A P.E.T. STUDY OF PROTON INDUCED RADIOACTIVITY IN DIFFERENT MATERIALS

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ABSTRACT

A possible application of the Positron Emission Tomography (PET) technique as a tool for in situ dosimetry during radio therapy with protons is investigated. Measurements have been performed on activation induced by 55 MeV protons in two different materials. The calculated dose distribution is compared with model calculations and 3-dimensional measurements with PET of the induced activity.

1. INTRODUCTION

If a patient or a material is irradiated with particles of sufficiently high energy, radioactive nuclei will be created along the trajectory of the particle beam. In target materials containing ^{12}C, ^{16}O or ^{14}N, the positron emitters ^{11}C ($T_{1/2}$=20 min) and ^{13}N ($T_{1/2}$=10 min) will be created. Using a PET scanner, the distribution of the activity can be measured in three dimensions and as a function of time. Of course, the PET scan has to be made very shortly after the irradiation, or even better: during the irradiation. As a pilot experiment for studying the feasibility of this technique we have performed a PET-measurement of the induced activity by protons in Melamine and Poly-ethylene-glycol.

2. EXPERIMENTAL TECHNIQUE

In Groningen we have benefitted from the convenient situation that the PET Center of the University Hospital is only 7 km from the KVI-cyclotron. The last experiment performed with the Philips cyclotron at KVI was an irradiation with 55 MeV protons of two target materials with different composition:

I) Poly-ethylene-glycol, mass composition:
54.3% C, 9.1% H and 36.6% O.

II) Melamine, mass composition:
28.6% C, 4.8% H and 66.6% N.

These materials have been selected because of the resemblance of their nuclear composition with tissue, but also to limit the possible amount of reaction types.

The beam was collimated to 4 mm diameter and each target was irradiated for 1 minute with a beam intensity of 10 nA. Current measurement during irradiation was done by integrating the current on the targets, which were isolated from ground. Since the range of 55 MeV protons in the target materials is approx. 22 mm, the 33 J deposited in each target is equivalent to an average dose of about 90×10^3 Gy, which is about 3000 times a typical dose delivered to a patient during a treatment.

After the irradiation the targets were quickly transported to the PET scanner, a Siemens ECAT 951/31, calibrated in absolute terms with ^{68}Ga and ^{18}F sources. The axial range of the tomograph is divided in 31 image planes with a slice thickness of 3.375 mm. The position resolution of the scanner is 6 mm FWHM.

In Fig. 1 a measured activity distribution, projected on a horizontal plane, along the image planes is shown. The plane nr. indicates the axial position.

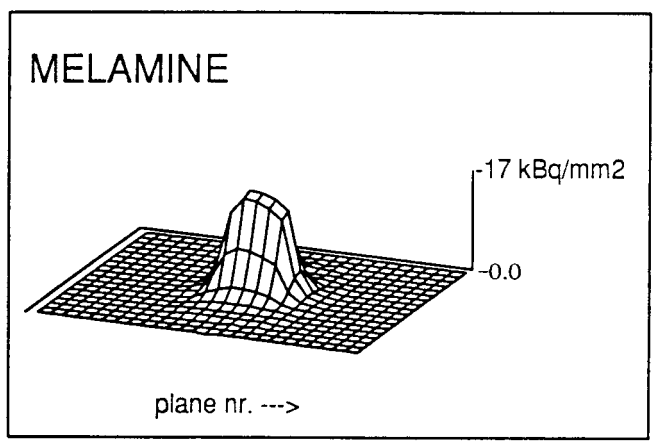

Fig.1. Distribution of proton induced activity in Melamine, in axial (=plane nr) and lateral direction. The vertical scale indicates 17 kBq/mm^2.

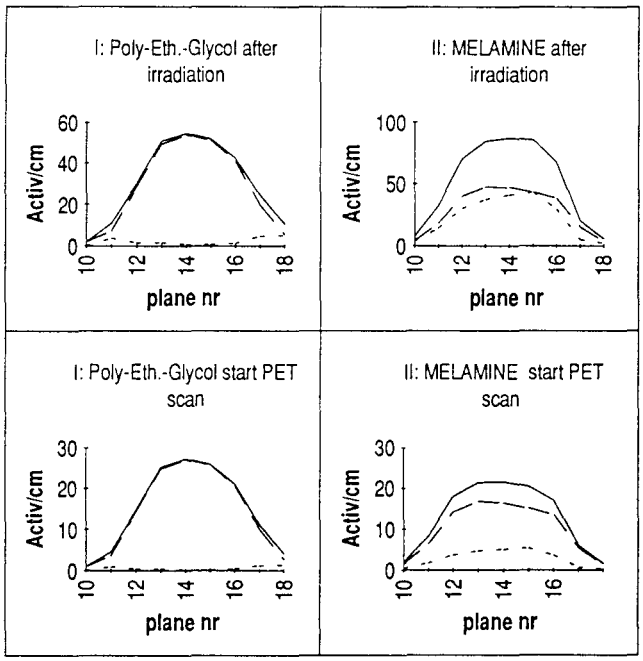

Fig. 2. Measured ^{11}C (dashed lines) and ^{13}N activity (dotted lines) as function of plane nr, at the beginning of the PET scan (bottom) and immediatly after irradiation (top).

The measurement of the activity distribution in target I started 20 min. after the irradiation and for target II 30 min. after irradiation. During 30 minutes, for every plane, 30 time intervals of 1 minute were measured and the measured intensity was corrected for ^{11}C-decay. At the beginning of the scan the coincidence count-rate from target I was 22×10^3 s^{-1} and from target II: 18×10^3 s^{-1}.

3. ANALYSIS

By measuring the lateral width of the activity distribution in each plane the spreading of the beam has been examined. No significant increase of the beam dimension has been detected.

By following the count rate as a function of time, the total activity can be separated in the contributions of ^{11}C and ^{13}N. This has been done for each image plane. In Fig. 2 these contributions and the total activity are shown as they were at the beginning of the PET scan (bottom) and extrapolated to the end of the irradiation (top).

As can be seen in Fig. 2, the contribution of ^{13}N has quickly vanished. This also results in a change of the shape of the total intensity versus plane nr. Although the ^{13}N-production in target I is almost negligible, the two reaction channels (i.e. the $^{16}O(p,2p2n)$ and $^{16}O(p,\alpha)$ reactions) show up clearly as the two little peaks at plane 11 and plane 17+18.

The integrated total activity at the beginning of the PET scan was:
target I : 5.1 MBq (5.0 MBq ^{11}C + 0.1 MBq ^{13}N)
target II: 4.1 MBq (3.4 MBq ^{11}C + 0.7 MBq ^{13}N)

Correcting for the different life times, this yields immediatly after a real treatment with 55 MeV protons the following coincidence count-rates:

Dose=30 Gy: Target I: 15 s^{-1} and Target II: 25 s^{-1}.

In a low background situation, as is the case for these PET studies, these count rates can be sufficient to be used for on-line analysis of the beam position.

4. MODEL CALCULATIONS

Energy dependent cross sections of the possible reactions producing ^{11}C and ^{13}N have been obtained from refs.[1-4]. Taking into account the energy loss of the protons along their trajectory an estimation of the activity as a function of plane nr. (z) can be made. In Fig. 3 the calculated activities and the doses are shown as a function of z for the two targets. A Gaussian shaped position-resolution function has been folded into the calculated activity curves. The curves shown in Fig. 3 are calculated for the moment where the PET scan starts, where the difference in half-lifes has been taken into account.

Since the Bragg peak in the dose distibution cannot coincide with a large cross section for nuclear reactions, this part of the trajectory cannot be mapped with this method. However, for energies larger than the reaction threshold (approx. 10 MeV in Melamine and 15 MeV in Poly-ethylene-glycol, the cross sections show a rather flat continuum, and so does the activity distribution for low z.

It can be seen, however, that there is a strong disagreement between the calculated and measured activity at the end of the trajectory in Melamine. Due to the large values of the cross sections of the $^{14}N(p,\alpha)^{11}C$ reaction below 20 MeV, according to ref.,[2] the calculation shows an increase of activity at high z, while Fig. 2, shows a decrease at high plane nr. However, for the lower plane nrs the overall shape of the ^{11}C and ^{13}N activities is in agreement with the data.

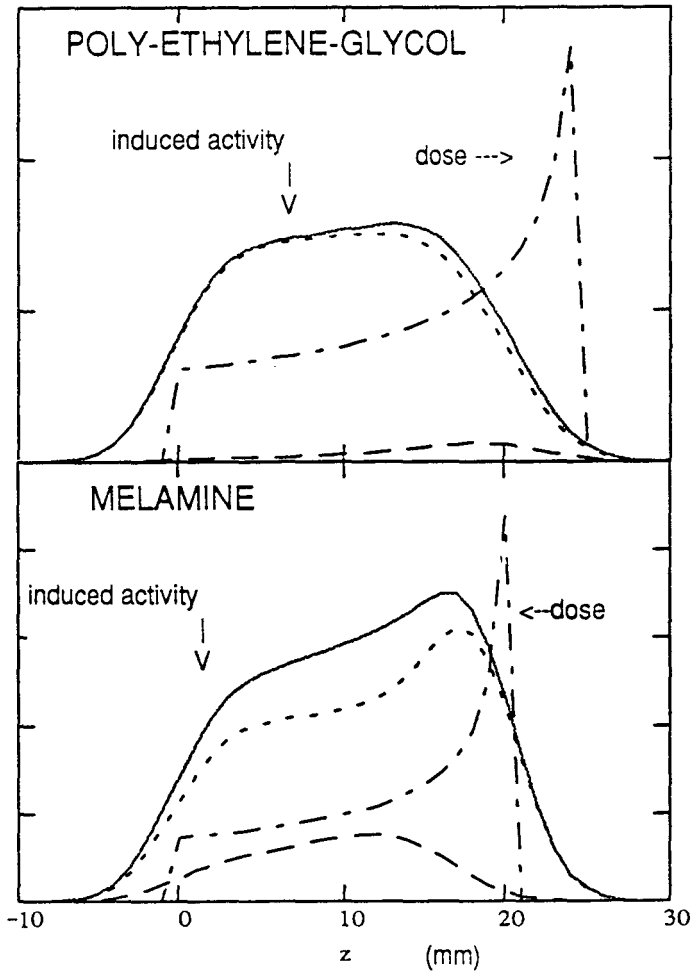

Fig.3. Calculated activity distributions in Polyethylene-glycol (top) and Melamine (bottom). ^{11}C: ...., ^{13}N: - - - and total activity:——. The dose, indicated with – – – –, is also shown in the figure.

Integration of the total induced activity as calculated, gives at the start of the scan:
target I : 6.2 MBq (5.9 MBq ^{11}C + 0.3 MBq ^{13}N)
target II: 6.4 MBq (5.3 MBq ^{11}C + 1.1 MBq ^{13}N)
Considering the uncertainties in the cross sections, these calculations are in rather good agreement with the data.

5. CONCLUSIONS

The radioactivity induced by proton beams in tissue-like (=consisting mainly of C, N and O) materials can be measured accurately by means of PET. It is expected that also the rather low amount of activity created during a therapy treatment can be detected with sufficient accuracy. Especially the region preceeding the Bragg peak in the dose distribution can be monitored quite well with this method. However, for the determination of an accurate Activity-Dose relation more data on the reaction cross-sections below 25 MeV is necessary.

We found that the calculated total amount of activity is in rather good agreement with the data.

We have shown that a dynamic PET study gives an accurate insight in the concentrations of the different types of positron emitters.

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6. REFERENCES

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