Reducing the uncertainties in modelling results through better understanding of the impact of physical uncertainties

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Introduction

In the field of radiation processing, modelling is an asset. It can be used to investigate different loadout, assess the viability of a process, determine whether a double-sided irradiation will be necessary, etc… To that end, understanding where the uncertainties stem from is a critical aspect, both with measurement and with simulated results. With regard to radiation processing, both the lowest dose and the highest dose received by the target are of importance, meaning that penalizing hypothesis cannot be used so as not to skew the results toward either high or low results. Nonetheless, for practicality reasons, hypothesis often need to be used regarding parameters such as chemical composition, thickness of radiation shielding, sources' activity, distance between source and targets, etc. Using the RayXpert® 3D Monte-Carlo software, we aim at evaluating the impact of standard uncertainty on the dose (water kerma) on a typical Co-60 irradiator. Uncertainties regarding the source activity, distance between target and source and thickness of parts of the packaging will be investigated.

Theory

The expected dependency on the different variables is :

- Linear for the activity in case of homogeneous increase
- No change for the randomized activity
- Inverse log to inverse quadratic for the distance
- About 2% for every mm differences in the thickness of the Al plating according to line-of-sight attenuation

Method

Using the RayXpert® 3D Monte-Carlo software, we modeled a typical Co-60 irradiation facility, with 12 different positions for targets and 256 ^{60}Co sources. The totes are made of 3 parallelepipeds (68 x 58 x 100 cm) of inorganic matter (Z_{eq} = 12.23, density 0.25g/cm³) on top of each other, with a 1 cm thick stainless steel frame on the edges. The totes are protected by a 3 mm thick aluminum cover on all 4 sides. Each totes has a sensitive volume (1 x 1 x 0.3 cm) facing away from the source panel, located halfway-up. Each sources is encased in a 34.4 cm high stainless steal casing with a 2.5 cm radius. The source itself is a 34 cm high cylinder with a 2 cm radius. The reference activity for each sources is 10^{15} Bq each. The source panel is arranged as a 32 x 8 rectangle.

Different modifications of the reference model (R) are investigated:

A. Modification of activity from 10^{15} Bq to 1.1 x 10^{15} Bq;
B. Randomizing activity for each source at 10^{15} +/- 5% Bq;
C. Varying Al cover thickness (from 3 to 2 mm);
D. Moving totes 15 cm (~10%) closer to the source.

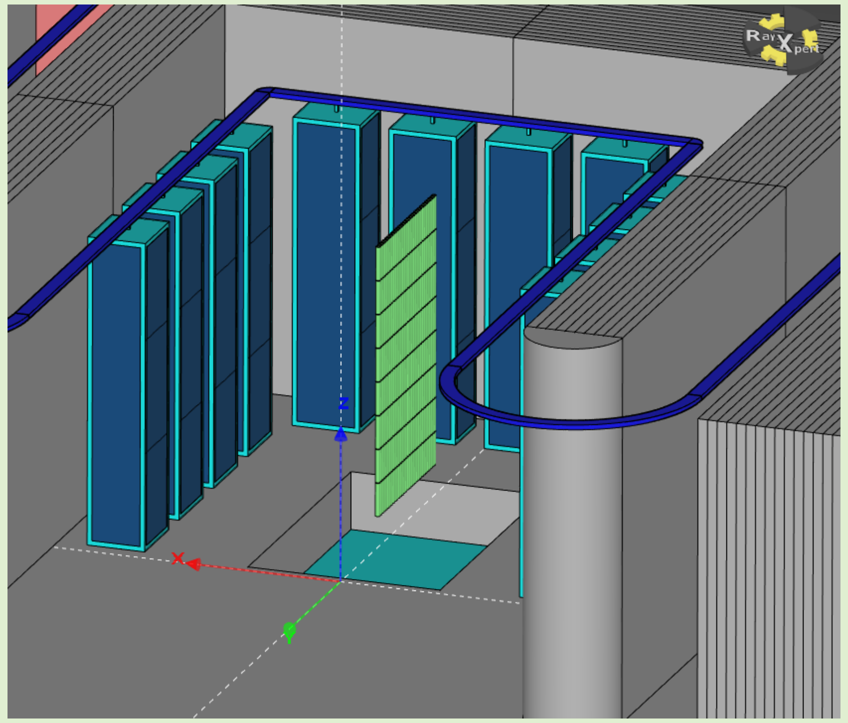

Figure 1. Overview of the irradiation bunker, with 12 totes (blue), the source panel (green) and the storage pool.

Results

Calculations were run for about 90 CPU.days each, simulating on the order of 10^9-10^{10} photons. Convergence was satisfactory with relative error < 3.4% albeit some advanced convergence indicators were not checked. Comparisons between the 12 detectors of alternative model A shows the expected 10% increase in dose rate, with ratio A/R comprised in [1.04 ; 1.16], sum of all detectors dose rate as 1.10. Model B (average activity : 9.98E+14 Bq ± 3.42E+13) also shows great agreement with theory, with ratio B/R in [0.96 ; 1.05], sum of all detectors dose rate as 1.00. Model C (2mm Al covers) shows uneven agreement with the expected results (**Fig.2**). The ratios C/R are comprised in [0.98 ; 1.11], while the expected ratio is 1.02. The sum of all detectors is in agreement (C/R = 1.02) with the theorical results. Model D shows good agreement (**Fig. 3**) with a squared inverse dependency to the distance between totes and source, except for detector 8. This dependency is commonly admitted to be valid at 5 Characteristic Lengths. This is not the case (about 1 CL). The increase in dose rate may be due in part to a decrease in the amount of material through which the radiation passes.

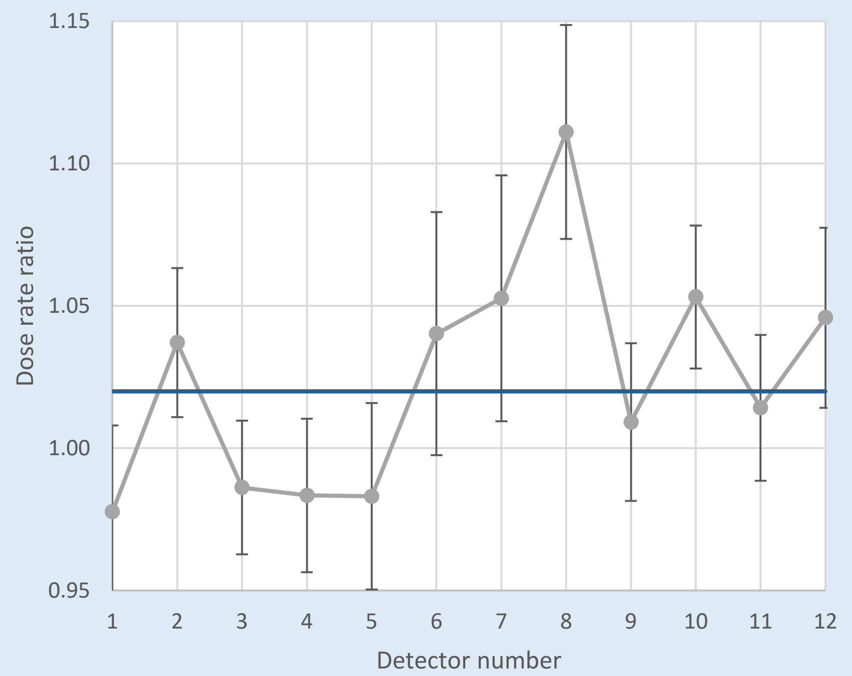

Figure 2. Dose rate ratio (C/R) for the detectors. In blue is the theoretical R/C ratio 1.08, grey is the result of the simulation with 1σ error bars.

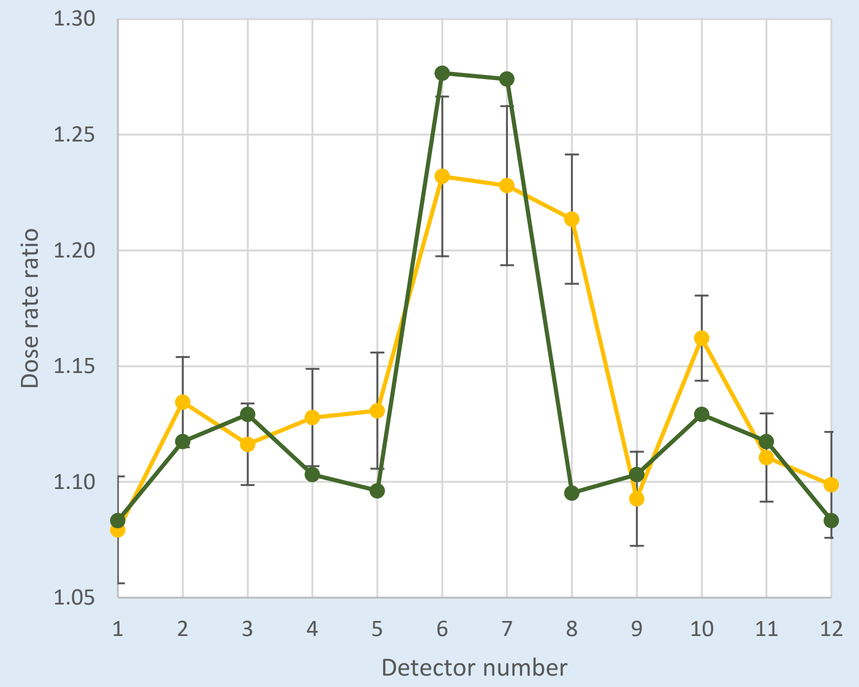

Figure 3. Dose rate ratio (D/R) for the different detectors. In green is the theoretical ratio assuming 1/r² dependency, yellow is the results of the simulation with 1σ error bars.

Conclusion

The results show a generally good agreement with what could be predicted. However, a few specific detectors may require a better convergence to be more representative of the real case. The importance of correct measurements (distance, thickness, activity) is highlighted. Some global effects are able to compensate for local inaccuracies (B case) as long as there is a great enough number of elements. These examples provide a basis for evaluating the accuracy needed to properly simulate an irradiation process. **This help to reinterpret discrepancy between dose rate measurements and simulation in light of inaccuracies during the modelling phase. Simulations can be also used to try and verify some of the inputs used for simulation.**

References

1. C. Dossat, Manuel d'utilisation de RayXpert® V1.8.0, TRAD Tests & Radiations (2020).