Production cross section of the short-lived $\beta^+$ emitters $^{12}$N, $^{29}$P and $^{38m}$K for online PET verification in proton therapy

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1. In-vivo PET range verification

- Comparison between measured and expected (MC codes) $\beta^+$ activity distributions required
- The accuracy of expected activity distributions depends on the underlying cross section data (input of the MC code)

Need of more accurate measurement of cross-section values in the full energy range (up to 250 MeV) so PET range verification method could give mm accuracy [3]

- Long-lived $\beta^+$ emitters: $^{11}$C, $^{12}$N (offline monitoring)
- Short-lived $\beta^+$ emitters: $^{12}$N, $^{38m}$K, $^{29}$P (online monitoring)

2. PET isotopes for beam-on range verification

- Compared to long-lived $\beta^+$ emitters, the short-lived provide real-time feedback on the dose delivered, a largest number of counts and are less susceptible to biological wash-out [4]
- State of the art:
  - Measurement of the integral prod. yield below 55 MeV, [7]
  - Measurements below 48 MeV for $^{12}$N, [4]
- Significant discrepancies between different available cross section data sets.

Figure from [1]

3. Experimental setup @ KVI-CART

- We have irradiated films of graphite, CaF$_2$ and P between 3 mm thick aluminium plates (the $\beta^+$ to $\gamma$-ray $\gamma$-conv ranges from 30% for $^{12}$N to 60% for $^{29}$P).
- The 511 keV photons are detected by cylindrical (1.5\,x\,1.5\,\text{cm}$^2$, height 1.5\,\text{cm}, bases 1.5\,\text{cm}$^2$ and 1\,\text{cm}) LaBr$_3$(Ce) detectors operating in coincidence.
- The absolute single and coincidence detection efficiencies are determined with a $^{22}$Na source.
- The beam current is monitored with a beam ionization chamber placed before the first target.
- The alignment has been checked using Gafchromic films placed before and after each target.

Irradiations at 90 and 150 MeV with several degraders: the overlap of two irradiation energies validates the measurements.

4. Preliminary analysis

- The production yield in each target is obtained looking at the 511 keV photons in coincidence (emitted mostly outside the target, somewhere in the converters).
- In case of the emission of characteristic $\gamma$-rays, they are also measured (emitted from inside the target).
- The production in the Al layers is also measured with empty targets (subtracted to total production).
- The decay curve (in red) is fitted to:
  $$A(t) = A_0 e^{-\lambda t} + C,$$
  to obtain the production cross section.

5. Conclusions & outlook

- Production yields between 20 and 150 MeV measured at KVI-CART, analyses ongoing.
- Geant4 simulations validated at CNA.
- Measurement at higher energies (up to 190 MeV) planned in 2020.
- Measurement below 55 MeV with better energy resolution (single shots) planned for 2020.

References

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