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LA-UR, 94-1100

Conf-9406107-2

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

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X-RAY SPECTRA

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SUBMITTED TO: HEALTH PHYSICS SOCIETY ANNUAL MEETING SAN FRANCISCO
JUNE 26-30, 1994

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MASTER

AN OPTIMAL TARGET-FILTER SYSTEM FOR ELECTRON BEAM GENERATED X-RAY SPECTRA

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ABSTRACT

An electron beam generated x-ray spectrum consists of characteristic x rays of the target and continuous bremsstrahlung. The percentage of characteristic x rays over the entire energy spectrum depends on the beam energy and the filter thickness. To determine the optimal electron beam energy and filter thickness, one can either conduct many experimental measurements, or perform a series of Monte Carlo simulations. Monte Carlo simulations are shown to be an efficient tool for determining the optimal target-filter system for electron beam generated x-ray spectra. Three of the most commonly used low-energy x-ray metal targets (Cu, Zn and Mo) are chosen for this study to illustrate the power of Monte Carlo simulations.

I. INTRODUCTION

Electron beam generated x rays have been used extensively as sources for x ray research, radiation biology research, and x-ray detector and dosimeter calibrations. With the proper selection of a target material, the x ray energy can be varied from a few keV to about 120 keV. The x ray spectrum consists of two distinct portions: the characteristic K and L x rays of the target, and a continuous bremsstrahlung spectrum with an energy up to the maximum electron beam energy. For research applications and detector or dosimeter calibrations, one often uses mono-energetic x rays as the source. A filter is used to attenuate the bremsstrahlung background as much as possible, without a significant loss of the characteristic x rays. The ratio of the x ray to the total photon production is defined as the purity of x ray source. The purity is a function of the electron beam energy and the filter thickness. To determine the optimal conditions for producing x rays, one can either conduct extensive experimental measurements or perform Monte Carlo simulations.

Since the bremsstrahlung production is proportional to Z^2 (where Z is the atomic number of target), and the ionization cross section is proportional to Z , the x ray production by direct electron beam bombardment is suitable only for low Z elements. Characteristic x ray production with high Z targets utilizes photons to excite the target atoms where the source photons are produced by the electron bremsstrahlung process.

In this article, we study several low Z metal target-filter systems. The calculations for high Z target-filter systems will be presented in a separate article.

II. MONTE CARLO SIMULATIONS

The Monte Carlo code ACCEPTP¹ of the Integrated TIGER series was used to perform the simulations. The physics, code structure, and various applications had been described in detail in articles by Halbleib¹. Version 3 of the code is utilized because the production of K and L x rays are specifically tallied.

The experimental geometry is shown in Figure 1a. The metal target is placed at 45 degree to the incoming electron beam. The exit port is perpendicular to the electron beam. The exit port consists of a 0.0127 cm Be window and filter. The model geometry for simulation is shown in Figure 1b. The thin metal target (0.0127 cm), is surrounded by two metal shells corresponding to the window and filter. The photon spectra are tallied every 10 degrees.

(a) Experimental setup.

(b) Model Geometry.

Figure 1.

III. CHOICE OF FILTER

For a metal target with atomic number Z , the choice of filter material is based on the following considerations:

1. The filter material has a K absorption edge energy either slightly higher than the energy of the K_β line or between the K_α and K_β lines of the target material. Thus, the filter can be either the target material or element of $Z-1$.
2. The filter material can be either in a metal form or stable chemical form.

For illustration, consider two target-filter combinations of a Cu target with Ni filter and a Cu target with Cu filter. Table 1 lists the K x ray energies for Ni and Cu.

Table 1, K X Ray Energies for Nickel and Copper
Energy (keV)

	Ni (Z=28)	Cu (Z=29)
K-edge	8.3318	8.9779
$K_{\alpha 1}$	7.4718	8.0399
$K_{\alpha 2}$	7.4548	8.0199
K_β	8.2640	8.9175

Figure 2. Photon Cross-Sections:
Ni (solid), Cu (dash)

Figure 2 shows the photon interaction cross sections of Ni and Cu. The energy of the Cu K_β line is slightly higher than the Ni K-edge. The Cu K_β will be highly attenuated, exciting the Ni atoms to produce Ni x rays. The final spectrum will consist of three Ni x

ray lines and two Cu K_{α} lines on a reduced continuum. The x rays energies are from 7.45 keV to 8.26 keV. For a Cu target with a Cu filter, the filter will attenuate both the K_{α} and K_{β} lines, with more effective attenuation on the higher energy side of the bremsstrahlung spectrum. The final spectrum consists of three Cu x ray lines on a reduced continuum. The x ray energies are from 8.02 keV to 8.92 keV. For detector calibrations, a low energy x ray detector, with an energy resolution of 0.5 keV, can resolve the Cu K_{α} and K_{β} lines, but will not easily resolve the Ni K x rays from the Cu K x rays.

IV. ANGULAR DISTRIBUTION

The bremsstrahlung has a forward angular distribution. The characteristic x rays are distributed isotropically. Because of the finite thickness of the target, the forward x rays are absorbed by the target itself. Figure 3 shows a typical angular distribution of the x rays.

Figure 3. X Ray Angular Distribution

V. RESULTS

A. Electron Beam Energy

Figure 4 shows the number of x rays at 135-degree as a function of electron beam energy for all three targets. In the energy range of interest, the x ray production increases almost linearly with beam energy. All targets generate very high yields. For example, for a Cu target at 100 kV, one electron produces 1.2×10^{-3} K_{α} x rays per steradian (sr). Thus for a machine of 1 ma current, 7.5×10^9 K_{α} x rays per msr per sec will be produced.

Figure 4. K_{α} X Ray Production as a Function of Electron Beam Energy

Figure 5 shows the K_{α} x ray purity at 135-degree as a function of electron beam energy for all three targets. Mo has a lower purity as compared with Cu and Zn targets, because of the higher bremsstrahlung production.

Figure 5. K_{α} X Ray Purity as a Function of Electron Beam Energy

B. Filter Thickness

1. Cu Target

Figure 6 shows the purity of K_α x rays from a Cu target at 135-degrees as a function of filter thickness for both Ni and Cu filters. The solid lines are for an electron beam energy of 50 keV, and the dashed lines are for 100 keV. Without a filter, the 100 keV beam generates a higher purity of K_α x rays. But with proper choice of filter (Ni foil with thickness between 15 to 20 μm), the 50 keV beam produces K_α x rays with a purity of 65%. The plots also show that an improper filter thickness not only reduces the intensity of K_α x rays, but also reduces the purity.

Figure 6. Cu K_α X Ray Purity as a Function of Filter Thickness, at 135° with Electron Beam Energies of 50 keV (solid) and 100 keV (dash).

Figure 7. X Ray Spectrum. Four lines are K_α and K_β of Cu and Ni.

Figure 7 shows the photon spectrum produced by 50 kV electron beam at 135-degree with a 15 μm Ni filter. These four lines are (from left to right) Ni K_{α} (7.47 keV), Cu K_{α} (8.04 keV), Ni K_{β} (8.26 keV) and Cu K_{β} (8.91 keV) respectively.

2. Zn and Mo Targets

Similar calculations were performed for Zn target with Cu or Zn as the filter and a Mo target with Nb or Mo as the filter. The results are shown in Figures 8 and 9. For a Zr target, the optimal thickness of the Cu filters are 20 μm for a 50 kV electron beam, and 10 μm for a 100 kV electron beam. They yield 64.4% and 63.3% purities respectively.

Figure 8. The same as Figure 6, but for a Zn Target.

Figure 9. The same as Figure 6, but for a Mo Target.

For a Mo target, as we expected, the bremsstrahlung production is much higher, and we achieve lower purities with both Nb and Mo filters. With a Nb filter, the optimal thickness is 120 μm for a 50 kV electron beam and a 44.9% purity, and 40 μm for a 100 kV electron beam and a purity of 43.6%.

VI. CONCLUSION

Monte Carlo simulations can be used to determine the optimal target-filter combination for characteristic x ray productions. Further, the simulation can also determine the number of x rays produced. This is important for the absolute efficiency calibration of detectors. The continuous bremsstrahlung and characteristic x ray spectrum is important for dosimeter response function calculations².

VII. REFERENCES

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