A computational methodology for estimating the detected energy spectra of the gamma-ray flux from irradiated nuclear fuel

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Summary

The aim of this work is to predict the gamma spectrum from nuclear test rodlets , knowing the burnup (BU) history and the instrument setup. The model is a combination of Monte Carlo simulations and closed-form analytical solutions, used to speed up the calculations. The work will be applied in the design of high-spatial-resolution Gamma Emission Tomography (GET) setups (which involve long and narrow collimators) but also in planning of measurement campaigns, by providing a priori the detector count rate of each nuclide of interest.
The model has been benchmarked using a measured spectrum of a rodlet sample subjected to a transient test in Halden Reactor.

Method

The method can be synthesized in four steps (Fig. 1):
First step: according to the BU history of the sample, the nuclide inventory, activity and line emission intensity are calculated using SERPENT.
Second step: starting from the gamma-lines obtained, the self-attenuation and the buildup generated in the fuel sample and in the surrounding structures are simulated using MCNP6 and included in the spectrum.
Third step: spectrum intensities are adjusted for the collimator geometrical efficiency, calculated using fast-computation closed-form integration over the optical field of view (OF) of the slit. Scattering and associated build-up generated in the collimator is thus neglected.
Fourth step: according the detector dimensions, the detector response is simulated for energies between 0 and 2.5 MeV using SERPENT, and included in the prediction model. Gaussian broadening and Poisson counting noise are applied to the simulated spectrum.

Experiment description

A Halden reactor experimental spectrum was used for bench-marking. The model used the 22 highest-activity nuclides present in the fuel. The majority of them are generated during the second short irradiation in the Halden reactor, after a pre-irradiation of the mother rod in a LWR fuel assembly and 12 years of cooling time, with a total BU of 60GWd/t_{HM}. The measurement was performed in a central lateral position using a 1 x 2 mm rectangular slit, with 705 mm of length. The contribution of the most active nuclides is represented in Fig. 2, while in Tab. 1 the results of the prediction method are summarized and compared with the benchmark measurement.

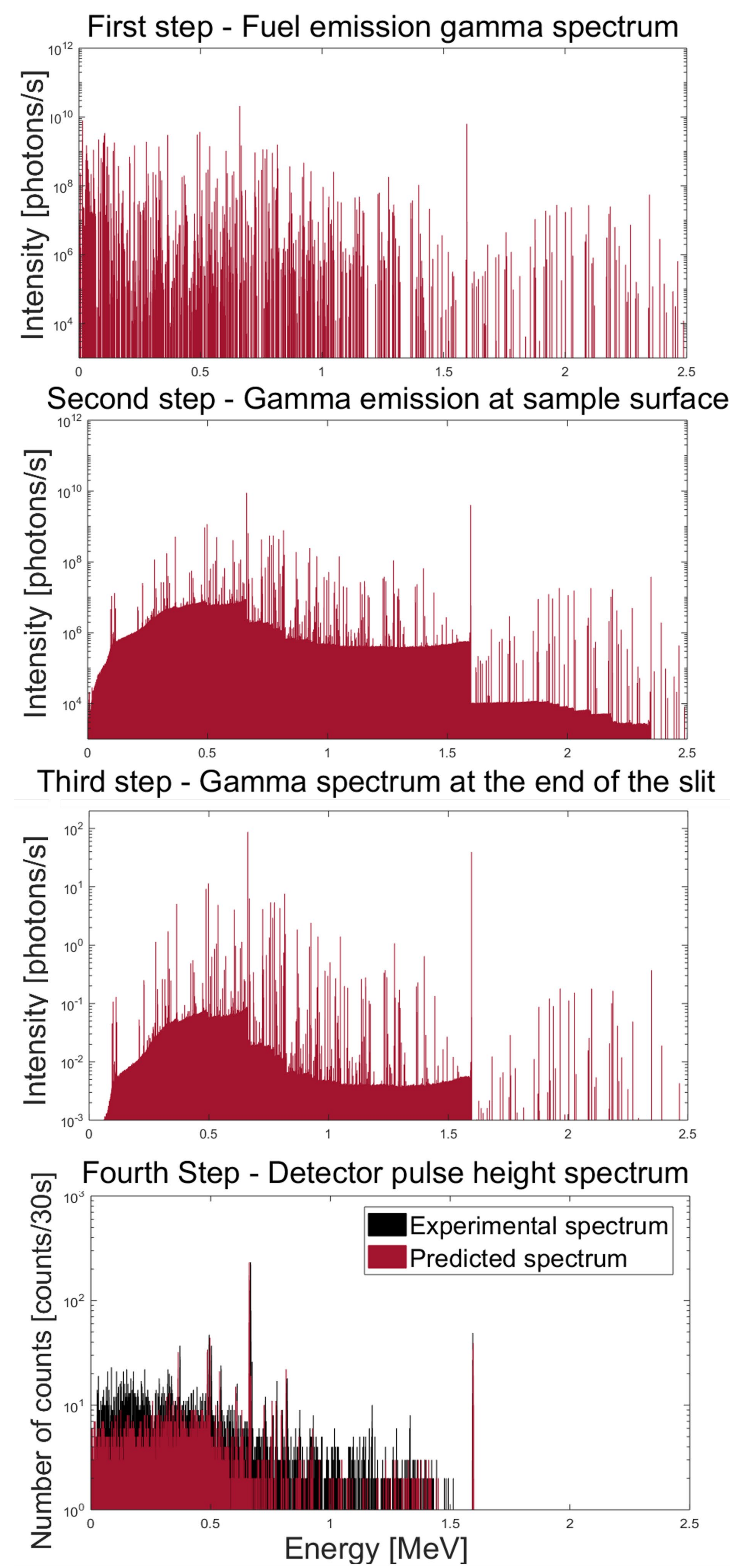

Fig. 1: Representation of the method step by step.

Contribution per nuclide in the detector counts

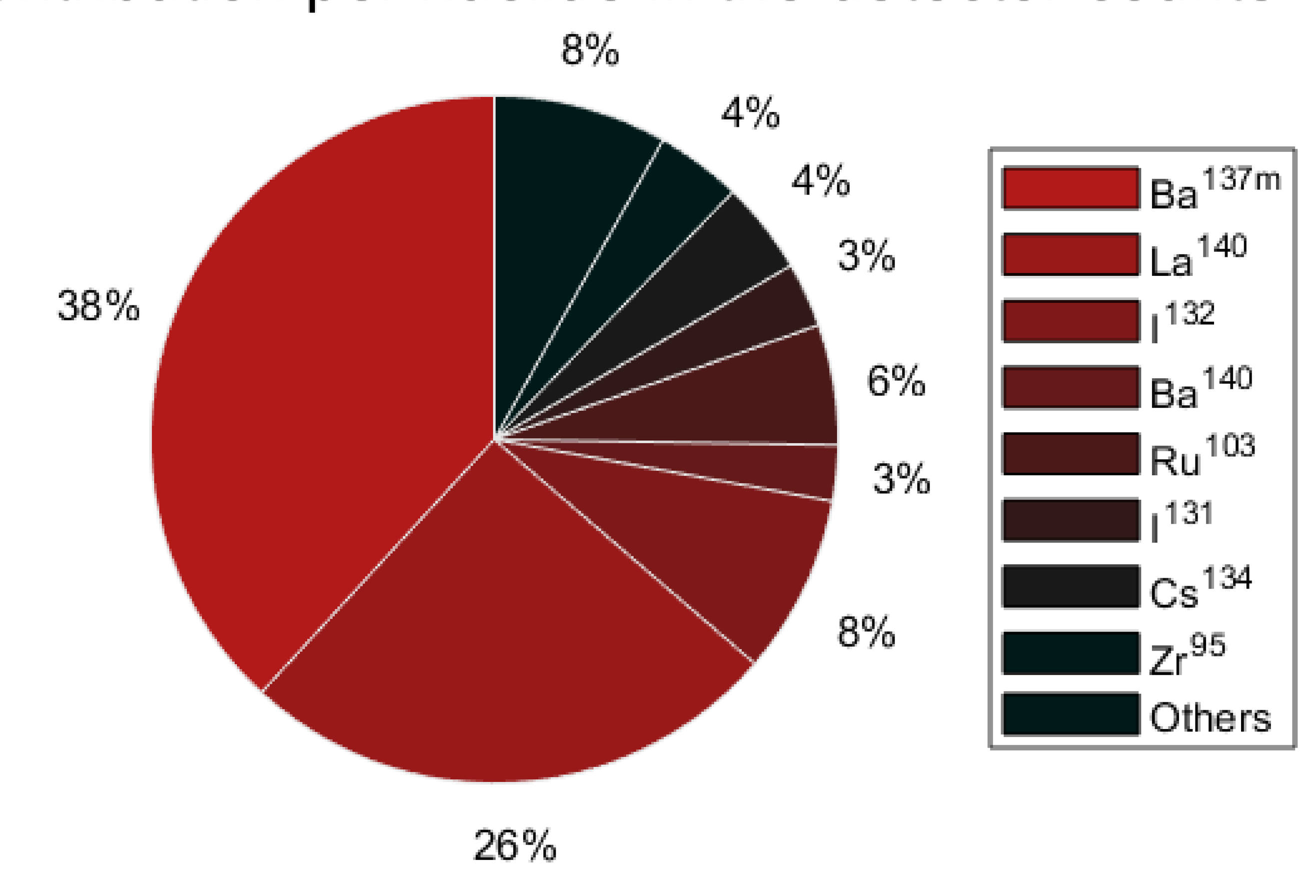

Fig. 2: Pie chart representing the contribution of the most active radionuclides over the total count rate of the spectrum.

Energy/nuclide/Half life	Simulations (OF only)	IFA test (No Bkg.)	Ratio Sim./ Exp.
662keV (^{137m}**Ba**) 30 a	735.7	716±34	1.03±0.05
1596 keV (^{140}**La**) 2 d	160.6	155±13	1.04±0.08
486 keV (^{140}**La**) 2 d	104.3	150±14	0.69±0.09
497 keV (^{103}**Ru**) 39 d	125.6	149±15	0.84±0.10
537 keV (^{140}**Ba**) 13 d	50.9	70±11	0.73±0.15
604 keV (^{134}**Cs**) 2 a	38.1	50±11	0.76±0.22
667 keV (^{132}**I**) 2 d	53.5	48±9	1.12±0.19
753 KeV (^{95}**Zr**) 64 d	40.9	46±8	0.89±0.17
815 keV (^{140}**La**) 2 d	54.1	60±9	0.90±0.15
Total spectrum counts	6513.5	8385±190	0.78±0.02

Table 1: Comparison of predicted peak intensities and measured data.

Conclusions and Outlook

The results show a general good agreement with the experimental ones, with a maximum discrepancy of **30%** for the full-energy peaks evaluated and about **20%** for the total counts. The observed discrepancies are likely caused by the inaccuracies of the model, but the results are considered good enough for planning a measurement campaign. The model will be used to perform a Pareto study to optimize the collimator dimensions of a new GET device, related to the measurement constrains, such as measurement time and signal-to-noise ratio.

Acknowledgments

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