TRANSMISSION FACTORS FOR THE NEUTRONS FROM SOME RADIOISOTOPE PRODUCTION REACTIONS FOR PET

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INTRODUCTION

The purpose of this work is to present the dose transmission factors of ordinary concrete, for neutrons originated during the production of some radioisotopes used in positron emission tomography (PET). PET is a technique used in nuclear medicine which use in image diagnostics is in permanent increasing, because of two unique characteristics : the spatial resolution is independent of depth, and, it is possibly to make absolute corrections to tissue attenuation. These characteristics make it possible to determine the real concentration levels of the radioactive tracer in tissues, as well as the parameters related to the functioning and metabolism of tissues and organs.

The availability of adequate positron emissors is one of the restrictions for the use of this technique in nuclear medicine Because of the short half lives of these isotopes (from 1 minute to 2 hours approximately), it is a common practice to install a particle accelerator capable to produce them in the surroundings of the PET. The positron producer isotopes commonly used are: ^{11}C, ^{13}N, ^{15}O, and ^{18}F, which are produced by means of the reactions $^{16}N(p,\alpha)^{11}C$, $^{16}O(p,\alpha)^{13}N$, $^{13}C(p,n)^{13}N$, $^{15}N(p,n)^{15}O$, $^{14}N(d,n)^{15}O$ and $^{18}O(p,n)^{18}F$.

This work is only related to the shielding necessities of cyclotrons with accelerating protons up to energies from 10 to 13 MeV, and for the reactions $^{18}O(p,n)^{18}F$ and. $^{13}C(p,n)^{13}N$ This is so, because some recent studies indicate that the optimum energy for these types of cyclotrons is around 11 MeV. As well, the reactions $^{18}O(p,n)^{18}F$ and. $^{13}C(p,n)^{13}N$ generate the most restrictive conditions for the shields [1].

The main requirement for shielding arise from rapid neutrons, coming from the nuclear reactions that are produced in the target, which have a high penetration and a high quality factor. The gamma radiation produced in the target normally is not relevant for the dimensioning of the shields, because the last ones must be capable to attenuate photon radiation originated in them, in particular by capture of thermal neutrons in hydrogen.

DETERMINATION OF THE SPECTRUM OF INCIDENT RADIATION

The spectrum of incident radiation was estimated supposing that the projectiles are fully stopped in the thick target, and that it may be neglected the lost of particles in nuclear reactions. The calculation of neutron spectrum was made using the cross sections for thin target , $\sigma(E)$ [2-7], and the number of incident particles interacting between the beam energy and the reaction threshold energy.

The number of neutrons produced by protons with energies between E and dE is $\sigma(E)\ N\ dE/(dE/dx)$, where N is the atomic density of the isotope considered in the target, and dE/dx is the lost of energy per unit length travelled by the particle [8].

The energy scale of the neutrons emitted is determined by analysing the energy distribution of the reaction, taking into account the masses of the intervening particles, the energy of the incident particle, and the angle between the velocity vectors of incident and emitted particles.

For neutrons emitted at 0°, when exist only one open reaction channel that produce a residual nucleus in ground state, the energy of the incident proton (E_p) and the emitted neutron (E_n) are related by $E_n=E_p+Q$, where Q represents the energy balance of the reaction. In the case that the residual nucleus remains in an excited state with energy W, the energy of the emitted particle will be $E_n=E_p+Q-W$. In both cases, the recoil energy of the residual nucleus was neglected, which is essentially valid if the mass of residual nucleus is much more than the mass of the emitted particle. Using this calculating method, it was possible to estimate the spectrum of neutrons emitted at 0° in the reactions $^{18}O(p,n)^{18}F$ and. $^{13}C(p,n)^{13}N$, in thick target condition, and for protons with energies between 10 and 13 MeV.

DETERMINATION OF THE TRANSMISSION FACTORS

It was used the discrete coordinates code ANISN[9] for obtaining the neutron spectra in the output of infinite slabs of ordinary concrete This code applies the method of discrete coordinates, or S_n, which is a numerical technique of finite differences, for solving the Boltzmann transport equation for steady state.

Because of the great variation of concrete compositions, we selected the TSF 5.5 concrete [10], with a density of 2.3 g/cm^3 and 15.5% by weight of water, as representative of ordinary concrete.

The source used was a parallel beam of neutrons, of unitary fluence, incident in almost right angle ($\cos\theta = 0.9894$) over the shield. The energy distribution of the beam was the estimated, in the form already described, for the reactions $^{18}O(p,n)^{18}F$ and. $^{13}C(p,n)^{13}N$. The calculations were made in xy (slab) geometry, with quadrature order 16 and Legendre polynomial expansion of order 3 (S_{16} P_3).

We used the cross sections corresponding to the coupled library VITAMIN C [11], with 171 neutron groups and 36 photon groups. That the library is coupled means that the secondary photons generated by the neutron interactions appear as sources for the gamma groups, which are subsequently transported by the ANISN code.

The neutron and photon spectra obtained outside the shield were converted to effective dose by means of the factors conversion presented in a publication based in the publication 60 of ICRP [12], for anterior-posterior (AP) irradiation geometry.

RESULTS

In figures 1 and 2 we present the transmission factors for effective equivalent dose (Sv cm^2), obtained for neutrons generated in the reactions $^{18}O(p,n)^{18}F$ and. $^{13}C(p,n)^{13}N$, with protons of 10, 11, 12 and 13 MeV, inciding almost normally on ordinary concrete. These factors take into account the primary radiation and the secondary gamma radiation generated in the shield.

CONCLUSIONS

The data presented are a suitable tool for making, in simple form, the approximated dimensioning of primary shielding, required for cyclotrons commonly used in the production of radioisotopes for positron emission tomography. It must be pointed that, the transmission factors obtained are slightly conservative in relation to real shielding, because they were calculated using a parallel beam of neutrons, inciding in almost right angle on the shield.

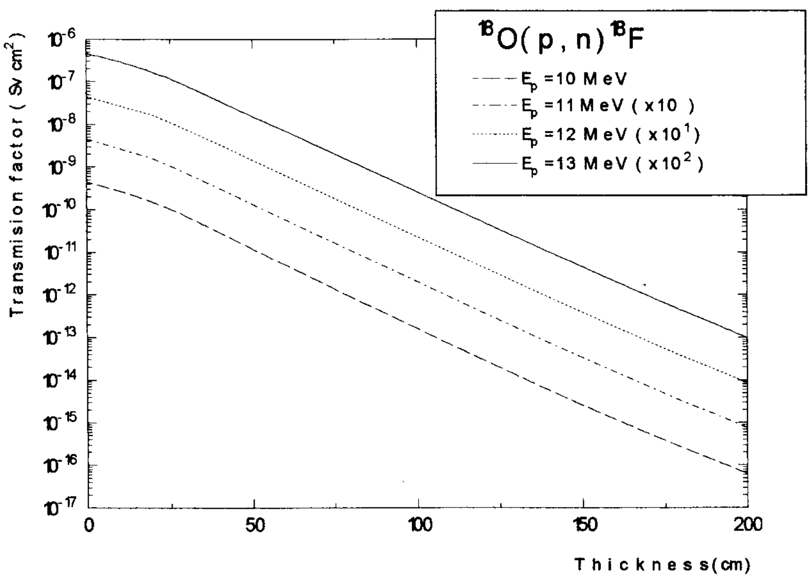

Figure 1: Transmission factors for the reaction $^{18}O(p,n)^{18}F$.

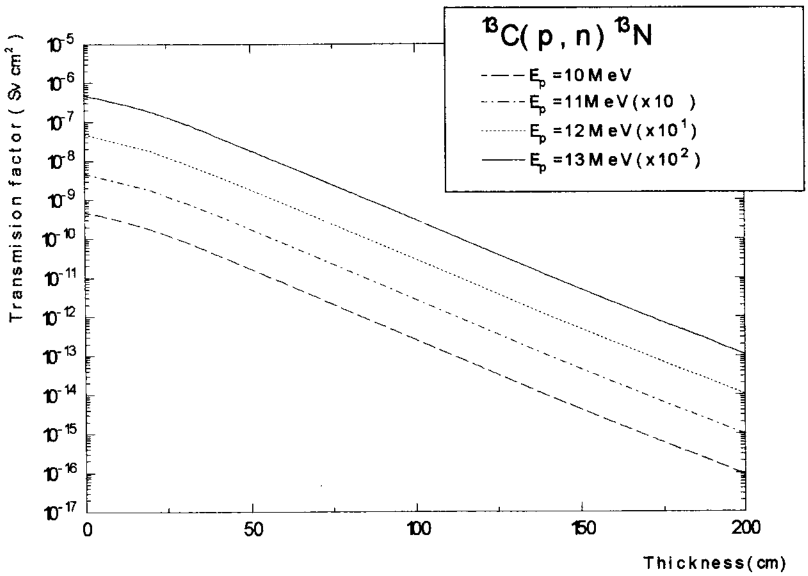

Figure 2: Transmission factors for the reaction $^{13}C(p,n)^{13}N$.

BIBLIOGRAPHY

[1] J. R. VOTAW and R. J. NICLES, Nucl. Instr. and Methods B40/41, 1093-1099, (1989).

[2] W. FRITSCH, K. D. BÜCHS, E. FINCKH, P. PIETRZYK Y B. SCHREIBER, , Z. Phys. 262, 65-70, (1973).

[3] J. D. ANDERSON, S.D. BLOOM Y C. WONG, Phys. Rev. 177, 1416-1435, (1969).

[4] H. MARK Y C. GOODMAN, Phys. Rev. 101, 768-772, (1956).

[5] P. M. BEARD, P. B. PARKS, E. G. BILPUCH Y H. W. NEWSON, Annals of Phys, 54, 566-597, (1969).

[6] T .J.RUTH and A. P. WOLF, Radiochem. Acta 26, 21-24, (1979)

[7] P. DAGLEY, W. HAEBERLI and J. X. SALADIN, Nucl. Phis. 24, 353-373, (1961).

[8] M. J. BERGER, "ESTAR, PSTAR, ASTAR, IAEA-NDS-144 (1993).

[9] W. W. ENGLE Jr., K-1693, Oak Ridge National Laboratory, (1967).

[10] CHILTON, A., NBS Report 10425, National Bureau of Standards, (1971).

[11] R. ROUSIN, C. WEISBIN, J. WHITE, N. M. GREENE, R. WRIGHT, J. WRIGHT, DLC-41, Radiation Shielding Information Center, (1980).

[12] Y. YAMAGUCHI and NAKA-GUN TOKAI-MURA, Radiat. Prot. Dosim. 55(4),257-263 (1944).