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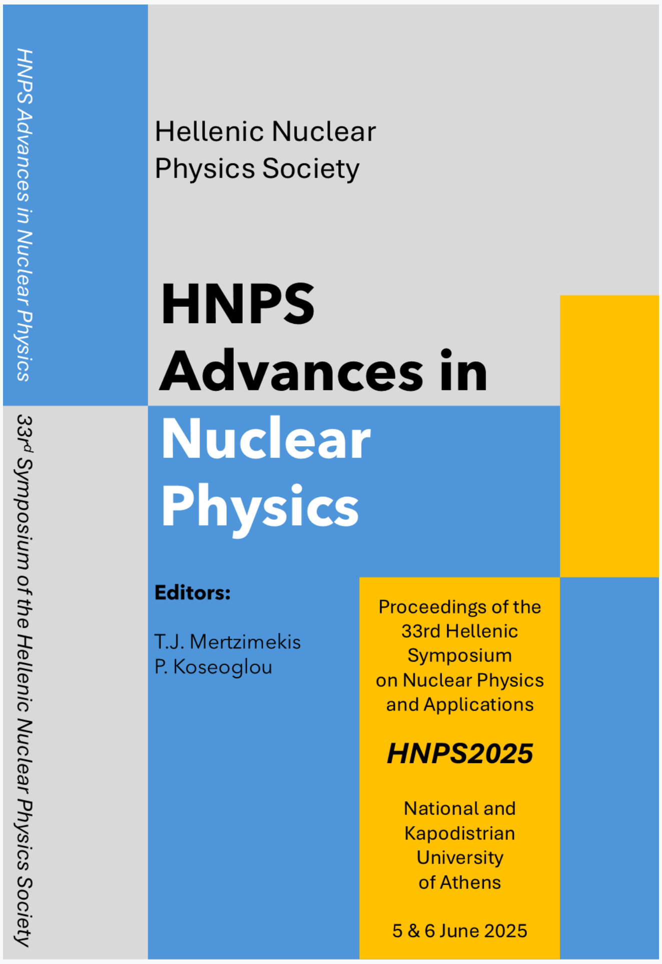

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ARTICLE

Simulations for Optimization of Proton Dose Delivery using the Advanced Markus Chamber

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Abstract
The Advanced Markus chamber is a vented, plane-parallel ionization chamber widely used in proton dosimetry, particularly in cases involving narrow spread-out Bragg peaks or steep depth-dose gradients. As part of the NuCapCure project, a series of *in vitro* and animal model irradiation experiments will be conducted to evaluate the efficacy of novel radiosensitive compounds designed to enhance the cancer cell-killing potential of proton therapy. To support these experiments, Monte Carlo simulations were carried out using the MCNP 6.1 code to model the irradiation setup at the Oslo Cyclotron Laboratory (OCL) that employs the MC-35 Scanditronix AB cyclotron. The computational model included the 16 MeV proton source, a tungsten filter, a beam monitor, and the Advanced Markus chamber. Special attention was paid to the effect of the chamber's entrance window, as it influences the location of the proton Bragg peak. The results of this study allow the optimal positioning of both the Markus chamber and the biological samples, thereby maximizing dose delivery during proton irradiation experiments.

Keywords: MCNP simulations; proton dosimetry; advanced Markus chamber

1. Introduction

In the framework of the NuCapCure project [1], a series of *in vitro* and animal model irradiation experiments will be conducted to evaluate the efficacy of novel radiosensitive compounds designed to enhance the cancer cell-killing potential of proton therapy. To support these experiments, Monte Carlo simulations using the MCNP 6.1 code [2] were carried out to model the irradiation setup at the Oslo Cyclotron Laboratory (OCL), which employs the MC-35 Scanditronix AB cyclotron. The computational model includes the 16 MeV proton source, a tungsten filter, a beam monitor and the Advanced Markus chamber [3]. Particular attention was given to the effect of the chamber's entrance window, as it influences the location of the proton Bragg peak.

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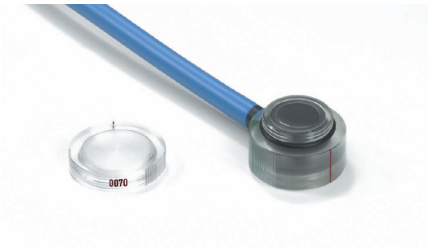
2. Advanced Markus Chamber (Type 34045)

Markus Chamber is a vented plane-parallel chamber that is used for dosimetry measurements. Its shape and characteristics are presented in Fig. 1 while the geometry described in the simulations is shown in Fig. 2.



Materials and measures	
Entrance foil	0.03 mm PE (polyethylene CH_2), 2.76 mg/cm^2
Protection cap	0.87 mm PMMA, 1.19 g/cm^3, 0.4 mm air
Total window area density	106 mg/cm^2, 1.3 mm (protection cap included)
Water-equivalent window thickness	1.04 mm (protection cap included)
Dimensions of sensitive volume	radius 2.5 mm depth 1 mm
Guard ring width	2 mm

Figure 1. Shape (left) and characteristics (right) of the Advanced Markus chamber type 34045, adopted from the PTW catalog.

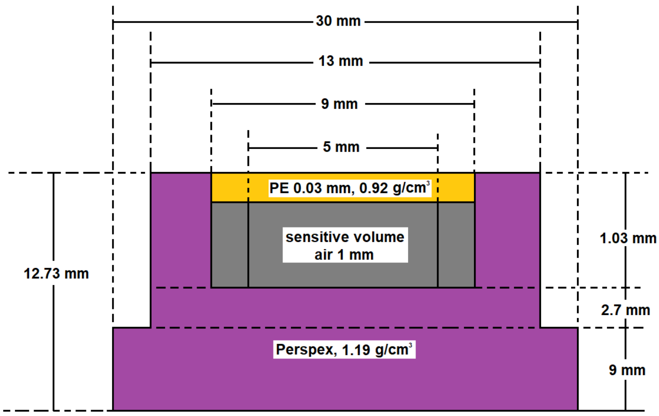
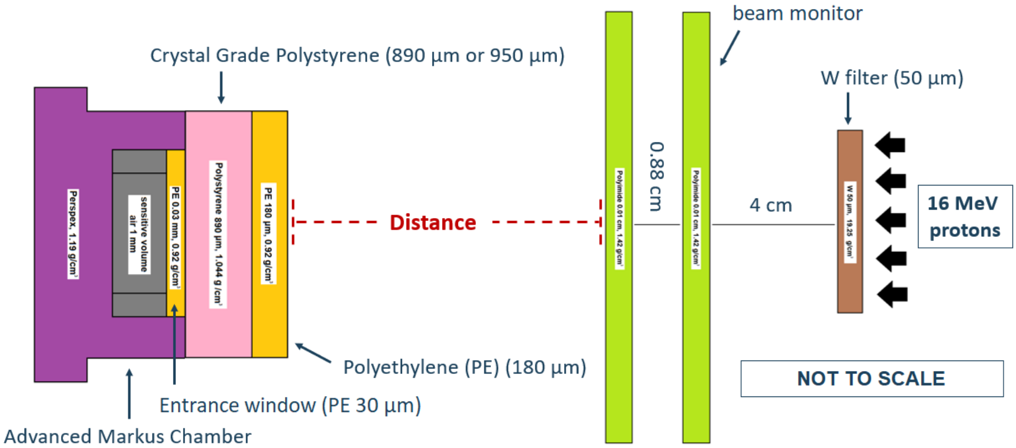


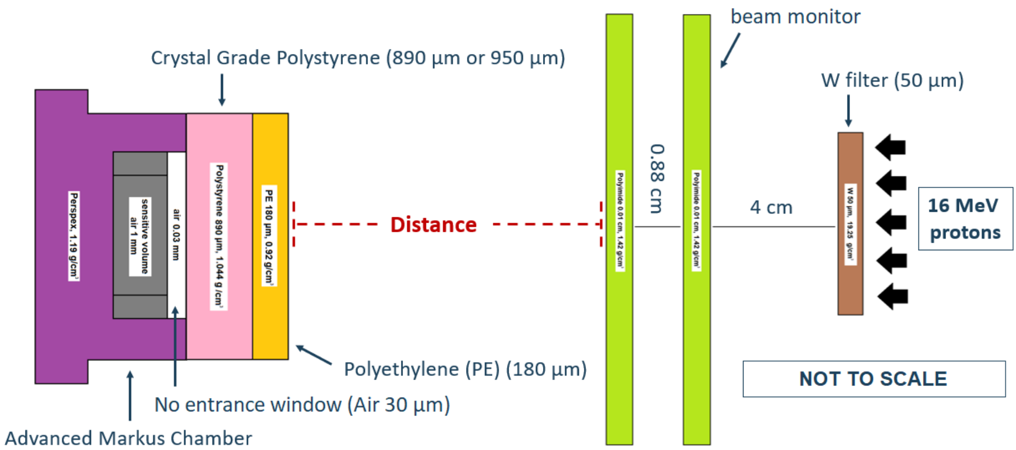
Figure 2. Schematic representation (not to scale) of the Advanced Markus chamber, as described in the simulations.

3. Simulations & Results

A schematic representation (not to scale) of the experimental setup is presented in Fig. 3. A 16 MeV parallel proton beam after passing through a W filter (50 μm thickness, 1.3 cm diameter) and beam monitor consisting of 2 graphite coated polyimide plates (0.01 cm thickness, 10 cm diameter, each) impinges on the Advanced Markus chamber, in front of which two absorbers are placed. Namely, a crystal grade polystyrene layer (either 890 μm or 950 μm thickness, 3 cm diameter) and a polyethylene (PE) layer (180 μm thickness, 3 cm diameter). The absorber materials studied are the ones to be used in the *in vitro* experiments. In particular, the polyethylene film is the bottom of the well-plates to which the cells will be attached. The protons will reach the cells after passing the bottom of the plate and therefore, the effect of this membrane has to be taken into account. The polystyrene interface is there to ensure that the Bragg peak can be achieved at a reasonable distance. Simulations were performed for different beam monitor to absorbers distance, so that the Bragg peak is met inside the sensitive area (grey color) of the Markus chamber.



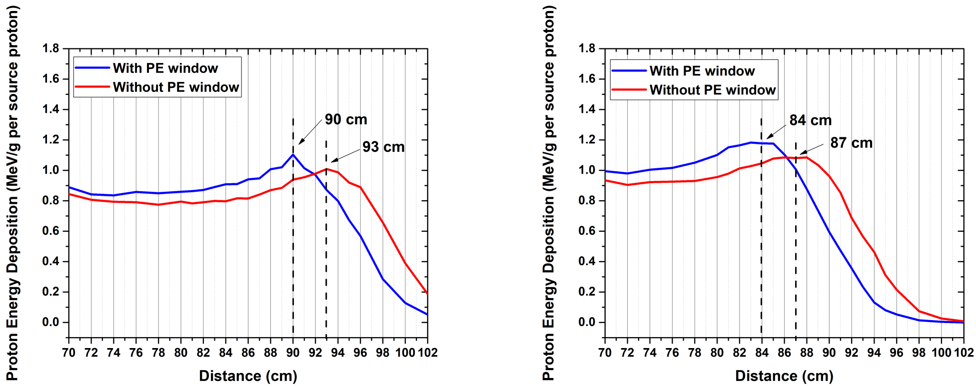
(a) With polyethylene (PE) entrance window.



(b) Without PE entrance window.

Figure 3. Simulation geometry (not to scale) with different materials in the Advanced Markus chamber entrance window (either PE or air).

The aforementioned two geometries, with and without PE entrance window, were simulated for both thickness values of the crystal grade polystyrene layer and the results of proton energy deposition in the sensitive area of the Markus chamber for 890 and 950 µm crystal grade polystyrene thickness are presented in Figs. 4a and 4b, respectively. As shown in Fig. 4b, the thicker crystal grade polystyrene layer leads to the observation of the Bragg peak at smaller distances from the beam monitor (84-87 cm) compared to the corresponding distances for the thinner crystal grade polystyrene (90-93 cm) (see Fig. 4a). However, in both cases, the effect of the PE entrance window is the same and leads to a 3 cm difference in the distance in which the Bragg peak is recorded. Specifically, if the Bragg peak is experimentally determined at position x with the Markus chamber, the sample should be placed at x+3 cm downstream to ensure it receives the maximum proton dose. It is noted that the proton energy degradation was also calculated using SRIM [4] for each individual material layer and was found in good agreement with the MCNP calculations. However, the MCNP code provides a distinct advantage in its ability to simulate 3D experimental geometries. By accounting for multiple scattering effects, angular distributions, and secondary particle interactions, MCNP yields a more realistic prediction of the proton transport behavior.



(a) Crystal grade polystyrene thickness 890 μm.

(b) Crystal grade polystyrene thickness 950 μm.

Figure 4. Proton energy deposition in the Markus chamber sensitive area in MeV/g per source proton obtained for the geometries presented in Figs. 3a and 3b and for (a) 890 μm and (b) 950 μm crystal grade polystyrene thickness.

4. Conclusions

Monte Carlo simulations were performed using the MCNP 6.1 code, to model the irradiation setup at the OCL and to study the effect of the Advanced Markus chamber's entrance window, as it influences the location of the proton Bragg peak. The conclusions obtained are the following: the position of the Bragg peak depends on the a) thickness of the crystal grade polystyrene layer and on the b) presence of the chamber's PE entrance window. For polystyrene thickness of 890 μm, the Bragg peak was found at a distance of 90 cm with PE entrance window, as compared to 93 cm in air, without PE window. For polystyrene thickness of 950 μm, the Bragg peak was found at a distance of 84 cm with PE entrance window, as compared to 87 cm in air, without PE window. Therefore, an adjustment of 3 cm from the beam monitor is required to correct for the perturbation of the proton beam due to the presence of the chamber's PE entrance window for measurements at 16 MeV proton beam energy, at the MC-35 Scanditronix cyclotron.

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References

[1] *NuCapCure Project*. Available at https://nucapcure.eu/.

[2] *Initial MCNP6 Release Overview MCNP6 Version 1.0*. Los Alamos National Laboratory report LA-U13-22934 (2013).

[3] *Advanced Markus Chamber Type 34045 User Manual by PTW*. Available at https://www.ptwdosimetry.com/fileadmin/user_upload/Online_Catalog/Detectors_for_Ionizing_Radiation/catalogs/DETECTORS_Cat_en_16522900_16/pdf/save/bk_35.pdf.

[4] James F. Ziegler, M.D. Ziegler, and J.P. Biersack. "SRIM – The stopping and range of ions in matter (2010)". In: *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 268.11 (2010). 19th International Conference on Ion Beam Analysis, pp. 1818–1823. DOI: 10.1016/j.nimb.2010.02.091.