Simulating gamma photon fluence from surface deposition of ^{137}Cs on a residential area using SERPENT2: Fluence rateand detector response at various locations

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1 Introduction

The work of William Lindberg et. al. [1] has led to the development of a model of a Swedish neighborhood in the particle transport code SERPENT2. The intent of this work was to investigate the behaviour of detector systems in a fallout afflicted neighborhood after a nuclear accident. The neighborhood model was used to estimate the average counts per second a carborne high purity germanium (HPGe) detector would obtain during a single pass through the neighborhood, driving at a constant speed of 30 km/h. Figure 1 shows a cross section of the SERPENT2 model in question.

The applicability of the developed SERPENT2 model is not limited to carborne HPGe detectors. Other measurement techniques which may be used to map the released radionuclides after a nuclear accident include measurements using detectors carried by a drone and longer stationary measurements using HPGe detectors. This short report focuses on results obtained when using the previously developed SERPENT2 model to simulate properties relevant to measurements done by drone carried and stationary detector systems.

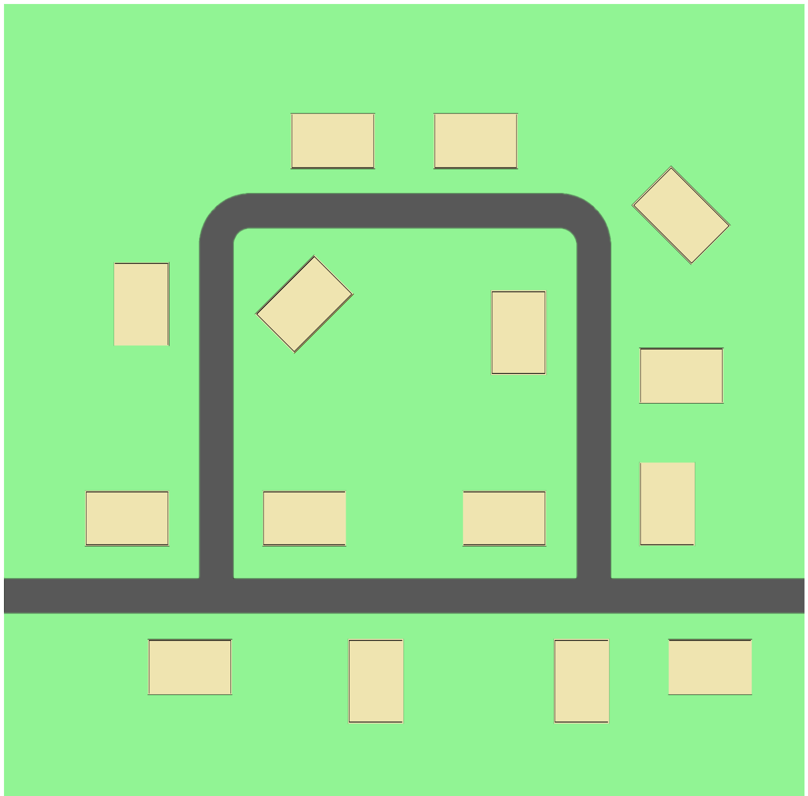


Figure 1: An overview of the neighborhood SERPENT2 model.

2 Simulations for drone measurements

SERPENT2 makes use of the accumulated track length (ATL), l, of the simulated particles to calculate detector responses [2]. To obtain the particle fluence inside a detector voxel, l is divided by the surface area of the voxel , A. Since the accumulated track length is directly proportional to the amount of simulated particles, n, SERPENT2 normalizes the detector response with respect to the the time it'd take for the simulated system to emit n particles. This time is calculated by entering the total activity of the simulated system. If no activity is entered the default setting sets it to 1 Bq, effectively dividing the detector response by n.

The total activity of the modeled neighborhood was obtained by assuming a radionuclide deposition of 100 kBq/m^2 of ^{137}Cs. However, it has been shown that the radionuclide deposition varies with the type of surface [ref]. To account for this the deposition on the street was set to 50 kBq/m^2 and 40 kBq/m^2 on the roofs. The total area of soil affected by fallout is 15388.9 m^2. The total area of the street and roof are 1961.1 m^2 and 2423.3 m^2 respectively. The total activity of the neighborhood model was calculated to 1.47 GBq.

The detectors used were several 460 × 460 grids of 30 × 30 × 30 cm voxels placed at different heights. THese detectors where setup to only detect the full energy photons which pass through them, as these particles are the most relevant for measurements using NaI detectors. The selected heights for investigation were 5, 6, 7, 8, 10, and 15 meters. An overview of the results can be seen in Figure 2 to 7.

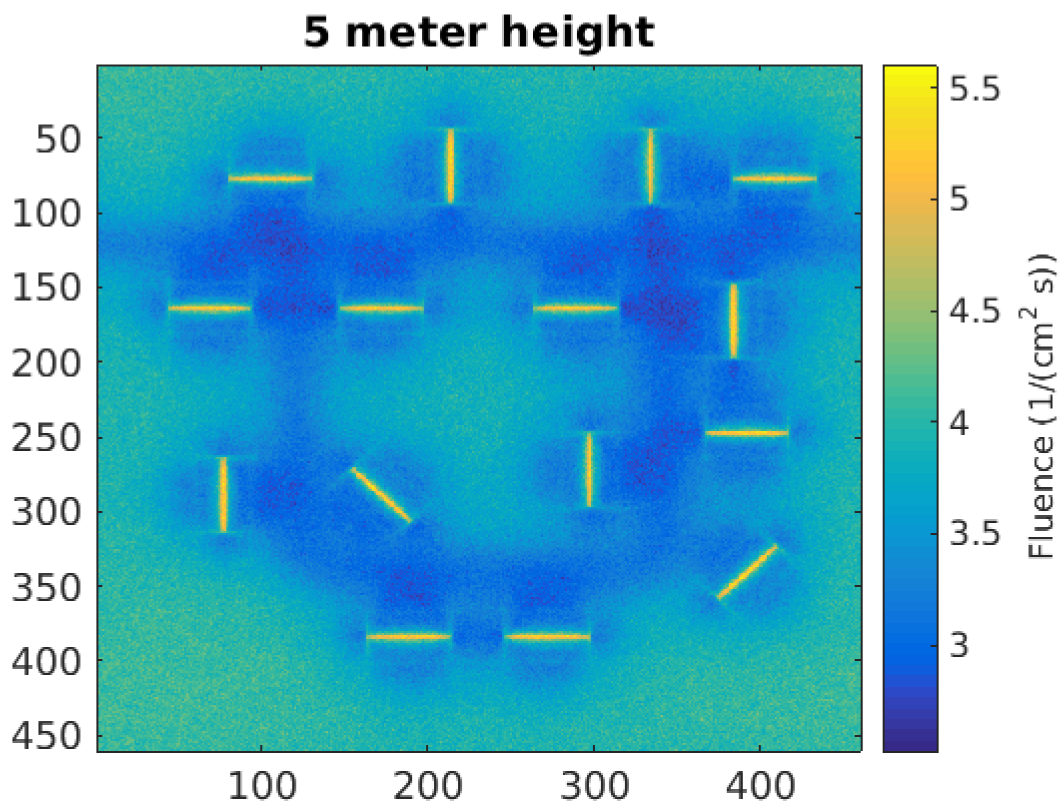


Figure 2: Fluence in each voxel in the detector grid placed at 5 m height.

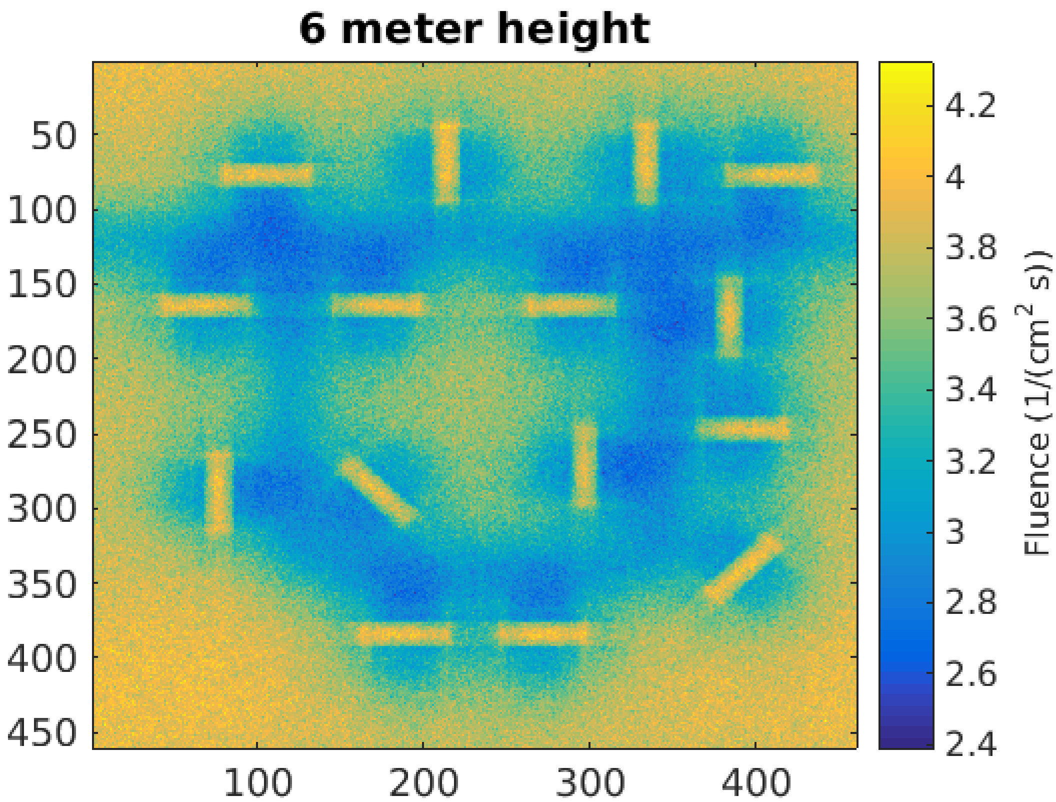


Figure 3: Fluence in each voxel in the detector grid placed at 6 m height.

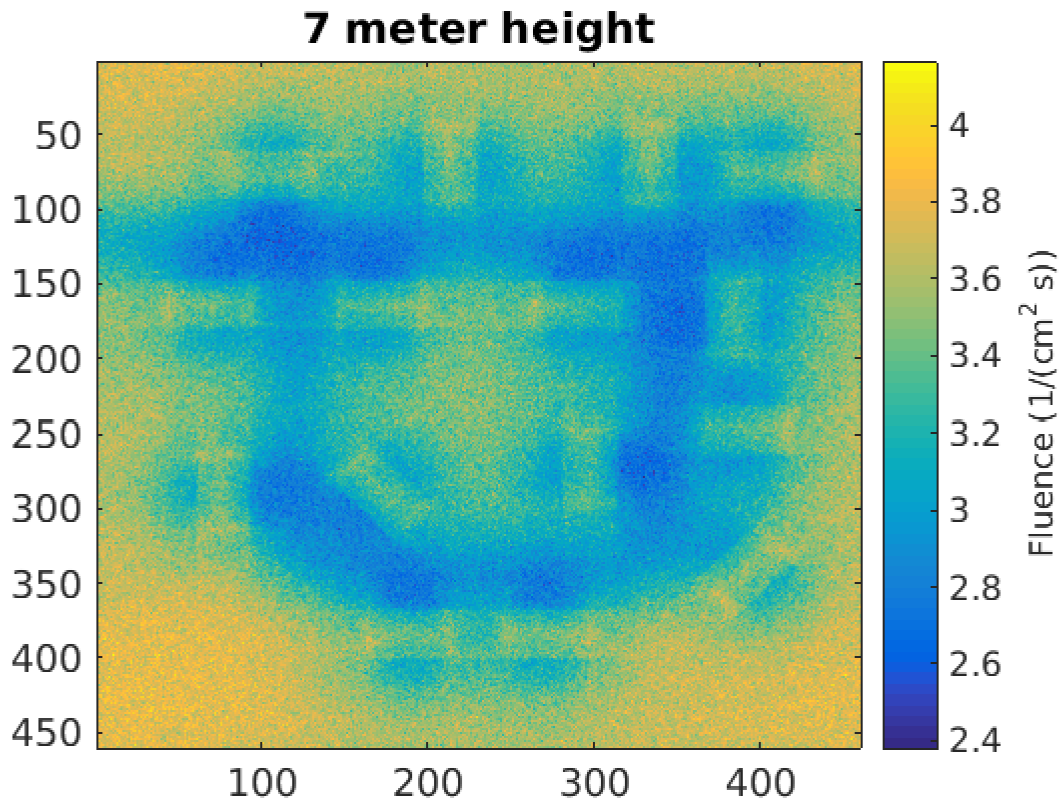


Figure 4: Fluence in each voxel in the detector grid placed at 7 m height.

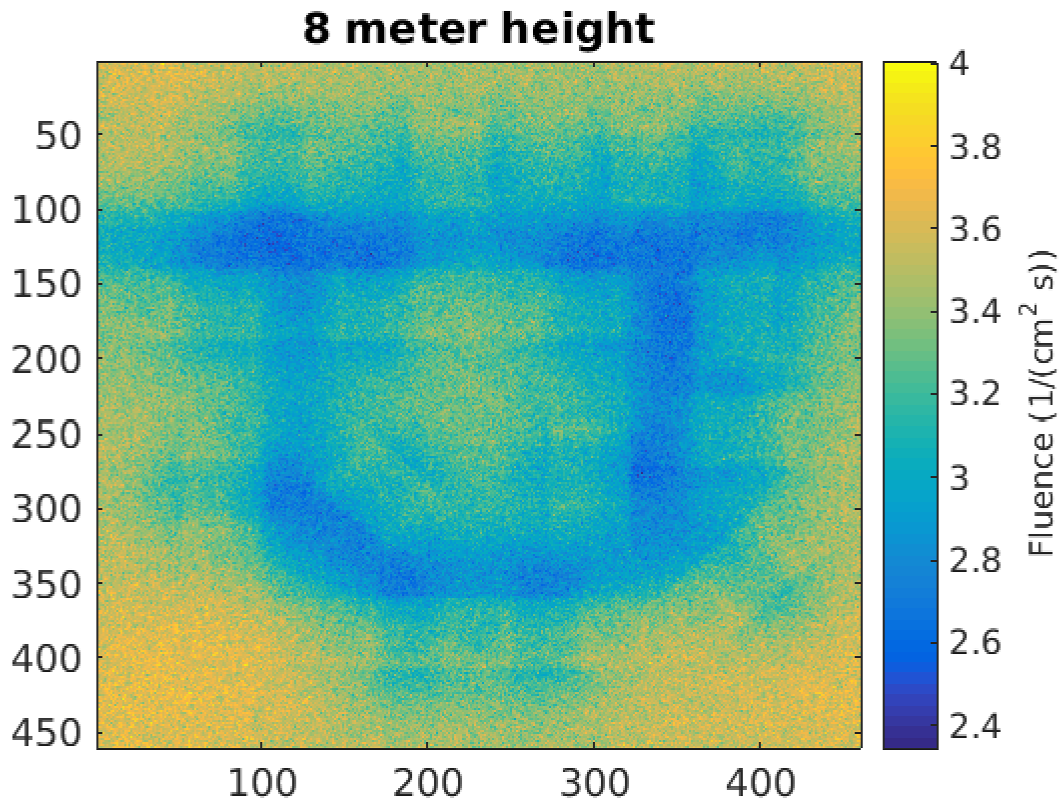


Figure 5: Fluence in each voxel in the detector grid placed at 8 m height.

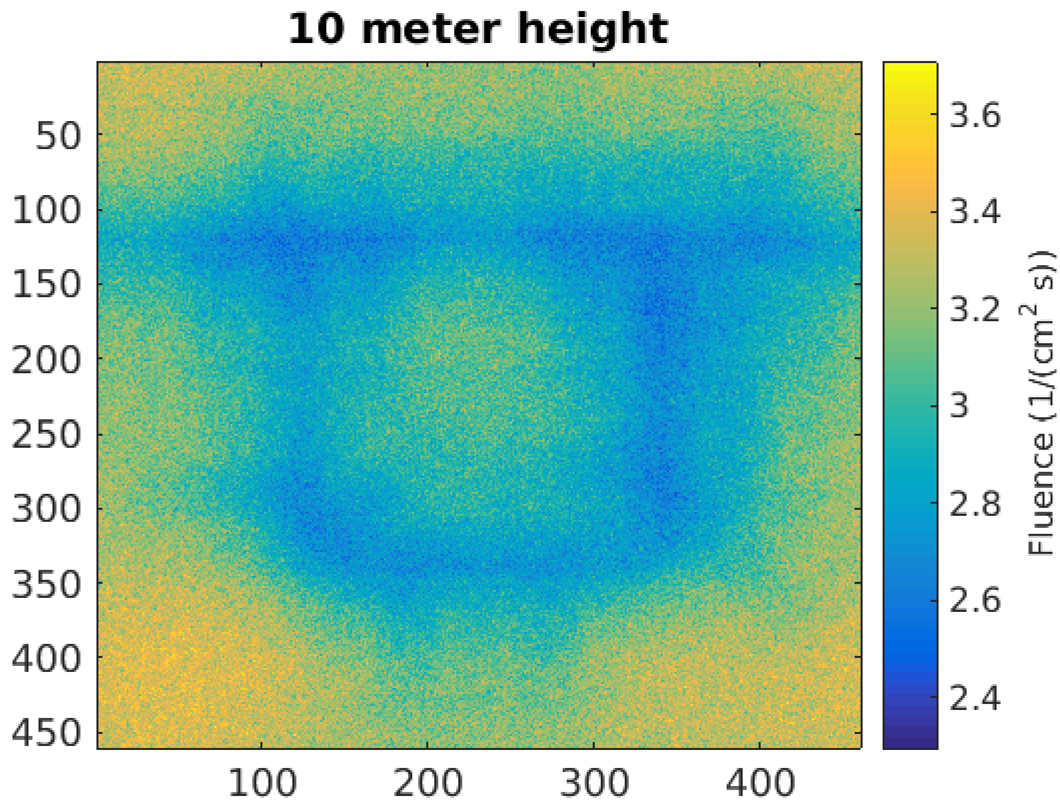


Figure 6: Fluence in each voxel in the detector grid placed at 10 m height.

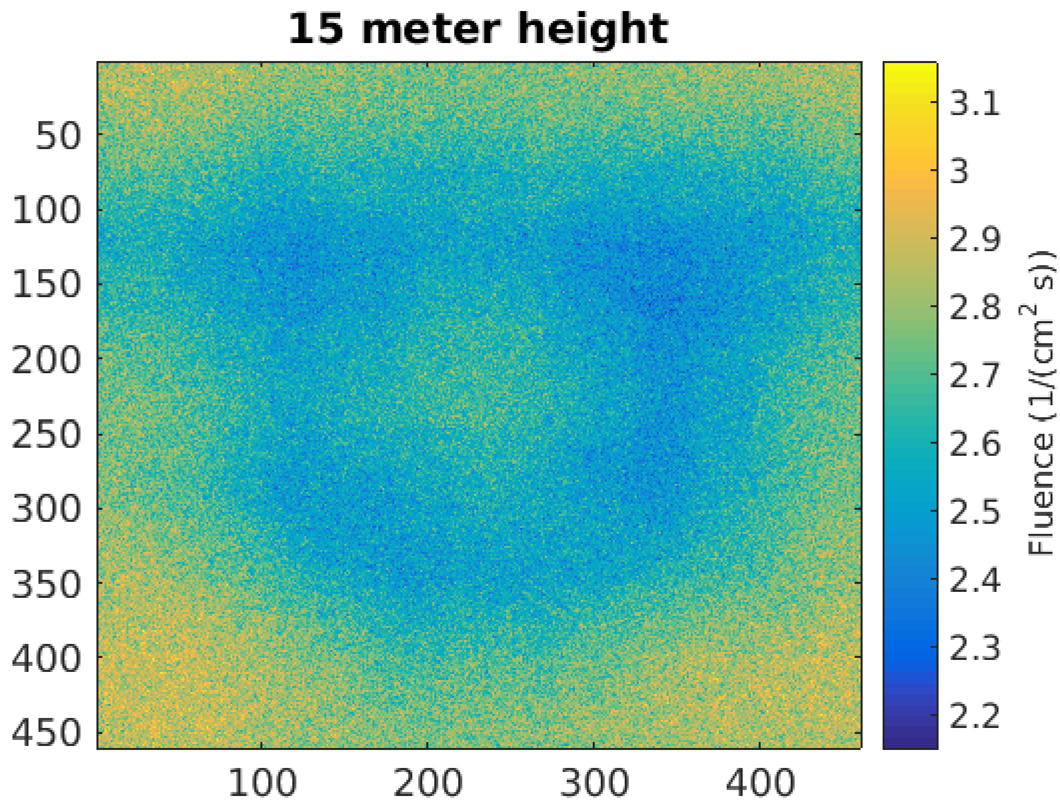


Figure 7: Fluence in each voxel in the detector grid placed at 15 m height.

3 Exponential deposition and inside of houses

In previous simulations, the radionuclide deposition to the soil has been treated as a homogeneous slab on 5 cm depth. In reality, the deposition will not be evenly distributed into the ground, but slowly seep into the ground forming a a distribution more akin to an exponential one. To simulate what the contributions of a exponential distribution may look like, $30 \times 30 \times 30$ cm voxels were placed 1 m above the ground in the center of three of the houses in the center of the neighborhood model, as well as a single voxel placed 1 m above the ground in the center of the entire model directly above bare soil. Particles were then simulated originating from 1 mm thin sheets placed at ground level, 1 cm, 2 cm, and 5 cm below ground level. Simulations were also performed with particles originating from the top layer of the roofs and street. The ATL in the voxels can then be compared between the simulations to get an estimate of the of the effect of deposition depth on dose contribution inside and outside of houses as well as the houses shielding effects. Figure 8 and 9 depicts the effects of deposition depth on ATL inside of the voxels.

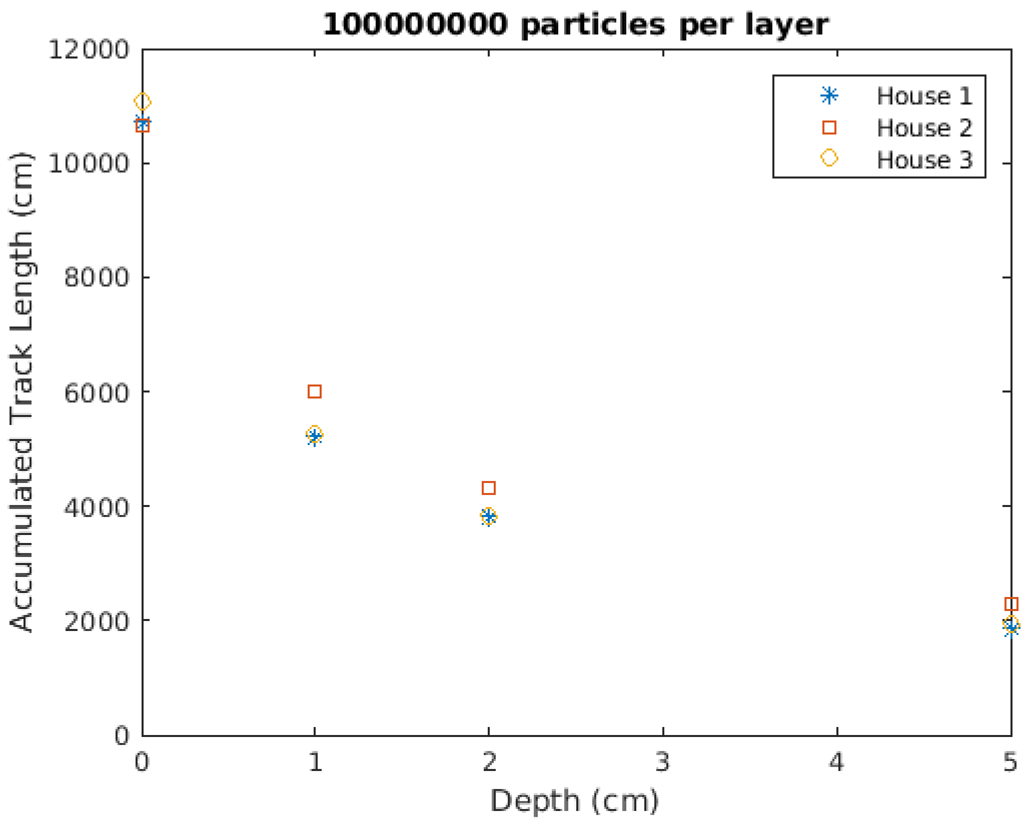


Figure 8: Accumulated track length per 10^8 simulated particles inside the three central houses.

Deposition	House 1 ATL (cm)	House 2 ATL (cm)	House 3 ATL (cm)
0 cm	10740	10660	11060
1 cm	5220	6000	5280
2 cm	3840	4320	3820
5 cm	1880	2300	1940
Roof	38440	38280	39040
Street	14420	15920	11760

Table 1: Accumulated track length for each simulation with voxels in the houses. Each simulation used 10^8 particles spread evenly on the soil, roof, or street area.

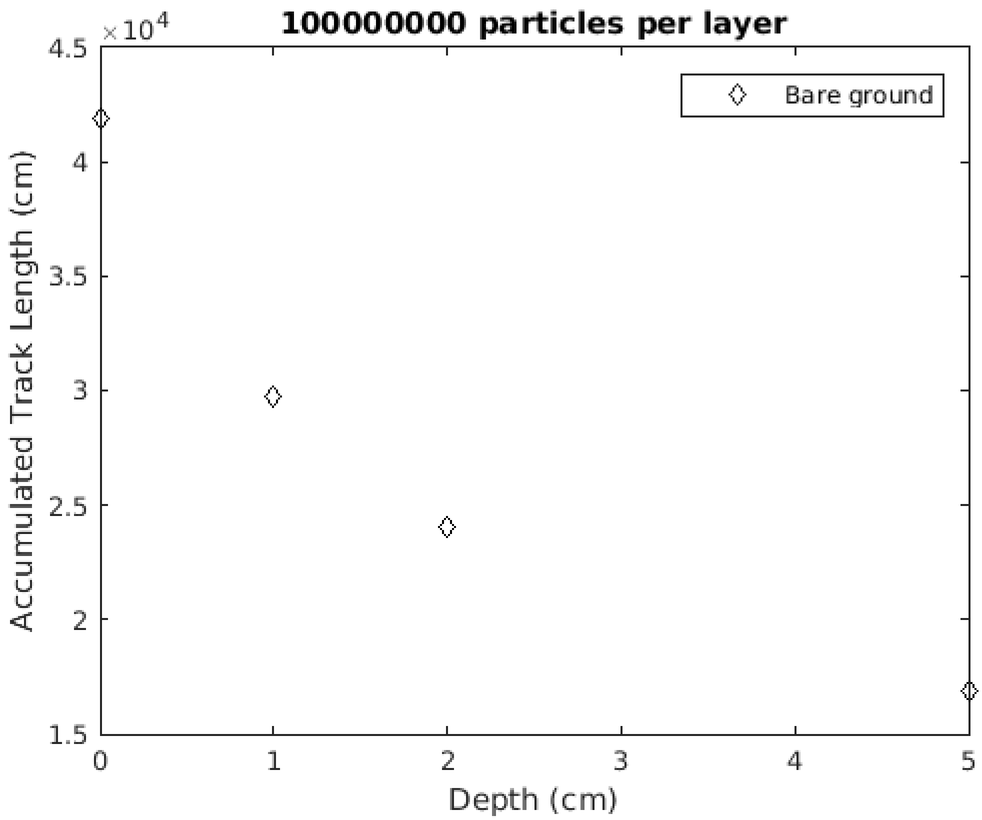


Figure 9: Accumulated track length per 10^8 simulated particles for the voxel above the bare soil (Note the $\times 10^4$) on the Y-axis.

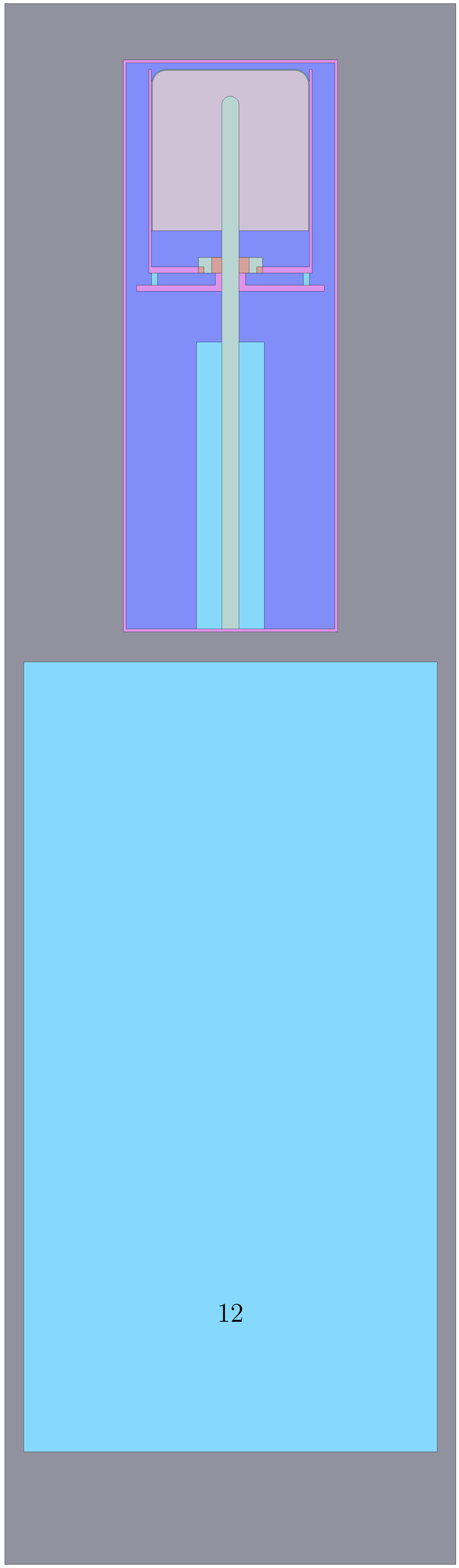
Deposition	Bare soil voxel ATL (cm)
0 cm	$4.19*10^4$
1 cm	$2.97*10^4$
2 cm	$2.40*10^4$
5 cm	$1.69*10^4$
Roof	42480
Street	7420

Table 2: Accumulated track length for each simulation with the voxel above the bare soil. Each simulation used 10^8 particles

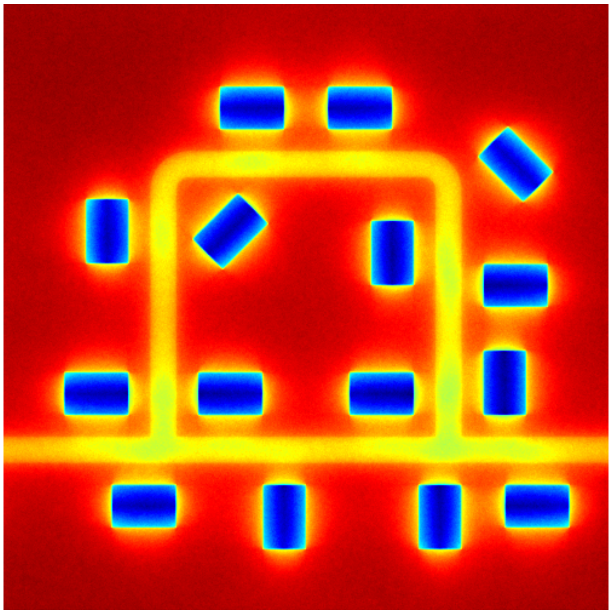
By weighting these simulation contributions with a exponentially decreasing function, one may gain more insight into how a more realistic radionuclide depositions contribution to different areas in the affected neighborhood. However, due to time constrains, this report does not make a estimate of a realistic dose contribution.

4 Full spectrum HPGE simulations

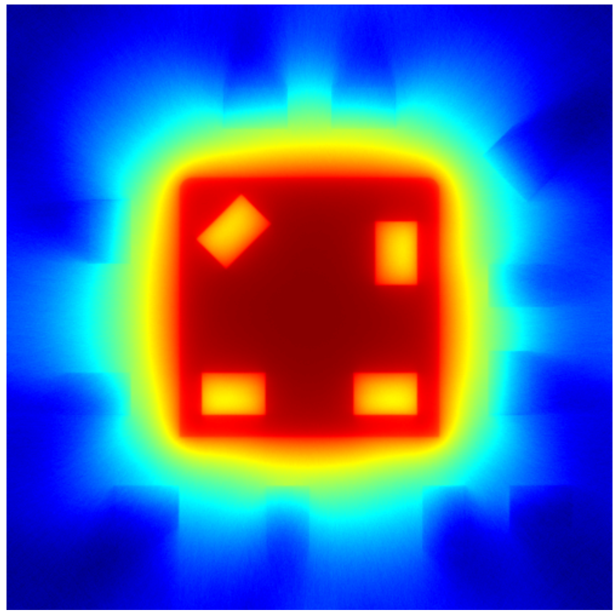
As previous investigations using the SERPENT2 neighborhood model either focused on full energy peak photons or the total contribution from all photons combines, it may be of interest to try to simulate a full gamma spectrum in a more detailed HPGE detector. Such a detector can be seen in Figure 10.



This detector model was placed in the center of the neighborhood model and was set up to detect a full gamma spectrum of the simulated particles. To improve the statistics in the detector, only the central 60×60 m square including 4 houses. By projecting each particle path simulated onto a plane, it is possible to get an overview of the layout of the simulation. This overview van be seen in Figure 11a to 12.



(a) A projection of particle paths throughout the modeled geometry when simulating particles from all relevant soil, streets and roofs.



(b) A projection of particle paths throughout the modeled geometry when only simulating particles from the soil in the center square.

Figure 11: An overview of the particle paths projected in the modeled geometry.

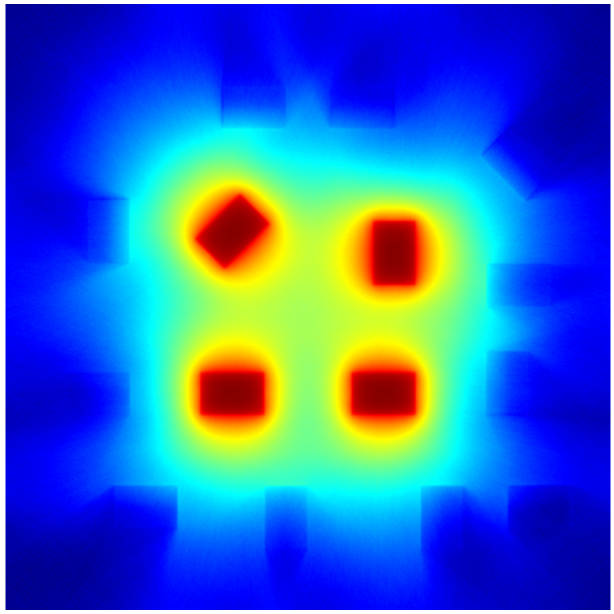


Figure 12: A projection of particle paths throughout the modeled geometry when only simulating particles from the 4 central roofs.

Each simulation made use of 30^8 particles, such that the simulation time on a 64 core cluster node lasted for roughly 24 hours. The spectrum which resulted from these simulations can be seem in Figure **??**.

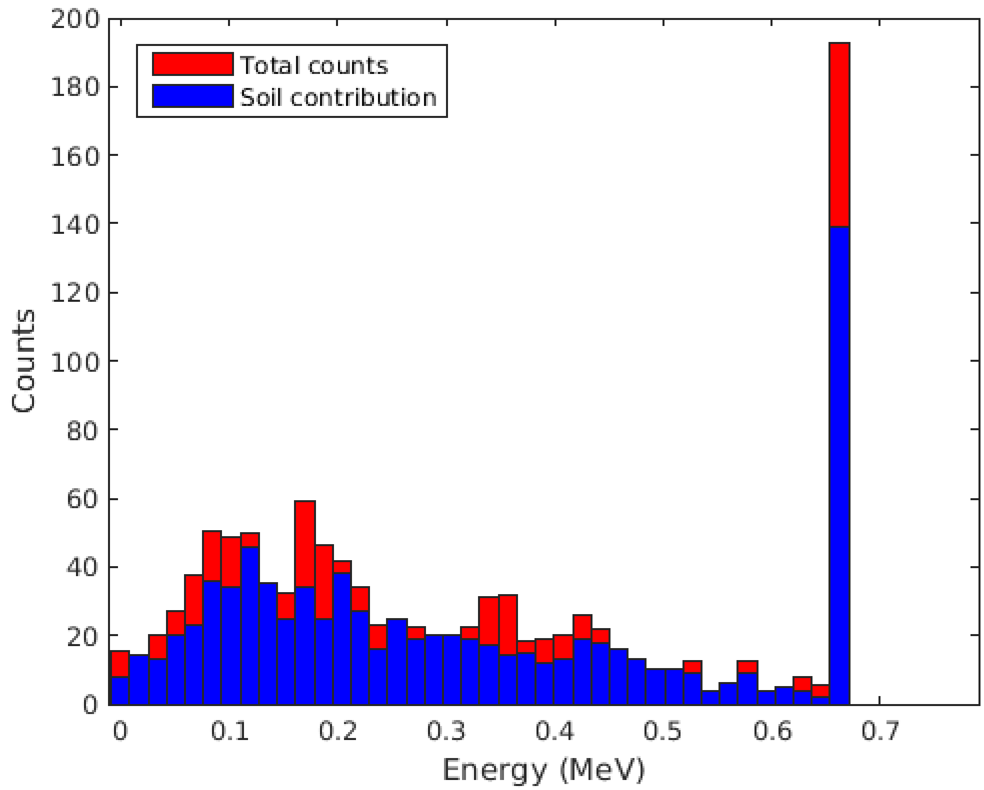


Figure 13: The gamma spectrum obtained from the simulations. The red part represents the full contribution counting both soil and roof contributions while the blue part is only the soil contribution.

5 References

[1] W. Lindberg, "Monte-Carlo response for mobile gammaspectroscopy in fallout affected residential areas" Uppsala University. 2021.

[2] Serpent – a Continuous-energy Monte Carlo Reactor Physics Burnup Calculation Code June 18, 2015