Environmental radioactivity simulations in Geant4

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The advancement in the field of gamma ray spectroscopy has contributed with high resolution detectors like HPGe but the most widely used detector in cases where the resolution is not an important issue are thallium doped sodium iodide (NaI(Tl)) scintillators. These detectors have high detection efficiency even at room temperature and are still available for research activities in nuclear medicine, environmental measurements, geophysics, and nuclear physics education. Other benefits of using NaI(Tl) detectors are low cost, lower power consumption and cooling free operation. For such a reason we at Facultad de Ciencias, Laboratory of Biophysical Chemistry and Radiation Studies (LBCRS) at Universidad Michoacana de San Nicolás de Hidalgo, México are developing gamma ray spectrometer consist of single NaI(Tl) detector which later will be upgraded with HPGe detectors.

With motivation how NaI(Tl) detector can help in monitoring the presence of heavy radioactive elements in environment for example in the geothermal microcosm of the Los Azufres (Mexico) we are developing simulations using Geant4 software [1].

Geant4 is most powerful, and require firm knowledge of C++ object oriented programming for the Monte carlo simulations of the passage of particles or photons through matter. In order to develop NaI(Tl) detector simulation package we implemented several classes to describe it's;

- detector geometry,
- source,
- physics,
- particle type.

The geometry of the detector together with it's logical and physical volume, it's material from the NIST database, sensitive region for the gamma ray interaction is done in the G4VDetectorConstruction class. The shielding physics which takes into account physics models like electro magnetic physics, decay and radioactive decay physics, hadron physics for low energy nuclear data and stopping physics of ions is incorporated in the G4VUserPhysicsList class. The definition of the source and its particle type is defined in the G4VPrimaryGenerator class which controls the kinematics of the beam particles. The collection of data is done under process hits using G4Step object by calling different methods like step→GetTotalEnergyDeposit().

A screenshot taken from the QT5 graphical interface of Geant4 is presented in figure 1. In this figure the scintillation material is NaI of disc shape (light green) geometry 2" x 2" is placed inside a candle (white) of size 2.4" x 4.8". A standardized bottle/container (dark yellow) for solid or liquid samples that fits into scintillator for screening of gamma contamination is placed on the top of the candle. To understand the performance of the simulations, the container is filled with standard soil assuming it can have fission products from the

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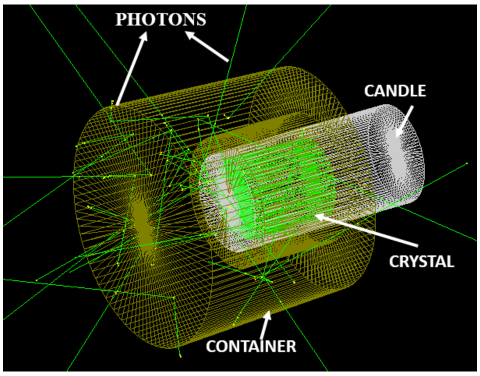

FIG. 1: (Color Online) A typical screen shot taken from the QT window of Geant4.

decay of Uranium or other fissionable isotopes. The γ-ray spectra are generated considering the intensity of daughter products mixed in the soil with minimum value of 10% which increased to 100% in steps of 0.1. The figure 2 is a presentation of traces of ^{137}Cs products contaminated soil using NaI(Tl) detector. The analysis of data is done using post-simulation method in python interface ROOT software [2]. As can be seen in the figure after integrating all events without incorporating resolution in the detector shows a sharp peak at 662 keV but this does not make sense since NaI(Tl) detectors are known to have resolution(R%) around 6 - 10 % at 662 keV. In all detectors, the number of counts generated behaves according to Poisson statics i.e. if the mean number of counts is $\bar{N}$, the statistical fluctuation in that number is given as [4]. Alternatively, it can also be expressed in terms of energy deposition as;

$$\sigma(E) = \sqrt{E_s}.\sqrt{\bar{E}} \qquad (1)$$

where E_s is the smallest energy measured and $\bar{E}$ is the average energy deposited. Considering minimum resolution of 6% as given on the website of Gammaspectacular Spectrometers and Detectors company [3], the peak is well defined and presented in figure 2. The gaussian fit is done and highlighted with yellow color. It is interesting to mention that with this resolution of NaI(Tl) scintillator one can also study the X-rays highlighted in green color the characteristic K X-rays of ^{137}Cs at around 32 keV. In the spectrum the Compton edge and backscatter peak can also be studied which of important for educating students of nuclear radiation physics.

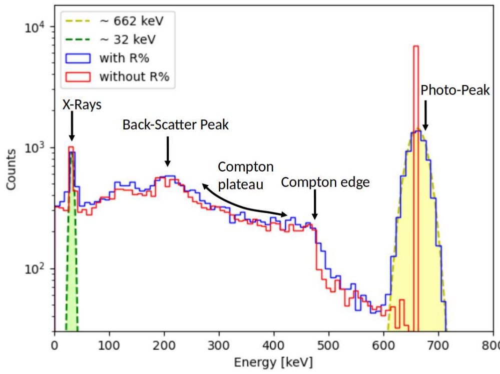

FIG. 2: Shown is the energy spectrum of contaminated standard soil with traces of ^{137}Cs products of half-life ($\approx$ 30 years) measured with NaI(Tl) detector.

Since the LBCRS project is under development, however, we will present ongoing development together with comparison of experimental and simulation results in the conference. VRS thanks INFN, Italy for financial support. BPS thanks DST, India and rest authors thank CONACyT for financial support.

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