

# The prediction of the $\beta^+$ -activity distribution on the basis of the patient CT using the FLUKA simulation code

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The in-beam PET technique for quality assurance of  $^{12}\text{C}$  therapy is based on the comparison of  $\beta^+$ -activity distributions measured during therapeutic irradiations with those predicted from the treatment plan. The generalisation of this method to all species of therapeutically relevant ions requires a precise description of both the stopping process and the nuclear interactions of the projectiles in tissue. The FLUKA radiation transport simulation code [1], [2] may meet these requirements since the implementation of suitable models for describing light ion nuclear interactions is in progress. Furthermore, it has been demonstrated that measurements of proton beam induced  $\beta^+$ -activity distributions can be rather well reproduced by calculations based on the FLUKA code [3]. The approach developed for the proton case may be feasible for other ion species: In a first step the spatial distribution of the flux of primary and secondary particles  $\phi(E, A, Z, \mathbf{r})$  is calculated on the basis of the FLUKA internal models of nuclear reactions. In a second step a realistic description of the production of positron emitters is obtained by combining these results with measured or semi-empirical cross sections [3].

The  $\beta^+$ -activity produced via target fragmentation strongly depends on the stoichiometric tissue composition, especially on the  $^{16}\text{O}/^{12}\text{C}$  ratio, which varies between 0.22 for adipose tissue and 4.05 for muscle. This ratio determines the relative abundances of  $^{15}\text{O}$  ( $t_{1/2} = 2.03$  min) and  $^{11}\text{C}$  ( $t_{1/2} = 20.38$  min) as the dominating  $\beta^+$ -active reaction products, and because of the different half-lives the activity in different tissue types. Especially for projectiles with  $Z < 5$ , where  $\beta^+$ -emitter can only be produced by target fragmentation taking into account the tissue stoichiometry is unavoidable for a correct description but also for heavier projectiles as e.g.  $^{12}\text{C}$  a refinement of the prediction of the  $\beta^+$ -activity distribution from the treatment plan is expected.

In a typical patient CT the Hounsfield numbers range from  $-1024$  to  $3071$  representing different densities and different chemical compositions of tissue. The CT numbers are converted by a Fortran code into a file which is

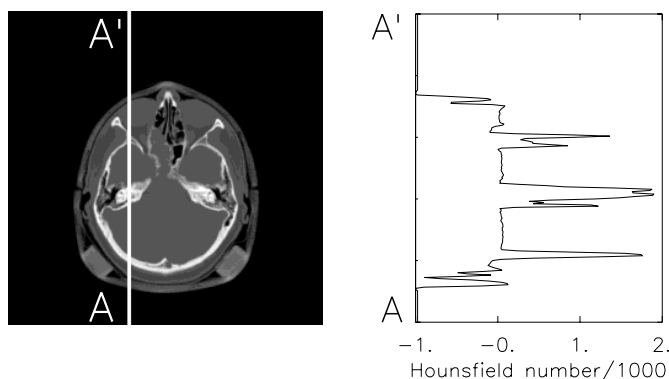


Figure 1: left: Patient CT, right: Profile of Hounsfield units along the section  $\overline{AA'}$ .

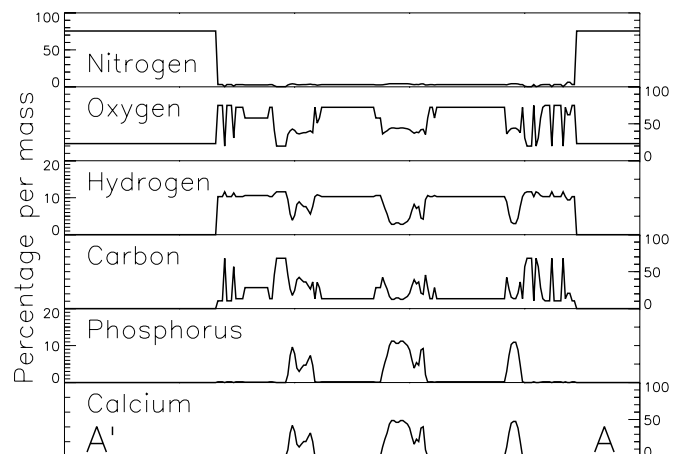


Figure 2: Chemical composition of the tissue along the section  $\overline{AA'}$  in Fig. 1 referring to the segmentation described in the text. Abundances below 1.5 % (Na, Mg, S, Ar, K) are not displayed in this figure.

adopted by FLUKA as geometrical input. For deriving the stoichiometric information we use the conversion of CT numbers to elemental weights established by [4], which gives the chemical composition for Hounsfield numbers between  $-1000$  and  $1600$ . Hounsfield units lower than  $-950$  are set to the composition of air, between  $-120$  and  $-950$  the composition of lung is assigned, in the range of soft tissue between  $-120$  and  $200$  a finer raster is applied and in the region above  $200$  a grid of  $100$  Hounsfield units is used. For Hounsfield units larger than  $1600$  the chemical composition has been extrapolated with the step width of  $100$  Hounsfield units up to  $3000$ , the Hounsfield numbers larger than  $3000$  are treated as titanium. This segmentation leads to  $39$  different tissue compositions. For each portal the distribution of position emitters can be calculated for each pencil beam using a file containing general information for the patient as well as the beam energy, focus and position as well as the number of particles for all points to be irradiated. This can be done before the treatment starts, after the fractionated irradiation these results can be combined with the time protocol of the irradiation and give for each positron emitter the time when it was created. Then all processes from  $\beta^+$ -decay to the detection of  $\gamma$ -rays can be done as described in [5].

## References

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