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Simulation for Absorbed Dose Assessment, a GATE for planning and evaluating new gamma-ray treatments

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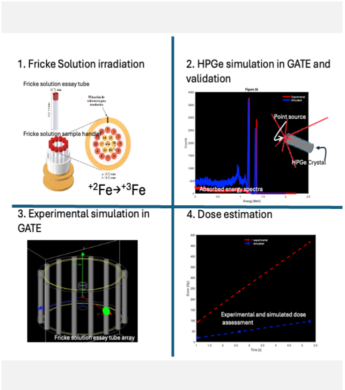

GATE, a Monte Carlo radiation transport code, was used for the first time for water treatment purposes, with promising results for estimating the absorbed dose within water solutions. First, essay tubes containing Fricke solutions were irradiated in a Gamma-cell irradiator type, and the absorbed dose was measured. Then, the absorption of energy, due to a radioactive source, within a germanium crystal was measured experimentally. These results were compared with a simulation performed in GATE. The similarity between simulated and experimental spectra for two different point sources validated the use of the code for dose estimation. Finally, a simulation of the solution irradiation was performed in GATE. The experimental absorbed dose was compared with the simulated counterpart. The comparison demonstrates the validity of using GATE for dose assessment and highlights the necessity of further refinement of the digital model.

Introduction

Ionizing radiation has been used as a proven method for the degradation of contaminants in water. However, planning new applications of this technology can be challenging due to the high level of safety required for handling radioactive material. Additional challenges emerge for the assessment of the dose imparted to the water that will be treated since it is necessary to evaluate the energy absorbed profile first.

These challenges can be overcome with the assistance of digital simulation. Several software packages can simulate the radiation transport within water. One of these options is Geant4, which is a Monte Carlo, code that is open-source and free. This software is being used in several scientific fields. However, it is not user-friendly, and it requires a deep knowledge of programming.

GATE is an application based on Geant4[1], that does not require programming knowledge, but it was conceived for medical purposes. This work aims to present GATE as a tool for dose assessment in planning and designing new environmental applications. For this purpose, comparison of experimental measurements of energy absorbed in various media is compared with simulated results.

Material and Methods

Acid solutions of $^{+2}$Fe (Fricke solution) were irradiated in a Gamma-Cell type irradiator. The samples were placed in 15 essay tubes that were arranged in a circular sample handler of 101,94 cm diameter (see graphical abstract). The tubes were exposed to a gamma source of 118.44 Ci activity. The doses used for irradiation were: 100, 150, and 500 Gy. Under the action of gamma rays, $^{+2}$Fe oxidizes into $^{+3}$Fe. The concentration of the last ion after irradiation was evaluated through spectrophotometry with the equipment Themo Scientific 60S Evolution at a wavelength of 614 nm.

The results obtained in GATE were validated for a water treatment application. For this validation, experimental absorbed energy spectra inside a medium produced by two different point sources were obtained. The sources used were Cs-137 and Co-60, while the medium at which the energy was absorbed was a Hyper Pure Germanium crystal (HPGe)[2]. In the experimental setup, this crystal was attached to a multichannel analyzer which was responsible for telling the different energies at which the radiation was absorbed inside the solid. In the simulated setup, each point source was placed directly over the HPGe crystal (see graphical abstract).

Finally, a simulation of the irradiation of the 15 essay tubes containing the Fricke solution was performed. The simulation consider 5×10^5 photons travel through the solutions. Simulated results were normalized to this number of photons while experimental results were normalized to the activity of the source.

Results and Discussion

Figure 1 shows the absorbed dose within Fricke solution as a function of the time of exposure. As expected, as the time increases the absorbed dose also increases.

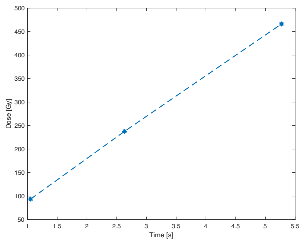

Figure 1. Absorbed dose within Fircke solution as a function of exposure time.

Figure 2a shows the comparison between simulated and experimental absorbed energy spectra for the Cs-137 point source. It must be noted that the experimental photopeak, i.e. the peak due to the emission of a photon during Cs-137 radioactive decay, fits with the simulated counterpart. This photon will be the one that gives its energy to the medium. Figure 2b shows the same comparison for a Co-60 point source. Even though both experimental photopeaks of Co60 do not fit exactly with their simulated counterparts, the results give a close estimation of the energy imparted by both photons.

These results validate the use of GATE for estimating the energy imparted to a medium. As noted in the figures, the absorption of energy is not a direct process, the energy spectra reflect the phenomena that take place during the interaction of photons with matter.

To evaluate the simulated imparted dose in Grays (Gy), the area under the spectrum is calculated. This value is normalized with the number of particles that were tracked in the simulation. The results are compared with the experimental data. Figure 3 shows a comparison between the normalized experimental dose and with normalized simulated dose.

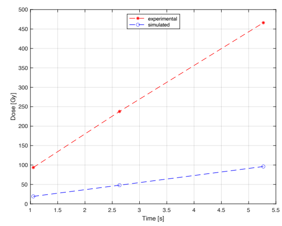

Figure 3. Comparison between simulated and experimental absorbed dose as a function of time in Fricke solution

The difference in the results highlights the necessity of further refinement of the simulation, however, the ability of GATE to estimate the imparted dose is corroborated. This approach can facilitate the application of gamma rays to certain advanced oxidation processes (AOPs).

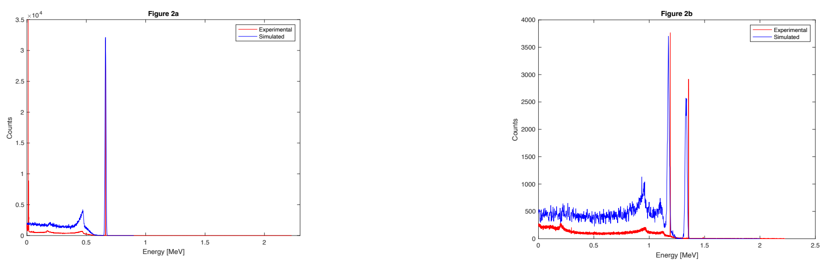

Figure 2. Absorbed dose within Fircke solution as a function of time of exposure.

Conclusions

GATE can replicate the results of the radiation transport within an HPGe crystal. This corroborates the ability of the medical purpose software to estimate the absorbed dose in several media. This ability was successfully tested for Frick solutions exposed to a Co-60 source. Results show that there is a difference between simulated and experimental results which indicates that further refinement of the details of the digital model is required.

Acknowledgments

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References

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