# Characterization Of Bremsstrahlung Radiation For 10 ,30 And 60 Mev Electron Beam From Thick Tungsten

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**Abstract:** Monte Carlo calculations have been made of electron-photon cascades in thick tungsten targets bombarded by electrons with energies 10, 30 and 60 MeV. The information's about the bremsstrahlung efficiency, the angular distribution of the emitted bremsstrahlung intensity, and the spectrum of bremsstrahlung radiation in different directions has been obtained. By thick targets we mean targets whose thickness is at least an appreciable fraction of the mean range of the incident electrons.The most complete work in which the characteristics of braking radiation were studied is the work of Berger and Seltzer [1]. This paper describes calculations of bremsstrahlung production in thick tungsten target irradiated by monoenergetic electrons with kinetic energy from 10, 30 and 60 MeV.

**Index Terms**: electronic accelerators, bremsstrahlung, shielding, Tungsten, optimum thickness, Bremsstrahlung Efficiency, Monte Carlo..

## 1 INTRODUCTION

Whenever a charged particle propagates in a medium, it interacts with the atomic field of the medium. The charged particle travelling in the field of the atomic nucleus gets accelerated. The accelerated charged particles emit electromagnetic radiation. This radiation is called bremsstrahlung radiation. Bremsstrahlung is an important phenomenon which is the result of coupling of the electromagnetic field and matter. Study of bremsstrahlung is important in almost all branches of physics such as nuclear, solid-state and elementary particle physics. Bremsstrahlung is an important tool in the experimental research. It has a wide range of technical applications[1]. Radiation therapy is a clinical modality dealing with the use of high doses of ionizing radiations in the treatment of patients mostly having malignant tumors. The aim of radiation therapy is to deliver a sufficiently high absorbed dose to a defined target volume resulting in the eradication of the tumor with as minimal a damage as possible to the surrounding healthy tissues. Radiotherapy with external high energy photon beams are the most common radiotherapy modality[2]. Electron beams are used either as the primary mode of radiation therapy or combined with photon beams. High energy electron and photon beams are typically produced by linear accelerators [3].

A number of investigations on photon energy spectra have been reported in literature. But, to the best of our knowledge as for angular distributions from thick targets, there are very few researcher have published their work. Our calculations provided important information about the characteristics of bremsstrahlung radiation in thick tungsten targets, such as the spectra of bremsstrahlung radiation emitted in different directions, angular distributions of bremsstrahlung intensity , and the dependence of the efficiency of the bremsstrahlung radiation on the thickness of the target at a distance of 1 m from the tungsten target of optimum thickness. Our Calculations of the characteristics of the fields of electrons and bremsstrahlung were performed by the Monte Carlo method using the fluka program [4]. We used an estimation based on intersections of surfaces in the form of disks with radius r located at a distance of 50 cm from the center of the target at different angles relative to the direction of the incident electron beam and a local estimation of the flow at points located at different angles at a distance of 100 cm from the center of the target. The process of bremsstrahlung has been studied theoretically and experimentally for several decades. The theoretical status of the field in 1959 was reviewed by Koch and Motz [5], who presented a compilation of theoretical formulae of various cross-sections, differentials in photon energy and photon scattering angle in thin targets and for a wide range of incident electron energies. The regimes of validity, in terms of incident energy, outgoing photon energy, angle and radiator atomic number, etc. are discussed and evaluated for thin targets. At a depth in a thick bremsstrahlung target, the intrinsic angular photon distribution for a thin target must be folded with the angular distribution of the electron produced by multiple scattering [6]. For semi-thin targets, Schiff [7] derived a formula for the angular photon distribution. A review, including extensive tabulations of bremsstrahlung photon spectra, has been published by Seltzer and Berger [8], [9]. A more recent review on various theoretical cross-sections that have been used in Monte Carlo codes are described by Salvata [10]. Despite the relatively advanced state of the theory, few accurate, absolute measurements have been made of the spectrum of bremsstrahlung photons produced by high-energy electrons. A number of measurements have been performed for electrons of energies below 30 MeV: Faddegon et al. [11], [12] and the references therein. The thickness of the radiators generally used in these experiments complicates their comparison with theory, as multiple scattering and secondary processes become important. Monte Carlo calculations, with the theoretical bremsstrahlung cross-sections as input, must be employed to account for the effects of radiator thickness and collimation on the photon spectrum and angular distribution. There has been much published on bremsstrahlung spectra over the past few decades. A wide range of techniques have been proposed to determine the bremsstrahlung: by early analytical modeling [7] and by elaborate Monte Carlo simulations [13]. Additional analytical models exist in the literature which usually fit phase spaces


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obtained from Monte Carlo simulations [14]. Unfolding of empirical radiation data measured by spectrometry [11], [15] has also been attempted. Reconstruction from measured or calculated dosimetric data, usually transmission measurements or depthdose curves [16] –[18] is yet another popular means. While each method offers different advantages and disadvantages, it is valuable to have an independent means to confirm the results of any given approach. Work on elementary bremsstrahlung cross sections [5], [8] has been complemented by work on the practical computation of bremsstrahlung from radiators [19],[20] in which different aspects of the bremsstrahlung spectrum are treated in different ways according to the intended application. A number of investigations on photon energy spectra have been reported in literature. But, to the best of our knowledge as for angular distributions from thick targets, there are very few researcher have published their work. The most complete work in which the characteristics of bremsstrahlung radiation were studied is the work of Berger and Seltzer [21]. In Berger's paper, the results of calculations of the characteristics of brake radiation were presented by the Monte Carlo method [ETRAN] . As a result of our calculations, important information has been obtained regarding the characteristics of bremsstrahlung radiation in thick tungsten targets.

## 2 GEOMETRY AND METHODOLOGY

The geometries of the studied compositions, differing only in size for different materials, were identical and are shown figure 1. The electron beam in the form of a disk unidirectional monoenergetic electron source with an energy of T0 and a diameter of $d_0$ = 1.0 mm perpendicularly falls on the diametrical surface of a sphere-shaped tungsten target. Based on the data of [22], the radius of the target was taken equal to the optimum thickness of the target given for different electron energies of the source in Table 1.

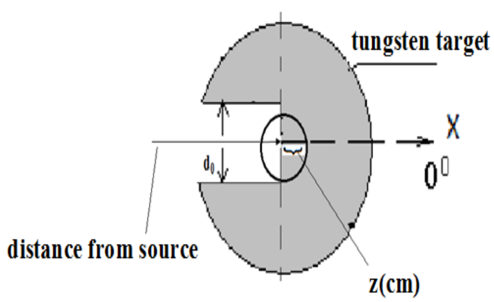


***Fig. 1*** *The geometry of the considered composition*

***TABLE 1***

*OPTIMUM TUNGSTEN TARGET RADII FOR DIFFERENT SOURCE ELECTRON ENERGIES*

| Energy $T_0$, MeV | 10 | 30 | 60 |
|---|---|---|---|
| R,cm | 0.14 | 0.33 | 0.62 |

The target thickness was assumed to be optimum, at which the maximum output of bremsstrahlung radiation was observed [22], [ 23].

## 3 BREMSSTRAHLUNG EFFICIENCY AND ELECTRON TRANSMISSION

One of the most important characteristics is the value of the total energy and numerical output of bremsstrahlung photons from targets of different thickness. The characteristic of the first value is the efficiency of the output of the bremsstrahlung radiation [ 24]

$$Y(T_0, z) = \frac{\Delta E_{brem}}{T_0} \quad (1)$$

Berger [21] determines the radiation efficiency $Y(T_0, z)$ to be the fraction of the kinetic energy $T_0$, of the incident electrons that emerges in the form of bremsstrahlung from a target of thickness z. More specifically, the direction of the incident beam is assumed to be perpendicular to the plane-parallel target, and we mean emergence from the transmission or forward face of the target. The efficiency, thus defined, takes into account the reduction of bremsstrahlung production due to the leakage of electrons from the target and the attenuation of the bremsstrahlung. within the target.

To calculate the optimum thickness of electron in target, firstly we must calculate the mean range electron in target . The mean range of electron a theoretical quantity evaluated from the expression

$$r_0(T_0) = \int_0^{T_0} \frac{dT}{L(T)} \quad (2)$$

Where L (T) is the mean rate of energy lose due to a collisions and bremsstrahlung. It determines the mean range of electron with energy $T_0$ [21]. The $r_0$ value is calculated according to the average energy loss per unit path, the $r_o$ values for tungsten are shown in Table II. [25].

***TABLE 2***

*ELECTRON MEAN RANGE IN TUNGSTEN* .[25]

| Electron energy, MeV | Mean range $r_0$,( g/ $cm^2$) |
|---|---|
| 60 | 16.5 |
| 50 | 15.3 |
| 40 | 13..8 |
| 30 | 12.0 |
| 20 | 9.66 |
| 15 | 8.14 |
| 10 | 6.23 |
| 5 | 3.69 |

the results obtained in this paper; Tsechanski [26] and Berger [21] for the efficiency of bremsstrahlung radiation for monoenergetic electron beams with electron energy 10 , 30 and 60 MeV, they are shown in Fig.2 and they have similar characteristics. All results first show an increase in the intensity of the bremsstrahlung radiation due to an increase in the amount of energy lost by the electron in the target. For a target thickness exceeding the optimum one, there is a decrease in efficiency as a result of the fact that more and more of the braking radiation begins to be absorbed in the target. Tsechanski et al. [26] calculated the efficiency of bremsstrahlung radiation for monoenergetic electron beams (2-60) MeV falling perpendicular to the tungsten target.

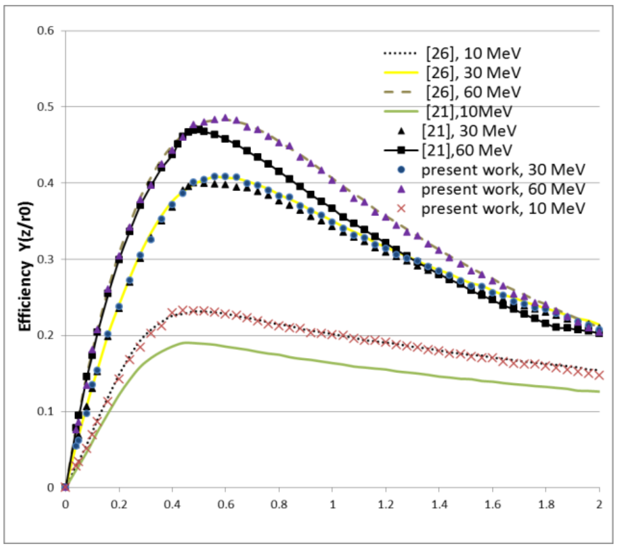


***Fig. 2.*** *Bremsstrahlung efficiency for monoenergetic electron beams of 10, 30, and 60 MeV incident perpendicularly on tungsten targets. in this paper, and in publications [21] and [26].*

They used the EGSnrc Monte Carlo simulation code. In fig.2 and table.III it is shown that the efficiency of tungsten for generating bremsstrahlung radiation for electron beam energies from 10 to 60 MeV reaches its maximum at target thicknesses between 0.51 r0 and 0.59 r0. These results [26] differ somewhat from the results of [21], and approximately coincide with the result of this work (in this work, the maximum efficiency is achieved for thicknesses from 0.50 $r_0$ to 0.58 $r_0$), whereas in Berger's publication [21], the maximum is achieved with a target thickness from 0.4 $r_0$ to 0.5 r0. In this work (table III), the optimal thickness is 15%, 8% and 20% higher than the optimal thickness in the publication [22] (table I) for the incident electron energies of 10, 30 and 60 MeV, respectively.

***TABLE 3.***
*COMPARISON EFFICIENCY RESULTS FOR TUNGSTEN TARGET IN DIFFERENT LITERATURES*

| | T0 [MeV] | $(z/r0)_{max}$ | $r_0$ CM | $Y_{max}$ | z (optimum thickness)cm |
|---|---|---|---|---|---|
| Tsechanski [26] | 10 | 0.511 | 0.321 | 0.231 | 0.164 |
| | 30 | 0.586 | 0.617 | 0.408 | 0.362 |
| | 60 | 0.585 | 0.841 | 0.483 | 0.492 |
| Berger [21] | 10 | 0.42 | 0.323 | 0.19 | 0.136 |
| | 30 | 0.48 | 0.622 | 0.4 | 0.299 |
| | 60 | 0.50 | 0.855 | 0.47 | 0.428 |
| Present work | 10 | 0.503 | 0.321 | 0.232 | 0.161 |
| | 30 | 0.578 | 0.617 | 0.408 | 0.357 |
| | 60 | 0.582 | 0.841 | 0.485 | 0.498 |

J. Galy et al. calculated the efficiency bremsstrahlung for tantalum using MCNPX in the energy range from 1 to 150 MeV, as shown in figure 3.the Results of Galy et al [27] using MCNPX do,in fact, confirm that the optimal thickness corresponds to about half the value of the average path of the incident electron, as shown in table 3.

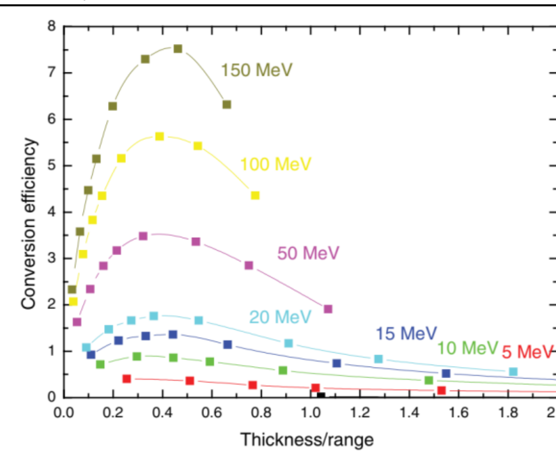


***Figure 3.*** *Bremsstrahlung efficiency for a mono-energetic electron beam perpendicular to the Ta target versus the ratio of the thickness over the range[27].*

The angular distribution of the intensity. I(θ). gives the amount of bremsstrahlung energy that emerges from the target per unit solid angle in direction θ (with respect to the direction of the incident electron beam). Fig.4 shows a comparison between our results and results in publication [26] for Angular distribution of bremsstrahlung intensity from tungsten. In the present work the Angular distributions are characterized by a distinct peak in the forward direction and a much less pronounced peak in the backward direction. in the forward direction at $T_0$ = 10 MeV. we have a peak at an angle of 20$^o$. at $T_0$ = 30 MeV. a peak at an angle of 10o. and 6$^o$ at $T_0$=60 MeV. we also have a very pronounced drop for an angle of about 90o. These results for the Tsechanski [26] are approximately the same as the results of this work (FLUKA). where the Difference between the maximum values of the corresponding curves I(θ) in the publication [9] and in this work of the curves is approximately 6% for the energies of 30 and 60 MeV and 5% for 10 MeV. also dependencies have similar behaviour. To get the results. Figure 4 uses a thickness equal to 1.36 $r_0$ at an all energies.

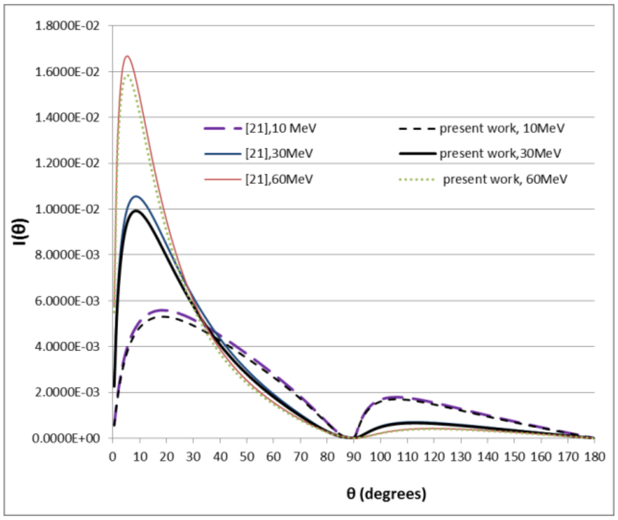


***Fig. 4**. Angular distribution of bremsstrahlung intensity from tungsten*

Fig. 5 shows the calculations of Seltzer and Berger [8] for the energy spectra of the bremsstrahlung of electrons with kinetic energy of 10. 30 and 60 MeV according to the formula described below. figure 7 uses the $K/T_0$ range from 0 to 1. the values of the energy spectra of the bremsstrahlung radiation at an electron energy of 10 MeV are greater than the values of the energy spectra of the brake radiation at an electron energy of 30 and 60 MeV. and this behavior differs from the behavior in Fig.6 for the same range of $k/T_0$. In figure 5. all the curves show a sharper decline than the curves in figure 6. especially in the $k/T_0$ above 0.8. Thick targets are targets whose thickness z is comparable to or greater than the electron mean range $r_0$

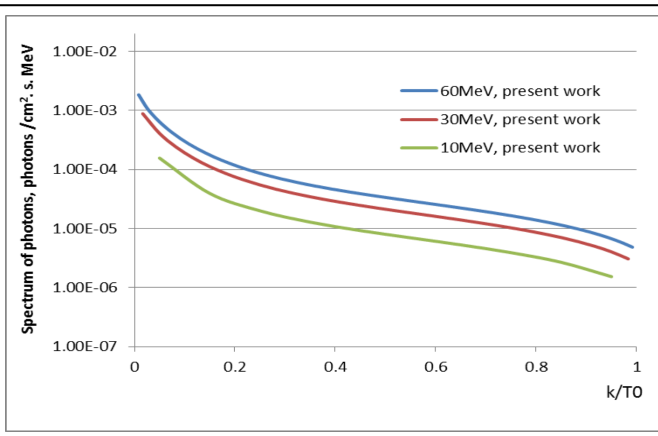


*Fig.5. Energy distributions of the bremsstrahlung photon flux at a distance of 1 m from the tungsten target in the direction of the primary electron beam at different primary electron energies, 10, 30 and 60 MeV, obtained by the Monte Carlo method (fluka)*

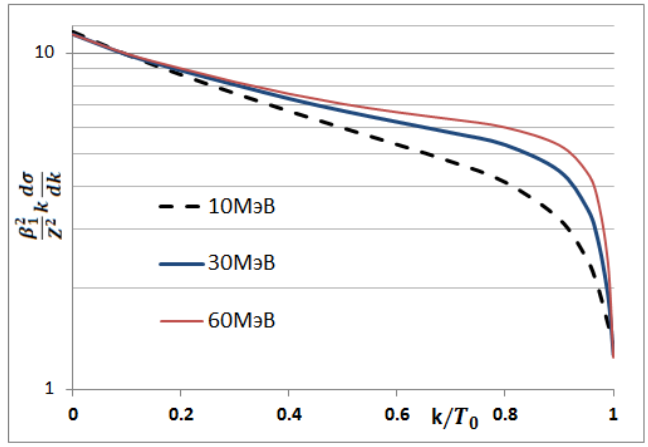


*Fig. 6. Scaled bremsstrahlung spectra for a tungsten target at energy incident electrons of 10.30 and 60 MeV [10]*

Seltzer and Berger [8] calculated the energy spectra of the braking radiation of electrons with kinetic energy from 1 Kev to 10 GeV falling on the shielded nuclei of atoms with z =1-100. Seltzer and Berger expanded the tables of Pratt et al.[28] in two ways (a) They extend to electron energies up to 10 GeV; b) Tables include not only cross-sections for the bremsstrahlung radiation obtained in the region of shielded atomic nuclei. but also for the bremsstrahlung radiation obtained in the region of atomic electrons.These extensions require the use and combination of various formulas from various theories of brake radiation. The cross section was estimated using a combination of results from high energy theory. For T≥ 50 MeV Cross section using a combination of results from high energy theory

$$\frac{d\sigma_n}{dk} = \frac{4\alpha r_e^2 Z^2}{k}\{\chi_{Born}^{unscr} + \delta_{screen} + \delta_{coul}\} \qquad (3)$$

Where $\chi_{Born}^{unscr}$ -is the Bethe-Hitler. Born-approximation result for an unscreened nucleus with no energy approximations (formula 3BN in [11]). $\delta_{screen}$- is a screening correction.. $\delta_{coul}$ - is a Coulomb correction. $\alpha$ - fine-structure constant. and $r_e$ - classical electron radius. For energy 2 MeV< $T_1$<50 MeV using the least-squares cubic-spline algorithm of Powell [12]. Fig. 7 and 8 show the energy distribution of the flow of bremsstrahlung photons at angles of 60 and 180 degrees at 10, 30 and 60 MeV for the present work and in fig.9 at 0 $^{0}$,15 $^{O}$,30 $^{O}$,60 $^{O}$,90 $^{O}$,180$^{O}$ for Sakharov's results [4].

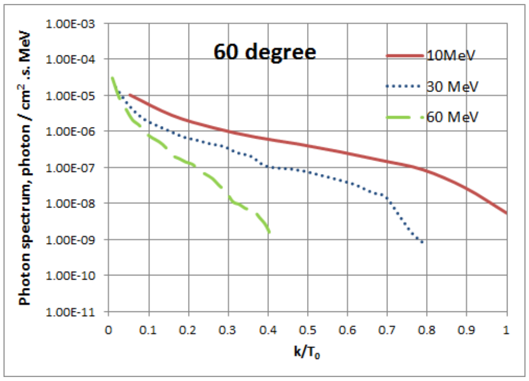


*Fig. 7*. *Energy distributions of the photon flux density of bremsstrahlung radiation at a distance of 1 m from the tungsten target at points located at 60 degree relative to the direction of the incident electron beam*

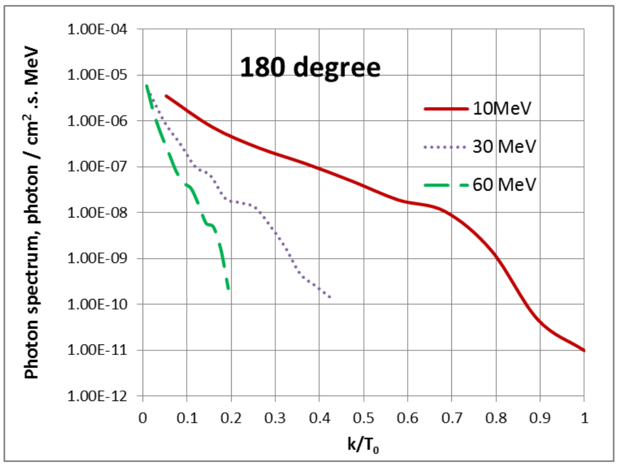


*Fig. 8*. *Energy distributions of the photon flux density of bremsstrahlung radiation at a distance of 1 m from the tungsten target at points located at 60 degree relative to the direction of the incident electron beam*

the same behavior is observed for the energy distributionof the flow of braking photons in the two figures 7 and 8. the Difference is only present in the values of the spectrum, where the results in the publication [4] are 3 orders of magnitude higher than the results presented in this paper. In the range (k/T0) less than 0.05, the spectrum values at 60 MeV are the largest, the spectrum values in the same range at 30 MeV are greater than the spectrum values at 10 MeV, in the range (k / T0) greater than 0.05, the opposite is true. The observed decrease in the values on the curves at electron energies of 60 MeV is more abrupt than the decrease in values at 10 MeV and 30 MeV. the smallest values of the spectrum are always observed for the largest angles 180 degrees, as shown in figures 7,8 and 9.

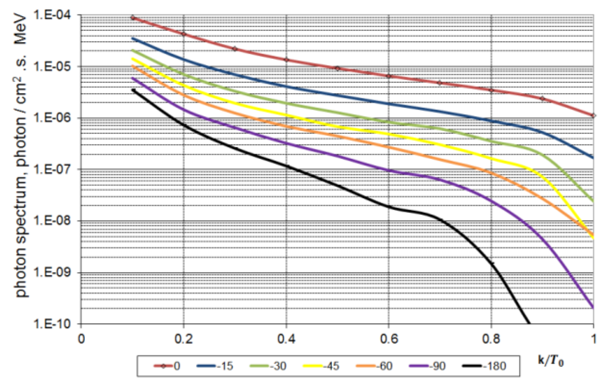


*Fig. 9*. *Energy distributions of the photon flux density of bremsstrahlung radiation at a distance of 1 m from the tungsten target at points located at different angles relative to the direction of the incident electron beam θ, deg: 0 ; 15 ; 30 ; 45; 60; 90 ; 180 when irradiated with electrons with an energy of 10 MeV*

from the obtained efficiency results (Fig. 2 and table 3). the dependence of this value on the thickness of the target was derived. From the obtained results for bremsstrahlung efficiency (Fig. 2 and table 3) we note the dependence of it values on the thickness of the target .The presence of a maximum values is caused by competing processes of formation of bremsstrahlung photons and their absorption in the target. Targets with a thickness that provides the maximum output of bremsstrahlung radiation are called optimum thickness. from the above results. we concluded that the conversion efficiency between electrons and bremsstrahlung photons depends on the electron energy. The Converter material. and the thickness of the Converter. For any given Converter material. there is an optimum thickness at which the efficiency of the bremsstrahlung radiation reaches the maximum value. This optimal thickness of the converter corresponds to approximately half the value of the mean range of incident electrons in a particular material. However. since the optimum thickness in this case is less than the electron path. most of the electron beam will pass through the Converter. which can lead to damage to the irradiated sample. For this reason. the thickness is usually chosen slightly higher than the maximum electron path at the highest energy used for activation. In addition. due to the strong Z-dependence of the conversion efficiency. the optimal target must consist of a material with a high z. In all calculations described in this paper. tungsten was used as a bremsstrahlung radiation Converter

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