CALCULATION OF PHOTON DOSE FROM POSITRON SOURCES

Khamis A. Nahdi [1,2], Manfred Tschurlovits[1]
[1]Atominstitute of Austrian Universities, A-1020 Vienna, Austria
[2]present address: Jeddah, Saudi Arabia

Abstract
This paper reports the results of detailed calculations of the different contributions to the total dose, where bremsstrahlung, annihilation and decay are considered. The calculations are carried for some ten radionuclides and for radiation protection purposes . The results were obtained by using analytical methods and Monte-Carlo techniquues. In order to have a presentation being consistent with gamma- emitting radionuclides, the results are given in terms of kerma rate constant in air of a shielded positron source.

INTRODUCTION

Positron emitting sources are becoming increasingly important in many applications of radiation. Sources are positron emitting radionuclides, positron beams, and induced as contamination at accelerators. Positron emitting radionuclides are used in nuclear medicine, e.g. positron emission tomography (PET) or in scientific applications. They are produced by accelerators (e.g. N-15(p,n)0-15 or by reactors (e.g.Cu-63(n,γ)Cu-64.
Since these sources both emit and produce some different kinds of radiation (positrons, bremsstrahlung, annihilation radiation), they contribute in different forms to all problems interesting in radiation protection, where dose assessment and shielding are the most important.

In order to make quantitative assessments, some aspects will considered in turn. The beta spectrum of the radionuclide were recalculated. Since detailed knowledge of positron interaction with matter is required to calculate quantities needed for shielding and dosimetry.
The work was separated into the following subchapters: calculation of positron spectra, assessment of the required absorber thickness, annihilation and bremsstrahlung production in the absorber leading to photon spectra for moneenergetic positrons. Radionuclide spectra, taking into account decay photons, are used for dose rate constant calculation

CALCULATION OF PHOTON PRODUCTION

Photons are produced in the absorber while the positron is slowing down via bremsstrahlung and annihilation processes. In addition, there are the decay photons in many of positron emitting nuclides, which are characteristic of the individual nuclide. From the Monte Carlo calculations, Fig. 2 shows as an example the relative intensity of the bremsstrahlung and the annihilation photons from a 1MeV positron beam with the respect to the thickness of the aluminium slabs.

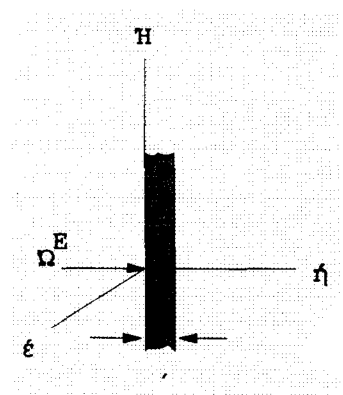

Fig. 1 Schematic diagram of the Monte Carlo simulation in which a positron beam is normally incident on the foil along the Z-axis.

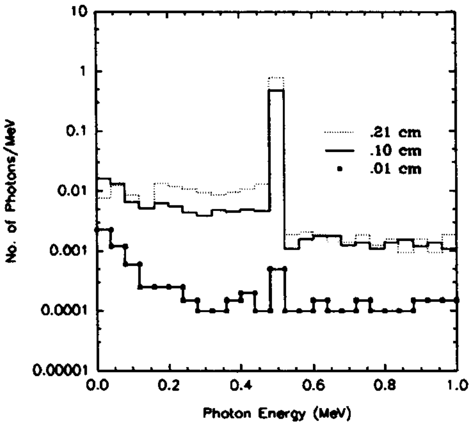

Fig. 2 Transmitted spectra of bremsstrahlung and annihilation photons from 1 MeV positrons on aluminium foils 0.1, 1.0, 2.1 mm thick.

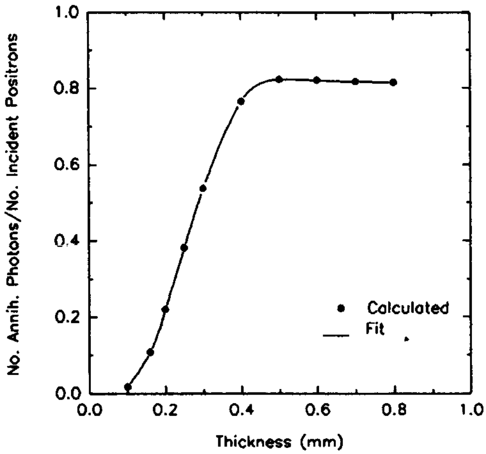

Fig. 3 Number of annihilation photons per incident positron from Cu-64 produced in aluminium foils.

PRODUCTION OF ANNIHILATION PHOTONS

The production of annihilation photons increases with the increase of the absorber thickness reaching a maximum when the thickness is equal to or more than the range of the maximum energy of the positrons, as shown in Fig 3 for Cu-64 source incident on aluminium absorber.

PRODUCTION OF BREMSSTRAHLUNG PHOTONS

As the production of the bremsstrahlung photons increases with the increase of the atomic number, and since only low Z-material is of concern here for the shielding of the positron emitting nuclides, it is expected that the contribution from bremsstrahlung would be minimal. However it is instructive to see how much this contribution is, especially that most of the work in the literature dealt with electrons only. Calculations of the bremsstrahlung production were first done for beams of 1, 2, and 3 MeV normally incident on aluminium slabs of different thicknesses, to obtain the

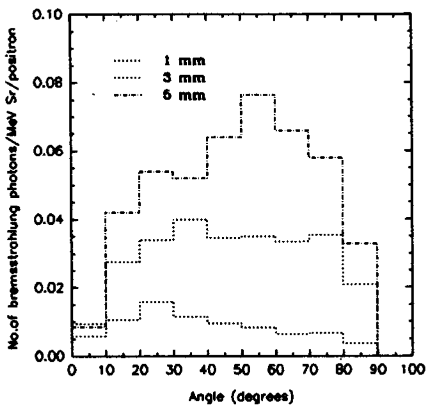

Fig. 4 Transmitted angular distribution of bremsstrahlung photons produced by 2 MeV positrons in aluminium foils.

average energy and number of photons produced per incident positron. For bremsstrahlung production in aluminium from a 1 MeV positron beam, there is a preference for transmission in the forward direction between 20° and 30° for a slab of 0.01 cm thickness. Increasing the thickness by a factor of 10, the magnitude of the spectrum increases by more than a factor of 2, and maximum direction is in 50°- 60°. Further increase of the thickness of the slab by a factor of 2, increases the bremsstrahlung production by about a factor of 2, and the maximum direction is shifted to 60°- 70°, but in a broader direction. In the case of the 3 MeV positron beam, the bremsstrahlung photons are transmitted in the forward direction with maximum between 10° and 20° when the thickness is 0.05 and 0.10 cm. The increase in the maximum is about a factor of 2 between 0.05 and 0.10 cm. With the increase in thickness the scattering increases and the photons leave the slab with higher probability of larger angles as can be seen in Fig. 4.

TOTAL PHOTON SPECTRA
As an example, transmitted spectrum of photons from a positron emitting nuclide is given below in Fig. 5 for Na-22, incident on aluminium slab whose thickness was equal to the range of the respective nuclide. It is clear from the spectra that the bremsstrahlung is low energy photons. These bremsstrahlung photons are comparable to the 0.511 MeV annihilation photons in number.

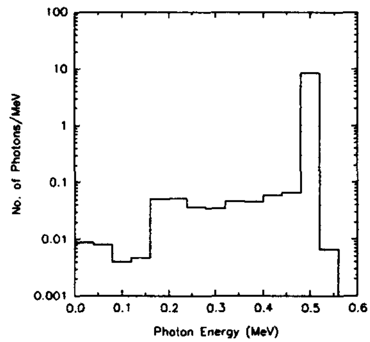

Fig. 5 Transmitted photon spectrum of Na-22 through aluminium foil whose thickness is equal to the range of the endpoint energy of Na-22.

DOSE RATE CONSTANT
The results of the calculation are compiled in the following table.

NUCLIDE	Air kerma rate constant (mGy m²/GBq hr)			
	Decay	Annih.	Brems.	TOTAL
C-11	0	2.309E-1	3.587E-4	2.313E-1
O-15	0	4.038E-2	2.200E-4	4.060E-2
F-18	0	1.308E-1	8.412E-5	1.309E-1
Na-22	1.220E-1	9.950E-2	2.318E-4	2.217E-1
Al-26	4.124E-1	2.401E-1	1.865E-3	6.544E-1
Sc-44	3.817E-1	3.628E-1	3.902E-3	7.484E-1
Cr-49	1.113E-2	1.281E-1	1.725E-3	1.410E-1
Fe-52	2.387E-1	1.039E-1	4.535E-4	1.282E-1
Mn-52	1.567E00	3.500E-2	8.887E-5	1.602E00
Ni-57	2.424E-1	7.883E-2	3.772E-4	3.216E-1
Cu-61	4.745E-2	1.888E-1	1.584E-3	2.378E-1
Cu-62	3.376E-3	7.765E-1	1.751E-2	7.974E-1
Cu-64	7.898E-4	2.515E-2	7.865E-5	2.602E-2
Zn-65	2.707E-2	7.576E-4	7.649E-7	2.783E-2
Ga-68	5.922E-3	1.574E-1	2.636E-3	1.660E-1
Zr-89	1.778E-1	4.939E-2	2.582E-4	2.274E-1

References see: K.A.Nahdi(1993) Thesis Dr. techn Technical University of Vienna 1993