

## A MONTE CARLO AND EXPERIMENTAL TOOL FOR ACTIVATION CALCULATIONS IN HIGH ENERGY X-RAYS IRRADIATION PROCESS

**N. ARBOR<sup>1</sup>, A. NOURREDDINE<sup>1</sup>, J. RIFFAUD<sup>1</sup>, F. KUNTZ<sup>2</sup>, A. NASREDDINE<sup>2</sup>,  
A. STRASSER<sup>2</sup>**

<sup>1</sup> *Institut Pluridisciplinaire Hubert Curien, CNRS / University of Strasbourg, Strasbourg, France*

<sup>2</sup> *Aerial-CRT, Illkirch Graffenstaden, France*

X-ray photons produced by electron accelerator are increasingly used for industrial irradiation. More penetrating than electrons, easier to manage than radioactive sources, X-rays are very interesting for various processes such as sterilization. But the question of the maximum energy that can be used without risk has been open for many years and is currently being debated worldwide. Using energies higher than 5 MeV would certainly improve the DUR (Dose Uniformity Ratio) while reducing the cost of utilization. However, it is essential to take into account the risk of photonuclear activation, which can lead to the production of radioactive nuclei. These nuclear processes can occur both in the irradiation room (walls, supports), the accelerator components and the irradiated object. The issue of the maximum irradiation energy thus requires being able to assess with high precision the total quantity of radioactivity produced during a given industrial process, as well as the corresponding risks in terms of radiation protection of workers and populations.

In the context of food sterilization, most of the reference publications, including the IAEA report on "Natural and Induced Radioactivity in Food" (IAEA-TECDOC-1287), conclude that food irradiated with X-rays up to 7.5 MeV to a dose of 30 kGy has a radioactivity well below the natural radioactivity in non-irradiated food [1,2]. These very low levels of induced radioactivity highlight both the need and the complexity to develop a tool for easily and efficiently controlling the irradiation process in terms of activation. Experimental gamma spectrometry is a useful but insufficient solution because it does not detect the presence of pure beta or alpha emitting radioactive nuclei, which are much more difficult to measure. Monte Carlo (MC) simulation and analytical codes for radiation-matter interactions are considered to be more powerful and practical tools for quantifying the radioactivity potentially induced during the irradiation. These numerical tools must however be used with caution for radiation protection purposes, as it can lead to very significant errors on the type and number of calculated radioactive nuclei depending on the accuracy of the modelling (accelerator design, sample geometry, materials composition). A step-by-step validation of the calculation chain is thus essential to ensure the reliability of the results.

We present a hybrid Monte Carlo and experimental tool for activation calculations in high energy X-rays irradiation process. The purpose of this tool, and its associated methodology, is to establish the safety of high-energy X-ray irradiation installations by quantifying with a high precision the additional induced radioactivity for a given process (and compare it to the natural levels). This work is the direct continuation of the study carried out on the assessment of activation in foods product irradiated with high energy X-rays, within the framework of the IAEA DEXAFI (Development of Electron Beam and X-Ray Applications for Food Irradiation) coordinated research project. The first part of the work consisted in identifying the most critical steps in the simulation chain for the accuracy of the activation calculations. The impact of nuclear data (cross-section), X-ray spectrum and materials composition has been evaluated by benchmarking several calculation codes such as MCNP, Geant4 and FISPACT-II (Figure 1 – left).

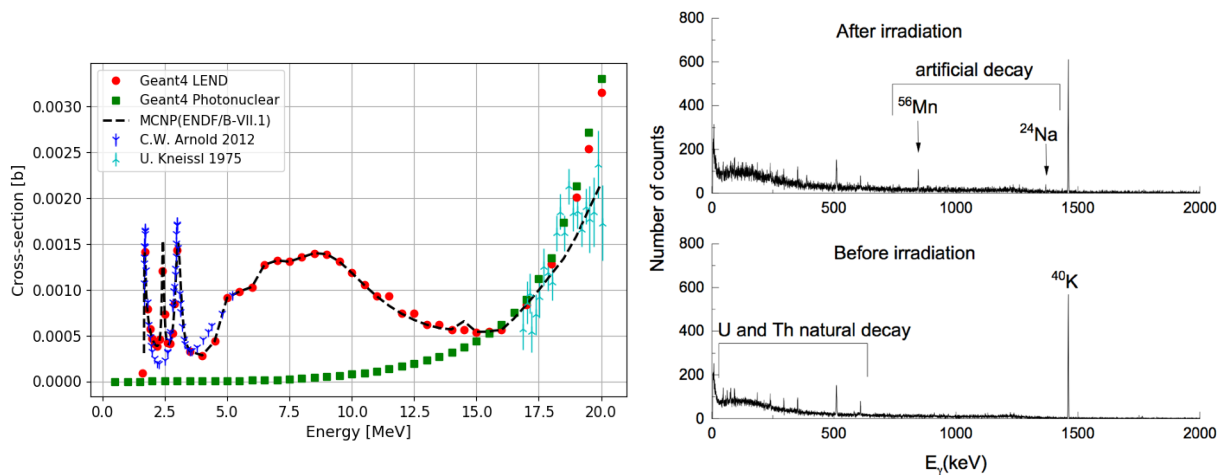


FIG. 1. Left: Comparison of Geant4 (G4Photonuclear and LEND models), MCNP (ENDF-BVII.1) and some experimental photonuclear cross-sections of  $^9\text{Be}$ . Experimental data are available on the JANIS database; Right: Gamma emission spectrum of rabbit food before and after irradiation (total dose of 14 kGy with 7 MeV X-rays)

The second part is to test different experimental methods, such as dosimetry, neutron/gamma spectrometry (Figure 1 – right) or activation foils, that can be applied to verify calculations. A methodology, adapted to industrial constraints, has been defined to allow validation of both the Monte Carlo modelling of the irradiation setup and the activation calculations. The experimental measurement of photoneutrons, around and in the irradiated sample, appeared to be one of the most reliable means of control. Innovative neutrons instrumentation, developed at the IPHC laboratory [3,4], could be used for this purpose. Experimental measurements were carried out at the new Feerix® (Faisceau d'Electrons Et Rayonnement Ionisants X) facility of Aerial (Strasbourg-France). This facility, based on advanced IBA Rhodotron® technologies, constitutes a reference installation for the development of the proposed tool which aims to allow better control of X-ray irradiation processes.

## REFERENCES

- [1] INTERNATIONAL ATOMIC ENERGY AGENCY, Natural and induced radioactivity in food, TECDOC (2002) Series 1287.
- [2] GRÉGOIRE, O., et al., Radiological safety of food irradiation with high energy X rays: theoretical expectations and experimental evidence, Radiation Physics and Chemistry 67 (2) (2003) 169–183
- [3] COMBE, R., ARBOR, N., HIGUERET, S., HUSSON, D., Experimental characterization of a fast, pixelated CMOS sensor and design of a Recoil-Proton Telescope for neutron spectrometry, Nuclear Instrument and Methods in Physics Research A 929 (2019)
- [4] ARBOR, N., et al. Real-time detection of fast and thermal neutrons in radiotherapy with CMOS sensors, Physics in Medicine and Biology 62 (2017) 1920-1934