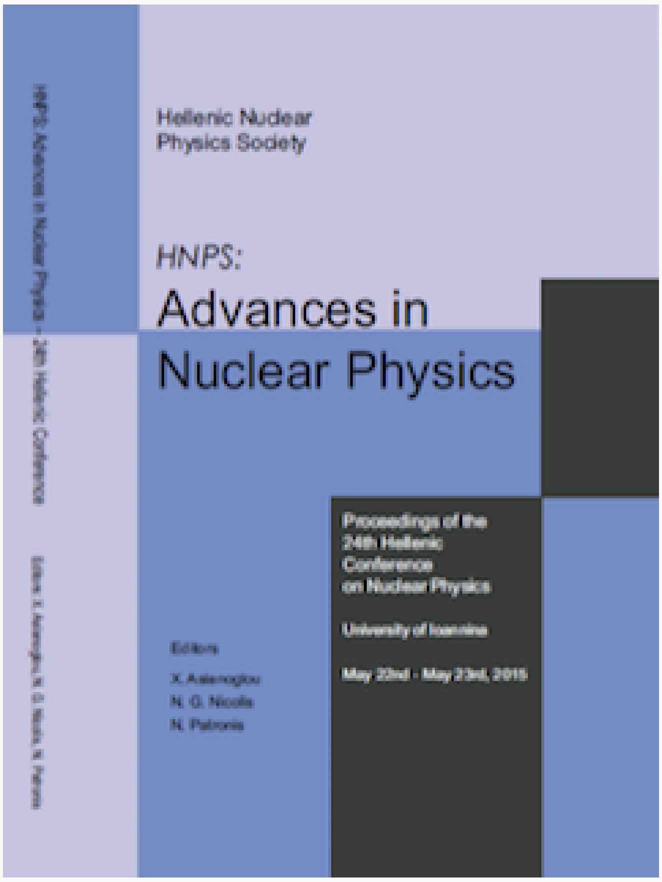
HNPS Advances in Nuclear Physics

Vol 23 (2015)

HNPS2015



Bremsstrahlung Spectra Characterization by Photo-Activation: Preliminary Results

E. Ntalla, T. Vasilopoulou, P. Georgolopoulou, I. E. Stamatelatos

doi: 10.12681/hnps.1890

Bremsstrahlung Spectra Characterization by Photo-Activation: Preliminary Results

E. Ntalla[1,2], T. Vasilopoulou[1] , P. Georgolopoulou[2] and I.E. Stamatelatos[1]

[1] *Institute of Nuclear & Radiological Sciences, Technology, Energy & Safety, NCSR "Demokritos"*
[2] *Department of Medical Physics, General Anticancer-Oncologic Hospital of Athens "Saint Savvas"*

Abstract A method for the determination of the bremsstrahlung spectra of medical linear accelerators by photo-activation measurements is discussed. A set of activation foils with different photonuclear reaction energy thresholds was irradiated at two linear accelerators of 15 and 23 MV. The activity induced was determined using a germanium detector based gamma spectrometry system. The spectrum was reconstructed using theoretical expressions for photons emitted by electron interactions in thick targets and cross-sections from the IAEA Photonuclear Data Library. The results of this study enable experimental validation of the functional forms of bremsstrahlung spectra commonly used in radiotherapy treatment planning in the clinical environment.

Keywords Photon Activation Analysis, Bremsstrahlung Spectra, Linear Accelerator

INTRODUCTION

Characterization of the photon spectra of medical linear accelerators is of great interest in radiation therapy for accurate radiation dosimetry and treatment planning. In this work, a method for the determination of the high energy part of the bremsstrahlung spectrum of medical linear accelerators is discussed combining theoretical expressions for photons emitted by electron interactions on thick targets and photo-activation measurements.

EXPERIMENTAL

A set of 11 high purity foils comprising of Ag, Au, Co, Cu, F, Mo, Nb, Ni, Ta, Ti and Zr was irradiated. The foils were positioned in a special holder (Fig. 1). The foils were selected on the basis of their different photo-activation reaction energy thresholds (Table 1). The selection criteria were: (a) the half time of the product nucleus, (b) the natural abundance of the target isotopes, (c) the energy and yield of the emitted gamma rays, (d) the competition between (γ,n) and (n,γ) reactions for the production of the same daughter nucleus and (e) the high cross-sections of the isotopes.

Irradiations were performed at the 15 MV (ELEKTA SL18) and 23 MV (Siemens Primus) linear accelerators of Saint Savvas Hospital, Athens. The irradiation cassette was positioned at 85 cm distance from the source. The beam size at the cassette level was 20 × 20 cm^2. The total irradiation was of 6000 MU. The gamma-spectrometer consisted of a coaxial high purity Ge detector (EG&G ORTEC, GEM-80) of 85% relative efficiency coupled to a digital signal processing and a data acquisition system. The detector full energy peak efficiency was determined using a set of standard sources.

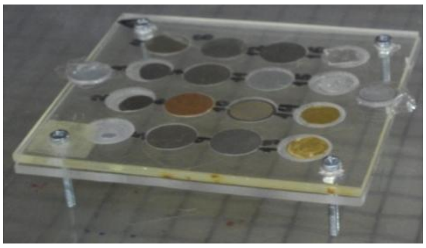


Fig. 1 Irradiation cassette

Fig. 2 Medical Linac ELEKTA SL

Table 1 Characteristics of the irradiated foils

Foil	Target Isotope	Threshold Energy (MeV)	Product nucleus	Half Time	Photon Energy (keV)	Yield (%)
F	^{19}F	10.43	^{18}F	1.83h	511	194
Ti	^{46}Ti	13.19	^{45}Ti	3.08h	511	170
					127.2	12.9
Ni	^{58}Ni	12.22	^{57}Ni	36.1h	511	80.8
					1377.6	77.9
Co	^{59}Co	10.45	^{58}Co	70.92h	810.8	99.4
Cu	^{65}Cu	9.91	^{64}Cu	12.7h	511	35.8
Zr	^{90}Zr	11.97	^{89}Zr	3.27d	511	45.5
					909.2	99
Nb	^{93}Nb	8.83	^{92m}Nb	10.15d	934.5	99.1
Mo	^{100}Mo	8.29	^{99}Mo	2.75d	140.5	90.7
Ag	^{107}Ag	9.54	^{106m}Ag	8.46d	511.8	88.2
Ta	^{181}Ta	7.58	^{180}Ta	8.15h	93.3	4.28
Au	^{197}Au	8.07	^{196}Au	6.18h	333	22.9
					355.7	86.9

SPECTRUM RECONSTRUCTION

The Bremsstrahlung spectrum is produced by electron interactions within a thick target and is attenuated by a field flattering filter and tailored by collimators [1]. There is no analytic expression fully describing the photon energy spectra of thick targets. However, it has been shown that a good agreement exists between measured and Monte Carlo simulated photon energy spectra produced by thick targets emitted in the forward direction with theoretical expressions proposed for thin targets after correction for attenuation by the total thickness of the target [2]. Kmar et al [3] calculated the differential photon fluence at energy E for thick targets by expression (1),

$$\Phi(E) = \frac{P}{E}\left\{\left[1+\left(\frac{Ee}{Eo}\right)^2 - \frac{2}{3}\frac{Ee}{Eo}\right][lnM(0) + 1 - \frac{2}{b}\tan^{-1}b] + \frac{Ee}{Eo}\left[\frac{2}{b^2}\ln(1+b^2) + \frac{4(2-b^2)}{3b^3}\tan^{-1}b - \frac{8}{3b^2} + \frac{2}{9}\right]\right\} e^{-A/E^n} e^{-CE} \quad (1)$$

where, $\alpha = \frac{2Z^2ro^2}{137}$, $b = \frac{2EoEeZ^{1/3}}{111E}$, $\frac{1}{M(0)} = (\frac{E}{2EeEo})^2 + (\frac{Z}{111}^{1/3})^2$, Z is the atomic number of the target material, r_o is the classical electron radius and $E_e=E_o-E$ the initial energy of the electron. Parameter C describes the absorption in the field flattening filter and in the target. Parameter P contains all energy independent values and can be calculated for each isotope from equation (2). Parameters A and n define the low-energy part of the bremsstrahlung spectrum.

$$P = R\int_{E_T}^{E_{\max}} \sigma(E)\Phi_t\, dE \qquad (2)$$

where, $\sigma(E)$ is the cross section for the (γ,n) reaction for each isotope, E_T is the energy threshold of each isotope $\Phi_t = \frac{1}{\alpha}\frac{d\sigma}{dE}$ and R is the reaction rate given by equation (3),

$$R = \frac{N_\gamma \lambda}{N_i\, \varepsilon\, p_\gamma\, e^{-\lambda \Delta t}(1-e^{-\lambda t_{irr}})(1-e^{-\lambda t_{col}})} \qquad (3)$$

where, N_γ is the number of γ-rays detected, N_i is the number of nuclei, p_γ is the number of γ-rays per decay, ε is the full energy peak efficiency for the specific γ-ray, t_{irr} is the irradiation time, t_{coll} is the collection time and Δt is the time between the end of the irradiation and the start of the measurement.

RESULTS AND DISCUSSION

Table 2 shows the results of the calculation of parameters R and P for the 15MV and 23MV linear accelerators, taking into consideration the cross-sections from the IAEA Photonuclear Data Library [4]. In the case of the 15MV accelerator, the foils Ti and Ag were not used.

The weighted mean value for the parameter P is 6.67E+07 for the 15MV linear accelerator and 7.34E+06 for the 23MV linear accelerator. Parameters A and n were taken from the bibliography to be 1.187 and 1.97, respectively [2]. Nevertheless, in future work parameters A and n will be determined experimentally through beam attenuation measurements for each accelerator. The analytical shape of the photon fluence (derived from equation 1) is shown in Fig. 3.

In this work, the high-energy part (above the photo-activation threshold energies) of the Bremsstrahlung spectra of the two medical linear accelerators was determined using photo-activation measurements. The results of this study enable experimental validation of the higher energy part of functional forms of bremsstrahlung spectra commonly used in radiotherapy treatment planning in the clinical environment

Table 2 Results for 15 and 23 MV accelerators

			15MV		23MV	
Foil	Parent Nuclide	Product Nuclide	R (sec^{-1})	P	R (sec^{-1})	P
F	^{19}F	^{18}F	3.686E-20	3.13E+07	1.920E-19	2.05E+07
Ti	^{46}Ti	^{45}Ti			5.347E-19	1.60E+07
Ni	^{58}Ni	^{57}Ni	8.660E-21	8.50E+06	3.342E-19	1.07E+07
Co	^{59}Co	^{58}Co	5.459E-21	6.21E+05	5.964E-20	5.27E+05
Cu	^{65}Cu	^{64}Cu	4.658E-19	2.71E+07	2.915E-18	2.04E+07
Zr	^{90}Zr	^{89}Zr	2.634E-20	2.28E+06	2.201E-18	8.73E+06
Nb	^{93}Nb	^{92m}Nb	3.698E-19	1.46E+06	2.185E-18	1.43E+06
Mo	^{100}Mo	^{99}Mo	7.734E-19	9.62E+06	3.153E-18	6.45E+06
Ag	^{107}Ag	^{106m}Ag			1.529E-19	4.06E+05
Ta	^{181}Ta	^{180}Ta	1.273E-18	5.02E+06	3.675E-18	3.26E+06
Au	^{197}Au	^{196}Au	1.369E-18	4.40E+05	5.682E-18	5.03E+06

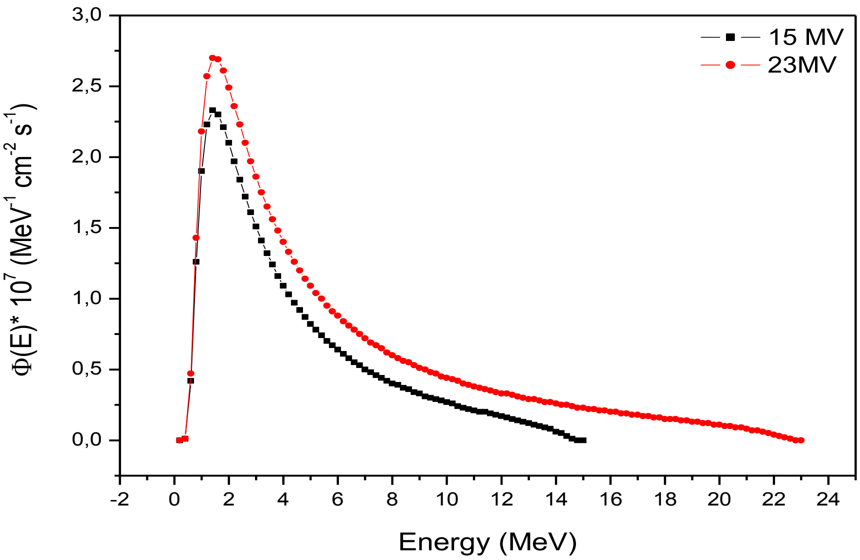


Fig. 3 Photon Energy Spectrum of 15 MV and 23 MV accelerators

ACKNOWLEDGMENTS
Work supported in part by the 1st Health District, ΕΛΚΕΑ, Ministry of Health, Greece

References

[1] H. W. Koch and J. W. Motz, Reviews of Modern Physics 31 (1959) 920-925
[2] A. Faddegon et al, Med. Phys. 18 (1991) 727-739
[3] M. Krmar et al., Phys. Med. Biol. 38 (1993) 533-544
[4] IAEA, Handbook of photonuclear data for applications: Cross Sections and Spectra, IAEA TECDOC-1178, Vienna, 2000.