# Polarization Bremsstrahlung in Thick Targets Produced by Continuous Beta Particles

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## ABSTRACT
Bremsstrahlung spectral photon distributions produced by continuous beta particles of beta emitter $^{147}$Pm and $^{45}$Ca in thick targets studied in a photon energy region 10-30 keV. The bremsstrahlung spectral photon distribution measured with X-PIPS Si (Li) detector. The experimental results were compared with the theoretical bremsstrahlung distribution obtained from ordinary bremsstrahlung (OB) theories and the theoretical model which describes total bremsstrahlung which includes the polarization Bremsstrahlung (PB) into OB given by Avdonia and Pratt (1999). The contribution of PB into OB has been calculated in the studied region and it has been found that it is decreases with increase of photon energy. Hence the contribution of polarization bremsstrahlung into total bremsstrahlung plays a vital role into the formation of a spectral shape of total bremsstrahlung spectra.

## Keywords
Total bremsstrahlung, Ordinary bremsstrahlung, Polarization bremsstrahlung

## 1. INTRODUCTION
The total bremsstrahlung (BS) is the sum of ordinary bremsstrahlung (OB) and polarization bremsstrahlung (PB). OB is the phenomenon by which the photon is generated by the electron decelerating in the static field of the target atom. PB is the phenomenon by which the photon emission occurred due to the target as a result of its polarization by incident electron. In OB process, the dynamic response of the target atom under the action of the field created by the incident electron is not taken into account. The OB studies in thin and thick targets given by various authors [1-5]. Later, Buimistrov [6] suggest a new kind of phenomenon, called polarization bremsstrahlung (PB). The calculations of polarization bremsstrahlung amplitude have been given by several authors [7-10]. Born approximation and distorted partial wave approximation (DPWA) are used to calculate the polarization bremsstrahlung (PB). For non-relativistic electron energies, in the Born approximation Amusia [9] has described that PB can be added with OB in a stripped atom approximation (SAA). The stripped approximation is efficient for obtaining the BS spectra for photon energies greater than the ionization potential of the outer shell electrons of the target atom. In SAA, the decrease of OB due to screening of outer shell electrons is completely compensated by additional PB produced by the same outer shell electrons. Therefore, the total bremsstrahlung (BS) is described simply by an ion containing the outer shell electrons. As the emitted photon energy exceeds the ionization potential of the inner most shell (1s), the bremsstrahlung occurs on the bare nucleus. The difference between the OB from an ion and the bremsstrahlung on bare nucleus gives the contribution of PB in the BS spectra. Avdonina and pratt [11] modifies the Elwert corrected (non relativistic) Bethe and Heitler [1] theory for OB and described the BS spectra i.e. (OB+PB) over a wide range of photon energy region, by applying the SAA.

For continuous Beta particles Bethe and Heitler [1] gave an expression for the bremsstrahlung spectral distribution $n(k, W_e^{'}, Z)$ in a sufficiently thick target to absorb an electron of energy $W_e^{'}$ with N atoms per unit volume. At lower photon energies in thick targets, the correction due to absorption of BS photons in the target and electron backscattering from the target cannot be neglected. Semaan and Quarles [12] have reported that the correction for the self absorption of BS photons in the target and electron backscattering are required for $n(W_e^{'}, k, Z)$ in case of low energy thick target bremsstrahlung. The BS spectral distribution $[n_{cor}(W_e^{'}, k, Z)]$ after absorption correction and electron backscattering correction in thick target is given by

$$n_{cor}(W_e^{'}, k, Z) = RN \int_{1+k}^{W_e^{'}} \frac{d\sigma(W_e, k, Z)/dk}{(-dW_e \ / dx)} dW_e \times \exp(-\mu x) \quad (1)$$

Here $-dW_e / dx$ is the total energy loss per unit path length of an electron in a target material taken from the tabulations given by Berger and Selzer [13]. $\exp(-\mu x)$ is the absorption factor, $\mu$ is the mass attenuation coefficient for the given target element taken from the tabulations given by Chantler et al [14] and $'x'$ is the optimum thickness of the target which is equal to the range of the beta particle in a target. 'R' is the electron backscattering factor.

The BS spectral distribution in a thick target obtained on complete absorption of beta particles of a end point energy $W_{\max}$ is expressed as number of photons of energy k per unit $m_o c^2$ per beta disintegration for continuous beta particle is given by S(k,Z)

$$S(k, Z) = \int_{1+k}^{W_{\max}} n_{cor}(W_e^{'}, k, Z) P(W_e^{'}) dW_e^{'} \quad (2)$$

Here $P(W_e^{'})dW_e^{'}$ is the beta spectrum of the beta source under study taken from Macklin et al. [15].

$^{147}$Pm (Wmax = 225 keV) and $^{45}$Ca (Wmax = 257 keV) soft beta emitters were used for the present measurements of BS spectra. For $^{45}$Ca, Subrahmanyam et al. [16] investigated the OB spectra, in different thick targets produced by continuous beta particles. In the present measurement, the experimental BS spectral photon distributions from the thick targets of Al, Cu, Sn and Pb, produced by the beta particles of $^{147}$Pm and $^{45}$Ca, were compared with the theoretical bremsstrahlung spectral distribution obtained from EBH theory, $F_{mod}$ BH theory which describes OB and $F_{mod}$ BH+PB theory which describes the total bremsstrahlung (BS) in SAA, in the studied photon energy region of 10 to 30 keV.

## 2. EXPERIMENTAL DETAIL

The measurement of BS spectra in thick metallic targets of Al, Cu, Sn and Pb, produced by soft beta particles of $^{45}$Ca and $^{147}$Pm, were carried out by using an experimental set up given in Fig 1. The experimental details have already been given in elsewhere [17]. A Perspex beta stopper technique was employed to obtain the BS produced in target material. After calibrating the spectrometer, two sets of measurements were taken for a time interval of 300000 second by placing the targets at position A and B respectively, as shown in Fig 1. The difference of the above two measurements gave the BS produced in target elements only. The details of the method for measuring the BS spectral photon distributions are also given in [17]. The statistical accuracy of the data was better than 1% in different targets and beta emitters, in the photon energy region of 10-30 keV.

## 3. RESULTS AND DISCUSSIONS

The experimentally measured BS spectral photon distributions for the targets of Al, Cu, Sn and Pb, produced by $^{147}$Pm and $^{45}$Ca beta particles, were compared with the theoretical bremsstrahlung spectral photon distributions obtained from Elwert corrected (non relativistic) Bethe-Heitler theory (EBH), modified Elwert factor (relativistic) Bethe-Heitler theory ($F_{mod}$¬BH) which describes OB spectra, and modified Elwert factor (relativistic) Bethe-Heitler theory ($F_{mod}$¬BH + PB), which describes BS spectrum in the photon energy region of 10-30 keV. The experimental results are in agreement with the theoretical bremsstrahlung spectral photon distributions obtained from $F_{mod}$¬BH + PB theory, which include PB into OB. The experimental results are showing deviation from EBH and $F_{mod}$¬BH theories, which describe OB spectra only. For $^{147}$Pm, these deviations are found to be varying from 37 to 10 % for Sn and Pb targets respectively from EBH and FmodBH theory, at photon energies of 10 to 30 keV. These deviations are varying between 24 to 10 % in the case of Al, and for Cu target the deviations are found to be varying between 29 to 13 % in the studied photon energy region of 10-30 keV. For $^{45}$Ca, these deviations are found to be varying from 29 to 12 % for Sn and Pb targets respectively from EBH and $F_{mod}$BH theory at photon energies 10-30 keV. However, these deviations are varying between 23 to 5 % in the case of Al and the deviations are found to be varying between 27 to 10% for Cu target throughout the studied photon energy region of 10-30 keV.

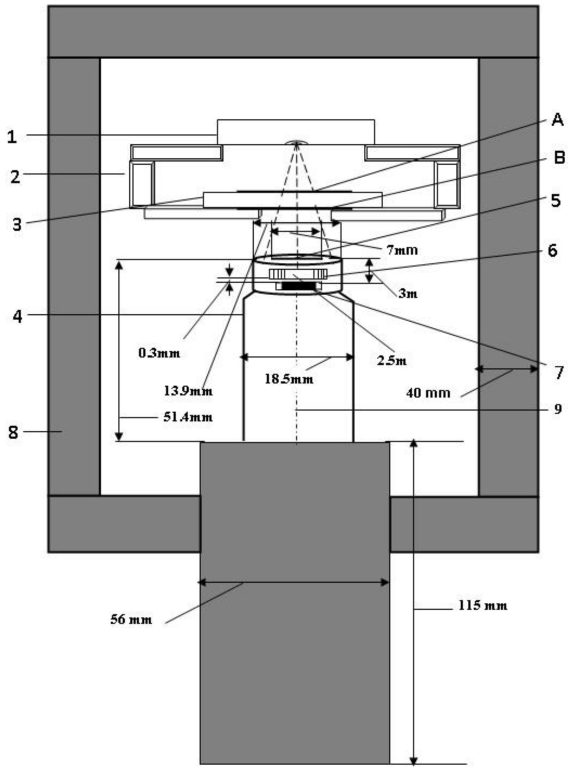


Fig 1

**Fig 1**

The contribution of PB into OB were calculated and given in Table 1 and Table 2. The result clearly indicates that contribution of PB into OB decreases with increase in photon energy. This study has wider scope to study the bremsstrahlung spectral distributions produced by the beta particles particularly at lower photon energy region where polarization bremsstrahlung plays an important role.

**Table 1. Percentage of contribution of PB into OB for $^{147}$Pm ($W_{max}$= 225 keV) at different photon energies**

| **Target-Aluminum** | | | |
|---|---|---|---|
| **Photon Energy (keV)** | **Number of photons of energy k per $m_oc^2$ per unit total photon yield** | | **Percentage contribution of PB into OB** |
| | **$F_{mod}$BH Theory** | **$F_{mod}$BH+PB Theory** | |
| 10.0 | 4.39E-01 | 5.13E-01 | 16.9 |
| 12.5 | 7.17E-03 | 8.25E-03 | 16.3 |
| 15.0 | 8.93E-04 | 9.92E-04 | 15.9 |
| 17.5 | 4.49E-04 | 4.93E-04 | 15.2 |
| 20.0 | 2.79E-04 | 3.02E-04 | 14.4 |
| 22.5 | 1.70E-04 | 1.83E-04 | 14.3 |
| 25.0 | 1.23E-04 | 1.32E-04 | 13.5 |
| 27.5 | 9.41E-05 | 1.00E-04 | 13.2 |
| 30.0 | 7.80E-05 | 8.25E-05 | 12.3 |
| **Target-:Copper** | | | |

| | | | |
|---|---|---|---|
| 10.0 | 5.37E-01 | 6.51E-01 | 20.3 |
| 12.5 | 1.49E-06 | 1.77E-06 | 19.5 |
| 15.0 | 8.91E-09 | 1.03E-08 | 18.5 |
| 17.5 | 3.49E-11 | 4.00E-11 | 18.3 |
| 20.0 | 3.79E-12 | 4.31E-12 | 18.1 |
| 22.5 | 8.98E-13 | 1.01E-12 | 16.6 |
| 25.0 | 4.36E-13 | 4.89E-13 | 16.6 |
| 27.5 | 1.85E-13 | 2.02E-13 | 15.3 |
| 30.0 | 1.20E-13 | 1.30E-13 | 14.3 |
| **Target-:Tin** | | | |
| 10.0 | 4.72E-01 | 5.96E-01 | 23.2 |
| 12.5 | 1.65E-07 | 2.00E-07 | 22.4 |
| 15.0 | 8.91E-11 | 1.05E-10 | 21.7 |
| 17.5 | 1.10E-12 | 1.28E-12 | 20.6 |
| 20.0 | 4.64E-14 | 5.36E-14 | 19.2 |
| 22.5 | 9.22E-15 | 1.04E-14 | 18.8 |
| 25.0 | 2.30E-15 | 2.58E-15 | 18.6 |
| 27.5 | 1.37E-15 | 1.52E-15 | 18.2 |
| 30.0 | 6.46E-16 | 7.15E-16 | 17.2 |
| **Target-:Lead** | | | |
| 10.0 | 5.15E-01 | 6.51E-01 | 25.3 |
| 12.5 | 2.59E-03 | 3.15E-03 | 24.2 |
| 15.0 | 3.62E-04 | 4.36E-04 | 23.5 |
| 17.5 | 2.20E-05 | 2.62E-05 | 23.3 |
| 20.0 | 9.13E-07 | 1.08E-06 | 23.1 |
| 22.5 | 4.62E-08 | 5.43E-08 | 22.6 |
| 25.0 | 1.21E-09 | 1.42E-09 | 21.9 |
| 27.5 | 2.33E-11 | 2.68E-11 | 20.6 |
| 30.0 | 3.53E-12 | 4.06E-12 | 20.5 |

**Table 2. Percentage of contribution of PB into OB for $^{45}$Ca ($W_{max}$= 257 keV) at different photon energies**

| **Energies** | | | |
|---|---|---|---|
| **energies** | **Number of photons of energy k per $m_oc^2$ per unit total photon yield** | | **Percentage contribution of PB into OB** |
| | **$F_{mod}$BH Theory** | **$F_{mod}$BH+PB Theory** | |
| 10.0 | 4.39E-01 | 5.13E-01 | 15.5 |
| 12.5 | 7.17E-03 | 8.25E-03 | 15.1 |
| 15.0 | 8.93E-04 | 9.92E-04 | 11.9 |
| 17.5 | 4.49E-04 | 4.93E-04 | 11.0 |
| 20.0 | 2.79E-04 | 3.02E-04 | 10.5 |
| 22.5 | 1.70E-04 | 1.83E-04 | 10.5 |
| 25.0 | 1.23E-04 | 1.32E-04 | 10.3 |
| 27.5 | 9.41E-05 | 1.00E-04 | 9.9 |
| 30.0 | 7.80E-05 | 8.25E-05 | 9.5 |
| **Energies** | | | |
| 10.0 | 5.37E-01 | 6.15E-01 | 19.0 |
| 12.5 | 1.49E-06 | 1.77E-06 | 18.5 |
| 15.0 | 8.91E-09 | 1.03E-08 | 18.0 |
| 17.5 | 3.49E-11 | 4.00E-11 | 17.5 |
| 20.0 | 3.79E-12 | 4.31E-12 | 17.1 |
| 22.5 | 8.98E-13 | 1.01E-12 | 16.1 |
| 25.0 | 4.36E-13 | 4.89E-13 | 15.9 |
| 27.5 | 1.85E-13 | 2.02E-13 | 15.2 |
| 30.0 | 1.20E-13 | 1.30E-13 | 14.1 |
| **Energies** | | | |
| 10.0 | 4.25E-01 | 5.96E-01 | 20.8 |
| 12.5 | 1.65E-07 | 2.00E-07 | 20.4 |
| 15.0 | 8.91E-11 | 1.05E-10 | 19.4 |
| 17.5 | 1.10E-12 | 1.28E-12 | 19.0 |
| 20.0 | 4.64E-14 | 5.36E-14 | 18.6 |
| 22.5 | 9.22E-15 | 1.04E-14 | 18.6 |
| 25.0 | 2.30E-15 | 2.58E-15 | 18.2 |
| 27.5 | 1.37E-15 | 1.52E-15 | 17.1 |
| 30.0 | 6.46E-16 | 7.15E-16 | 16.8 |
| **Energies** | | | |
| 10.0 | 5.15E-01 | 6.51E-01 | 24.8 |
| 12.5 | 2.59E-03 | 3.15E-03 | 24.1 |
| 15.0 | 3.62E-04 | 4.36E-04 | 23.6 |
| 17.5 | 2.20E-05 | 2.62E-05 | 23.2 |
| 20.0 | 9.13E-07 | 1.08E-06 | 22.9 |
| 22.5 | 4.62E-08 | 5.43E-08 | 21.4 |

| | | | |
|---|---|---|---|
| 25.0 | 1.21E-09 | 1.42E-09 | 21.3 |
| 27.5 | 2.33E-11 | 2.68E-11 | 20.5 |
| 30.0 | 3.53E-12 | 4.06E-12 | 20.3 |

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