Reaction cross sections of prompt-gamma and PET radioisotopes for range verification in proton therapy

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Although protontherapy is advantageous over more traditional radiotherapy from the point of view of dose delivery and sparing of organs at risk, its full potential has not been reached yet [1]. A lot of effort is focused on proton range verification techniques to improve dose localization. Several of these techniques profit from the secondary emission induced by protons to identify the proton range and to estimate the dose deposited in patients [2]. They include the generation and detection of PET radioisotopes, and the production of prompt gammas (PG) by proton-induced reactions. It is nonetheless crucial to have reliable cross section values of the more interesting reaction channels. The radiation induced on natural tissues is not always the most suitable to perform proton range verification. Thus the use of contrast agents that provide an increased induced radioactivity near the Bragg peak region has been suggested to improve the range verification capabilities [3,4]. Our studies show several promising candidates.

Water-18 ($H_2{}^{18}O$) has a great potential as a contrast agent both in PET and in PG thanks to the oxygen ^{18}O isotope. As a PET contrast agent the most interesting reaction channel is the (p,n) one, which produces ^{18}F, which is a β^+ emissor with a halflife of 109 min. The cross section values up to 10 MeV are well known because of its medical use as radiotracer. On the contrary, the relevant energies in protontherapy amount up to 220 MeV and therefore it is necessary to know the cross section values up to this energy. We will report on measurements performed using the 220 MeV cyclotron at the Quirónsalud protontherapy center in Madrid. Samples were irradiated in the beam at several energies and measured offline using a setup based on fast $LaBr_3$(Ce) scintillator detectors coupled to a digital acquisition system. The results are illustrated in Fig. 1 (left), where measurements of an irradiated 100 µl water-18 sample was irradiated at 150 MeV. We will report on the cross section results and on the benchmarking measurements carried out at the 5-MV tandetron accelerator of the Center for Micro Analysis of Materials (CMAM) [5] in Madrid (Spain).

Prompt gamma emission from water-18 also is promising for proton range verification due to the presence of intense, discrete γ-rays. We have performed measurements of PG production at low energies at CMAM in the energy range 1–10 MeV using a set-up consisting of two pairs of collinear opposed $LaBr_3$(Ce) detectors and a fully digital acquisition system with high-rate capabilities. We will report on results, shown in Fig. 1 (right), which highlight the presence of prompt γ-rays from ^{18}O visible above background for the irradiation of an admixture of distilled water (93)% and water-18 (7%).

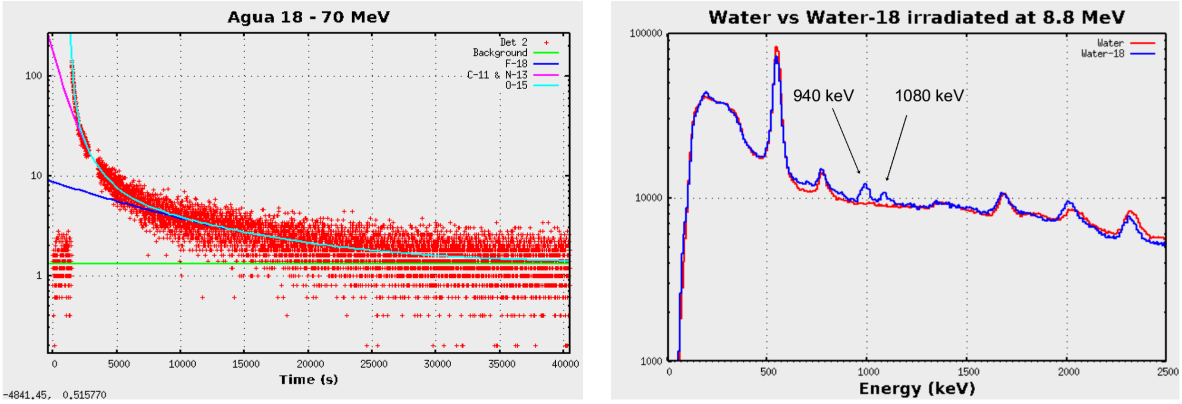

Figure 1: (Lef) PET activity as a function of time for a water-18 sample irradiated at Quirónsalud at 150 MeV. (Right) PG spectrum at 8.8 MeV measured at CMAM.

Another promising candidate for proton range verification using contrasts is Iodine. It is routinely used as a contrast agent in several other medical applications. Proton-induced reactions produce ^{127m}Xe with 69-s halflife, via the (p,n) channel, which can be used for online range verification [6]. Since the reaction cross sections were not known down to the low energies relevant for the Bragg peak we have performed irradiations in the 4–10 MeV range in the external microbeam line at CMAM. The measurements made use of the on-line setup based on $LaBr_3$(Ce) detectors mentioned above. We will report on the results and the comparison to model calculations, which support the viability of ^{127}I as a contrast agent for proton radiotherapy. Concerning the production of prompt gammas we will report on the measurements carried out at CMAM at low energies, and at the Quirónsalud cyclotron up to 220 MeV proton energies.

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