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LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

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Frederick R. Kovar

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MASTER

COMPARISON OF ETRAN CALCULATIONS WITH EXPERIMENTS*

Frederick R. Kovar^a

ABSTRACT

A modified version of the electron-photon transport code, ETRAN, has been used to calculate charge and voltage generation, caused by IEMP effects. Calculations on forward and backward surface emission have been compared to three independent, incident x-ray experiments and to data from literature on electron back scattering from thick targets. The results of these comparisons indicate agreement to $\pm 30\%$ for incident photon energies in the 10- to 100-keV region and agreement to $\pm 35\%$ for incident electron energies from 10 keV to 10 MeV.

INTRODUCTION

The National Bureau of Standards developed the ETRAN code and checked it for high energy photon and electron sources (0.5 to 10 MeV) with very good agreement.¹ Since its adoption by the Laboratory, we have attempted to confirm predictions with available data.

In an effort to improve our predictions we have modified the original code to include multi-material, multi-layer geometry, and we have added LLL photon cross-sections to include all elements. Finally, we have developed a routine to calculate fields and voltages, generated by the charge transfer, within the material. This

routine includes an option to move charge between zones (e.g., between shorted conductors) and to rezone the problem.²

FORWARD AND BACK SCATTERED ELECTRONS FROM THIN FOILS³

To measure forward and back scattered electrons, we subjected thin foil targets of aluminum, copper, and gold to an x-ray spectrum of 35.8-keV average energy from a Blumlein generator.⁴ Figure 1 shows the experimental sample chamber which can be vacuum pumped to a pressure of 10^{-3} Torr. Beryllium windows throughout the chamber minimize x-ray attenuation and scatter.

A double wall construction in the sample chamber minimizes electrical interference from the Blumlein generator, an intense source of electrical noise. Noise voltages of the order of volts are commonly observed on electronic components in the vicinity of a pulsed Blumlein. By using the double wall sample chamber, triaxial signal cables, and great care to eliminate ground loops, we reduced the electrical noise in the diagnostic system to a few mV.

The x-ray burst produced by the Blumlein machine is approximately 50 nsec (fwhm) long. We placed absorbers between the beam and the sample to filter out the very low energy (<15 keV) components of the x-ray pulse. Thus, the bulk of

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Fig. 1. Blumlein experimental arrangement. Principal components shown are the Blumlein generator, beam filter, sample vacuum system, and x-ray monitor. The x-ray beam is collimated so as to expose only the sample and chamber windows to the pulse.

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^aLawrence Livermore Laboratory, Livermore, California.

the radiation occurs in the 15 to 60 keV range with a distinct maximum near 30 keV.

We measured both direct and filtered spectra (Fig. 2) with a bent crystal spectrometer. The x-ray film detector density calibration was made by comparison with a direct current x-ray source of known intensity and spectral distribution.

The dose measured for the filtered and unfiltered spectrum at the sample location is 0.2 rads and 6 rads ($\pm 10\%$), respectively (air or plastic). The dose was determined by averaging the readings of a number of LiF thermoluminescent detectors which were exposed at the sample position. The variation of the dose with angle was found to be very small over the region subtended by the experimental apparatus.

Each pulse of the Blumlein was monitored by scintillation counters. A NaI fluor was used to monitor the total x-ray yield while a thin plastic scintillator⁵ was used to measure the rate dependence of each burst.

The targets were thin foils of aluminum (0.001 in. thick), copper (0.00038 in. thick) and gold (0.0001 in. thick). The walls of the inner chamber served as the collector for the scattered charges. To count only forward scattered electrons, a surface layer of beryllium several electron path lengths thick was placed on the front side of the sample facing the source. Conversely, to count only back scattered electrons, the sample was reversed so that the beryllium layer was now on the side of the sample facing away from the source. Secondary electron emission was suppressed by means of grids, not shown in Fig. 1.

ETRAN calculations were made using the Blumlein spectrum as the input spectrum and the appropriate sample material as the target. Table 1 compares the calculations with the experimental data.

MONOENERGETIC X-RAY SOURCE INCIDENT ON THIN FOILS

In this experiment, we subjected thin foil targets of aluminum, copper, and gold to monoenergetic beams of x rays.

Forward and back scattered electrons were measured with the same apparatus described in the first experiment. The technique for production of monoenergetic x rays from 8 to 98 keV has been previously described in detail.⁶ Briefly, two radiographic x-ray machines operating at constant potential are used to excite fluorescent x rays in an elliptically shaped foil of greater than 99.9%

purity. The foil is inclined at an angle of 45° with respect to both the primary bremsstrahlung beam and a set of collimators that determine the experimental axis. The fluorescers are approximately 0.5 mean free paths thick for their own characteristic x rays. The x-ray spectrum so produced is filtered by an absorber whose K absorption edge falls between the energies of the K_α and K_β x-ray lines. This filter removes most of the K_β x rays and virtually all of the L x rays. In most of these experiments, the bremsstrahlung beam was also filtered to reduce the scattered bremsstrahlung intensity. In this way, the fluorescent x-ray flux was 10 times greater than the scattered continuum

Fig. 2. Blumlein spectrum. The solid curve is the unfiltered spectrum (note the tungsten target L lines near 10 keV). The dashed curve is the measured spectrum after passing through the beam filter listed above. Typical errors are shown. Both the high and low energy parts of the spectrum have large uncertainties because of poor resolution by the crystal spectrometer in these regions.

Table 1. Comparison of ETRAN Calculations with Experimental Data for the Blumlein Filtered Spectrum.^a

Foil	Experiment ^b	Forward scattering		Experiment ^b	Back scattering	
		ETRAN ^b	ETRAN - Experiment Experiment		ETRAN ^b	ETRAN - Experiment Experiment
Al (0.001 in.)	5.3	4.6	13% low	3.0	2.3	23% low
Cu (0.00038 in.)	32	31	3% low	28	20	29% low
Au (0.0001 in.)	87	130	50% high	73	95	30% high

^aExperimental uncertainty of measurements is $\pm 30\%$.

^bValues are 10^{-8} coulombs per incident calorie.

flux, as determined by a high-resolution Ge(Li) spectrometer of known efficiency. X-ray energy is estimated to be known within ± 1 keV.

Figures 3 through 5 show plots of charges released in the forward or backward direction vs photon energy incident on aluminum, copper, and gold foils. The same figures also show ETRAN calculations using monoenergetic x rays as photon input on similar targets.

INDUCED ELECTRON CURRENTS FROM METAL TARGETS

In these experiments, monoenergetic x rays from the source described in the second experiment were incident on thick and thin metal targets of aluminum, silver, and gold.⁷ Measurements

made on thin targets of gold and aluminum were particularly interesting since the calculations made for the second experiment were applicable. Figures 6 through 9 show comparisons between ETRAN calculations on thin foil targets of the second experiment with Ebert et al. data.

Figure 6 is a plot of the sensitivity of aluminum and gold foils (expressed in coulombs of charge released per keV of incident photon energy vs photon energy). The geometry of Ebert's experiment was such that both forward and backward scattered electrons were simultaneously detected. ETRAN's data points are correspondingly the sum of forward and back scattered electrons.

Figures 7 and 8 show quantum efficiency (electrons released per incident quantum) plotted against incident photon energy. ETRAN calculations for monoenergetic x rays on a 0.0001-in. Au sample (4.9 mg/cm^2) are compared with Ebert's data for three different thicknesses of Au foils. Photons strike the target at normal incidence ($\theta = 90^\circ$).

Figure 9 is a plot of the ratio of forward scattered to back scattered electron current. Note

Fig. 3. Comparison of ETRAN calculations with Weingart's experiments for aluminum foils (6.86 mg/cm^2).

Fig. 4. Comparison of ETRAN calculations with Weingart's experiments for copper foils (8.6 mg/cm^2).

Fig. 5. Comparison of ETRAN calculations with Weingart's experiments for gold foils (4.9 mg/cm^2).

Fig. 6. Sensitivity of aluminum and gold foils.

that the foil thickness used for the calculation is approximately 50% thicker than the foil used in the experiment because the same calculational data from the first and second experiments were used. At low energies, the thinner foil should exhibit a larger ratio than for the thicker foil while at higher energies the ratio should be independent of foil thickness. There seems to be a discrepancy at the higher energies but this may result from Ebert's measurement techniques. His equipment detects all electrons, including those scattered from the windows and walls. This added contribution to both numerator and denominator would tend to depress the ratio. However, even at the 80-keV K-edge the discrepancy is less than 25%.

ELECTRON BACK SCATTERING COEFFICIENT

The back scattering coefficient, η , is defined as the ratio of the number of electrons back scattered from a target to the number of electrons incident on the target. T. Tabata, R. Ito, and S. Okabe⁸ developed an empirical equation for η

Fig. 7. Quantum efficiency vs energy for gold foils of specified thickness.

Fig. 8. Quantum efficiency vs energy for gold foils of specified thickness.

Fig. 9. Ratio of forward scattered to back scattered electron current.

for thick metal targets of carbon, aluminum, copper, silver, and gold. They compared the results of 25 different experiments with their empirical equation. Their empirical curves as well as the experimental data are shown in

Fig. 10. ETRAN calculations for electrons of several different energies incident on similar thick metal targets are also shown in Fig. 10.

There is good agreement between ETRAN and experimental data and between ETRAN and Tabata's empirical curve. The largest error was 34% for Al at 2.5 MeV. Most other differences between ETRAN and Tabata et al. were within $\pm 10\%$. The average of all differences was $\pm 9.2\%$.

SUMMARY AND CONCLUSIONS

Comparisons indicate that the ETRAN code is predicting surface charge emissions from single-layer geometries to within a factor of $\pm 30\%$ for incident photons in the 10- to 100-keV energy range. Comparisons of electron back scatter data indicate agreement within $\pm 35\%$ over the energy range of incident electrons from 10 keV to 10 MeV.

ETRAN's predictions for internal-charge displacements in complex multi-layer geometry require validation by experiments that are more sophisticated than those presently available. However, potential difference calculations³ and agreement among referenced experiments indicate that the predictions are valid.

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Fig. 10. Back scattering coefficient (η) of electrons as a function of incident energy (E) on thick targets. (a) C, Al, and Cu; (b) Ag and Al.

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Kovar - Fig. 1

Kovar - Fig. 2

Kovar - Fig. 3

Kovar - Fig. 4

0.049 60 0.048 5/10 212 0

Kovar - Fig. 6

Kovar - Fig. 8

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Kovar - Fig. 9

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Kovar - Fig. 10