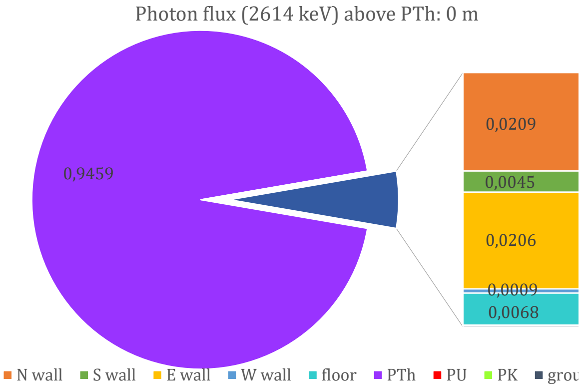
Building structures contribution to measured spectra



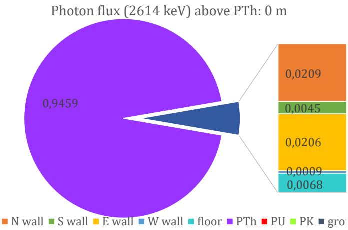
Building structures contribution to measured spectra

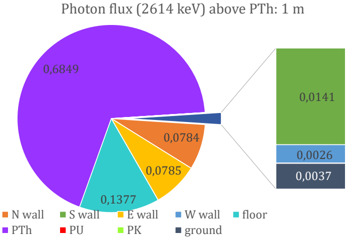


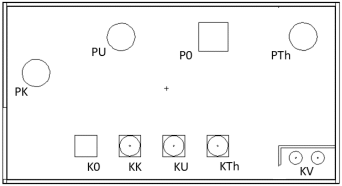
Building structures contribution to measured spectra



Building structures contribution to measured spectra







Conclusion

- Model allows to describe radiation field inside the facility in various different ways
  - direct spectra calculation
  - dose rate mapping with custom spatial resolution
  - comparison of different building structures contribution to spectra at arbitrary point
- The deviation of the model from the real situation is within 10% relative error (depends on location).

Thank you for your attention

References

International Atomic Energy Agency. *Radioelement mapping*, Vienna, STI/PUB/1463. 2010. ISBN 978–92–0–106110–2.

Kerma in air

position	height [m]	kerma rate [nGy/h]	
		experiment	simulation
PK	0.5	146 ± 7	138 ± 18
PU	0.5	127 ± 6	124 ± 16
P0	0.5	55 ± 3	49 ± 7
PTh	0.5	180 ± 9	169 ± 22
PK	1	117 ± 6	111 ± 14
PU	1	104 ± 5	100 ± 13
P0	1	68 ± 4	60 ± 7
PTh	1	132 ± 7	121 ± 16

Kerma rate in air