ENERGY PER PHOTOELECTRON IN A COINCIDENCE LIQUID SCINTILLATION COUNTER AS A FUNCTION OF ELECTRON ENERGY

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ABSTRACT

The pulse height spectrum was measured for the minimum detectable event of a coincidence liquid scintillation counter - the two photoelectron event. Using a chemiluminescence source of single photons the chance coincidence events for one photoelectron produced in each multiplier phototube within the coincidence resolving time would represent the two photoelectron spectrums. The peak of this spectrum gave the average pulse height of the two photoelectron event. Using different radionuclides which decay by emission of discrete energy events; conversion electrons, X-rays and/or gamma rays; the pulse height spectra produced by given energy electrons were measured. From these the average number of photoelectrons corresponding to the pulse height was calculated. The energy divided by the number of photoelectrons was measured over the electron energy range 3.4 to 1067 keV.

The average energy per photoelectron was approximately constant at 0.68 keV/ photoelectron for electron energies greater than 200 keV. Below 200 keV the values increased to about 0.95 keV/photoelectrons at 5.9 keV. These data are compared to data for a non-coincidence, single multiplier phototube counter.

INTRODUCTION

The pulse height-energy relationship and average energy to produce one photoelectron have been previously measured for a single multiplier phototube (MPT).[1-3] In this paper, the measurements have been repeated for a commercial coincidence type liquid scintillation system.

EXPERIMENTAL

The radionuclides listed in Table 1 were used to calibrate the energy response of a Beckman LS 9800 (or LS 5800) series Liquid Scintillation Systems. Each of these radionuclides produced one or more characteristic electron energy response as listed in Table 1.

Table 1. Energy Calibrations for Liquid Scintillation Solutions

RADIONUCLIDE	Energy, keV	Type of Radiation	Source
^{55}Fe	5.9	Mn - K x-ray	Dissolved
$^{109}Cd-^{109m}Ag$	22.1	Ag - K x-ray	External
^{125}I	27.5	Te - K x-ray	External
^{241}Am	(33) 59.5	Gamma ray Gamma ray	External
$^{113}Sn-^{113m}In$	369 24 3.4	Conversion electron In - K x-ray In - L x-ray	Dissolved
$^{137}Cs-^{137m}Ba$	630	Conversion electron	Dissolved
$^{137}Cs-^{137m}Ba$	478	Compton edge	External
^{207}Bi	989 495 75 11	Conversion electron Conversion electron Pb-K x-ray Pb-L x-ray	Dissolved
^{22}Na	1067 340	Compton edge Compton edge	External
^{57}Co	130 14.4	Conversion electron Conversion electron	Dissolved
^{51}Cr	315 178 5.0	Conversion electron Compton edge V-K x-ray	Dissolved
^{113}Ba	207	Compton edge	External
^{54}Mn	640	Compton edge	External

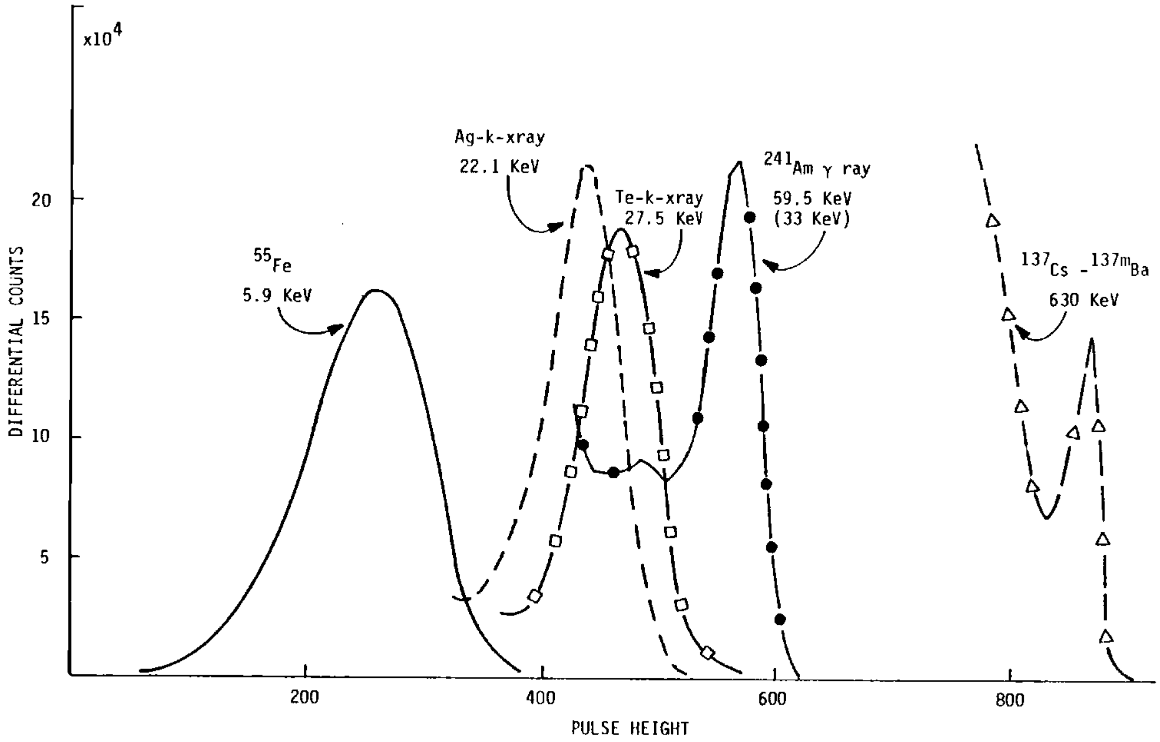

Figure 1. Typical pulse height spectra of several radionuclides for energy calibration of the liquid scintillator coincidence type systems.

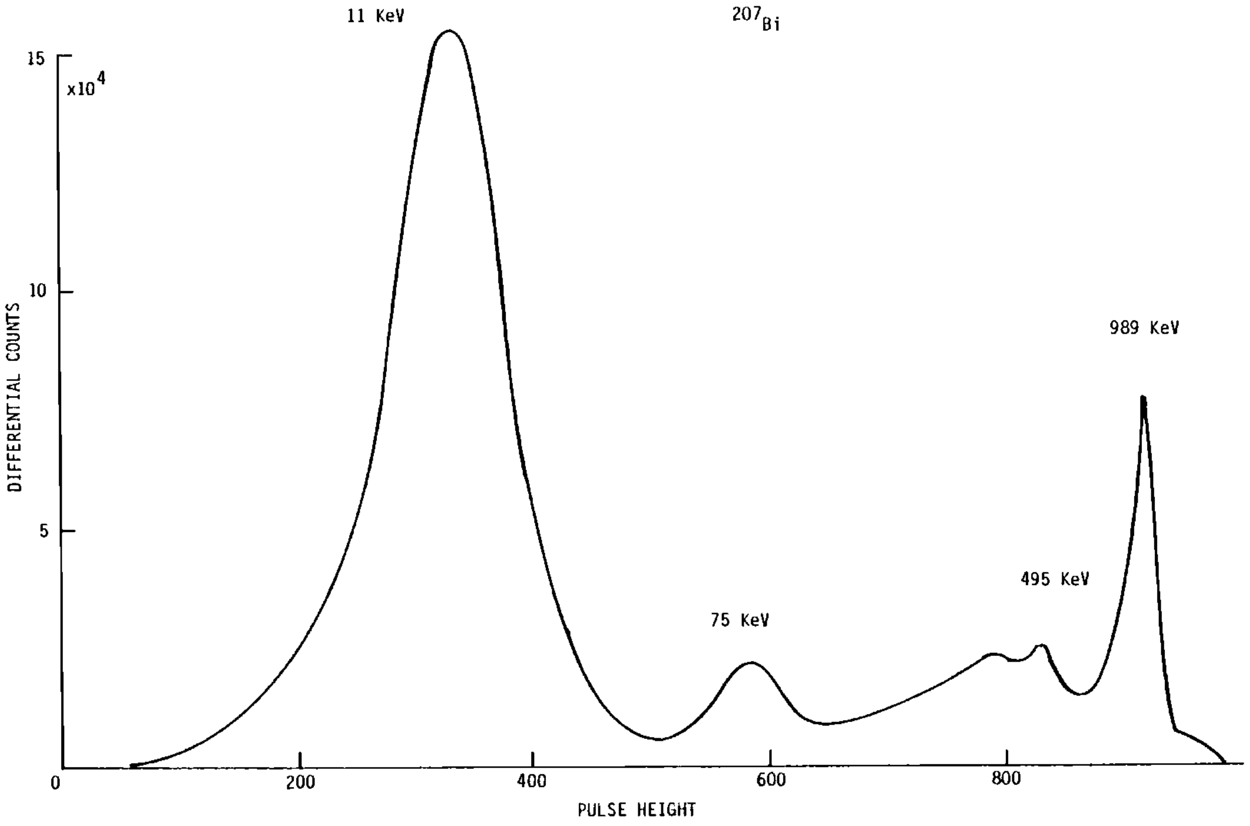

Figure 2. Pulse height spectrum of ^{207}Bi.

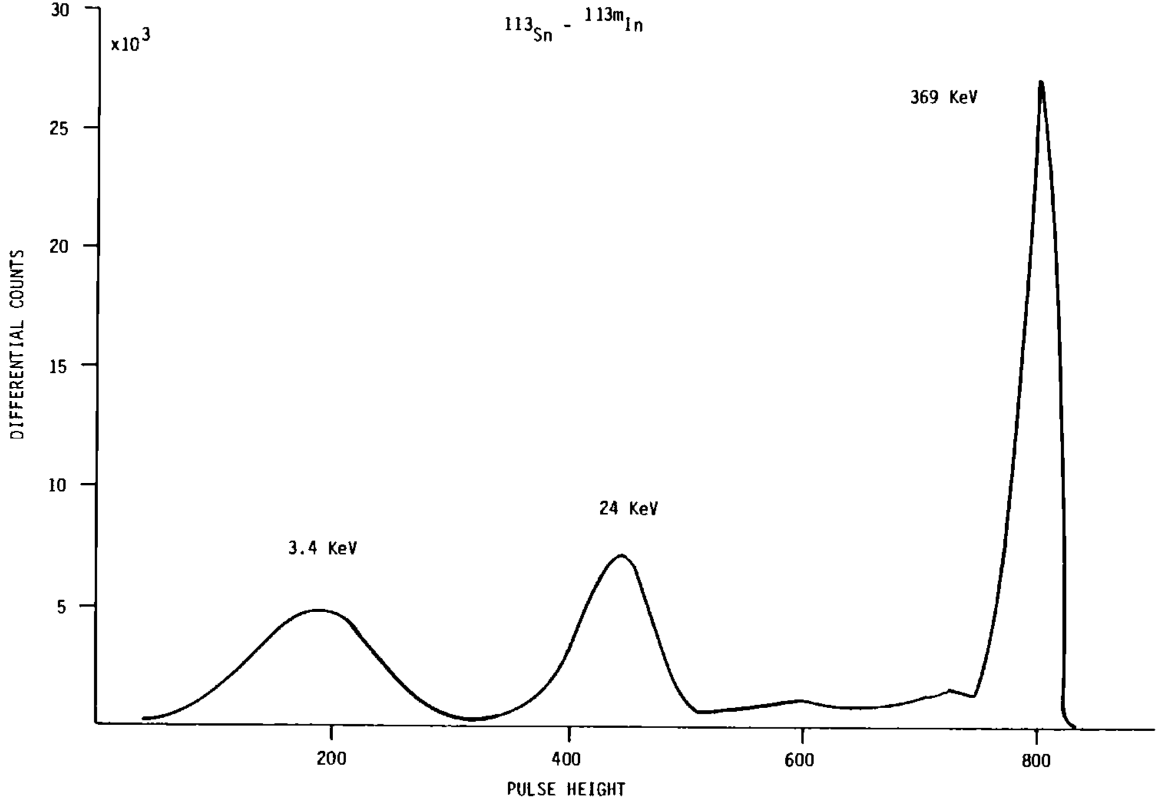

Figure 3. Pulse height spectrum of ^{113}Sn-^{113m}In.

The pulse height spectra of these radionuclides were measured in the LS 9800 multi-channel analyzer. Figures 1-3 show some typical pulse height spectra obtained. Figure 4 shows the pulse height spectrum of the 2 photoelectron response - one photoelectron from each MPT summed together. This spectrum was obtained using a sample which generated only single photon events (a chemiluminescence reaction). The spectrum was obtained in coincidence which represents the chance coincidence between one photoelectron from each MPT photocathode within the coincidence resolving time (20 nsec).

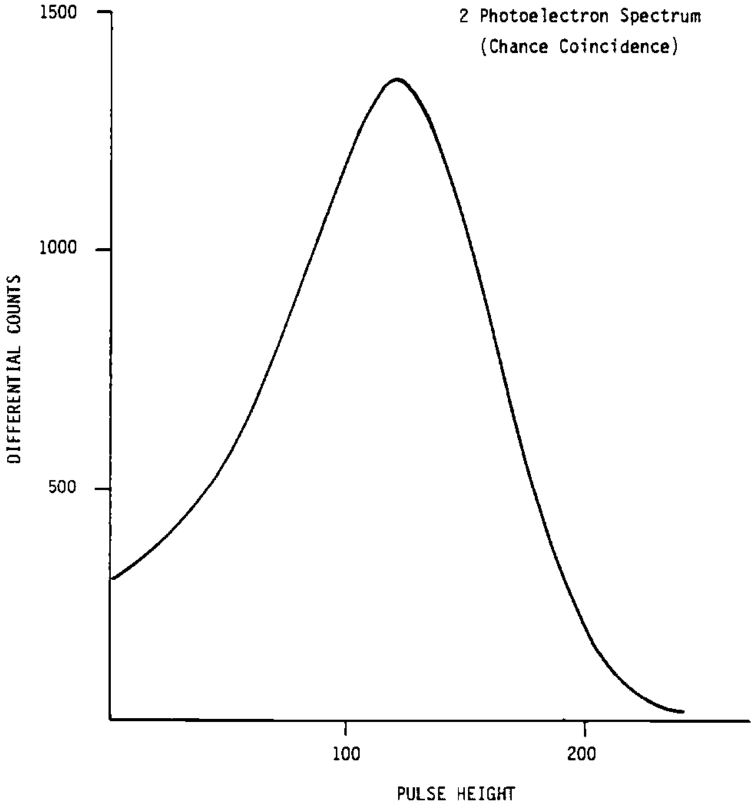

Figure 4. Pulse height spectrum of 2 photoelectron response from chance coinicidence of 1 photoelectron from each MPT.

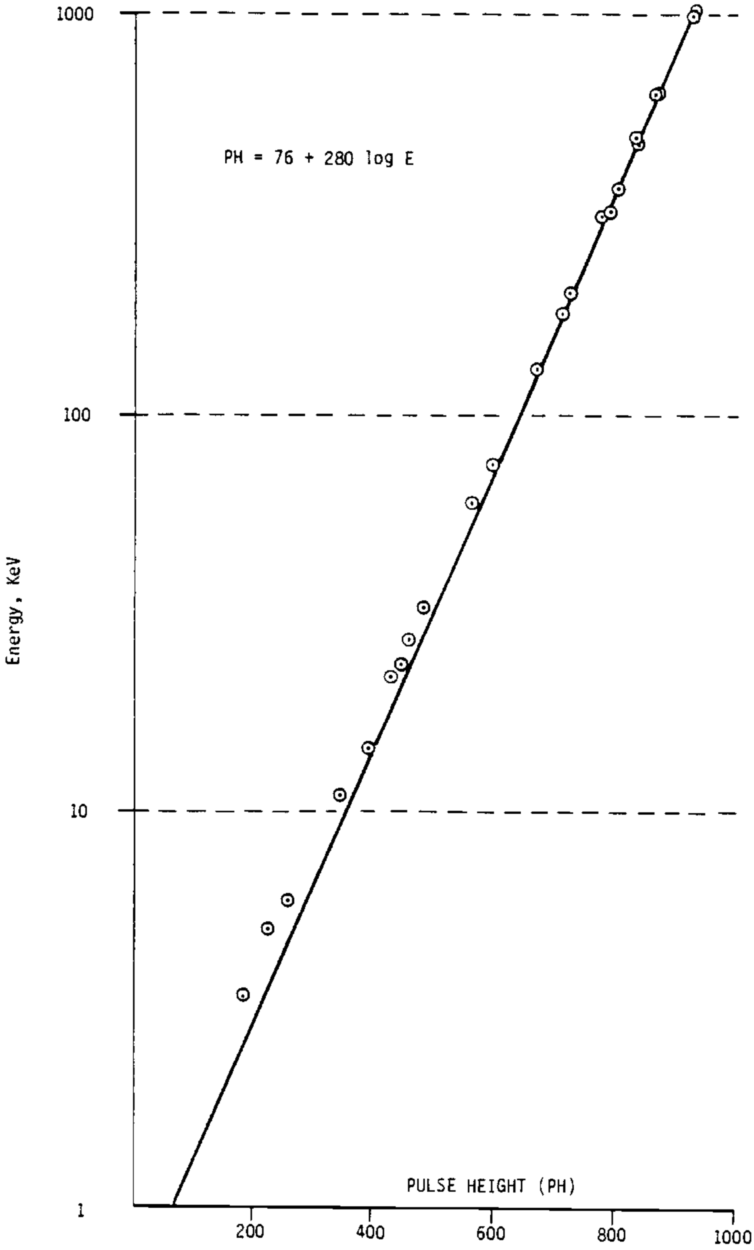

Figure 5. Measured pulse height vs electron energy (log scale) showing high energy (above 300 keV) relationship PH = 78 + 280 log E.

RESULTS

From the 2 electron spectrum in Figure 4 and the value of the electronic amplifier and log circuit slope of 280, it was calculated that the pulse height (PH) equivalent in the number of photoelectrons (#e) is given by the equation:

$$PH = 36 + 280 \log (\#e) \qquad (1)$$

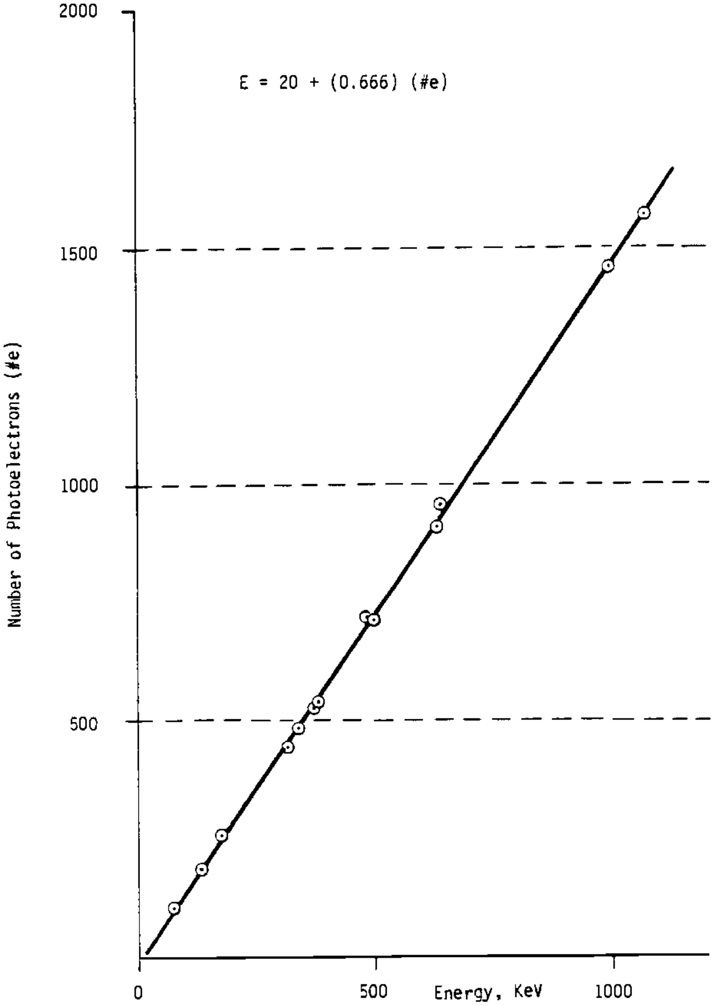

Figure 6. Electron energy vs calculated number of photoelectrons showing high energy relationship: $E = 20 + (0.666)(\#e)$.

Figure 5 shows the experimental data of the measured pulse height response (corrected for quench) as a function of the log of the energy of the excitation for electron excitations. Knowing that the electronic slope is 280 and that the scintillator system yield is linear with energy above 300 keV, the best fit equation for the pulse height (PH) response versus electron energy (E) in keV is given by the equation:

$$PH = 76 + 280 \log E \qquad (2)$$

The measured pulse height response deviates from equation 2 for electron energies below 300 keV as previously observed[1]. Figure 6 shows the same data as Figure 5 but translated to a linear energy response versus the equivalent number of photoelectrons as calculated from equation 1. The extrapolation to the zero photoelectron response gave an energy equivalent value of 20 keV as shown in Figure 7 which is the low energy range expanded. This agrees well with the 18 keV intercept measured in the earlier reports[1,3]. The relationship between the number of photoelectrons (#e) and energy (E) in keV is given by the equation:

$$E = 20 + (0.666)\,(\#e) \qquad (3)$$

From the pulse height response measured for a given electron energy and the number of photoelectrons equivalent to that pulse height response (Equation 1), the energy required to produce a single photoelectron was calculated. Figure 8 shows the calculated keV/photoelectron values as a function of electron energy for the commercial coincidence system. Also, Figure 8 shows the data for a single MPT system, Reference 2.

DISCUSSION

The plot of the keV/photoelectron versus energy gave the same shape for the single MPT and commercial coincidence systems. The single PMT system required about 0.15 - 0.20 keV less per

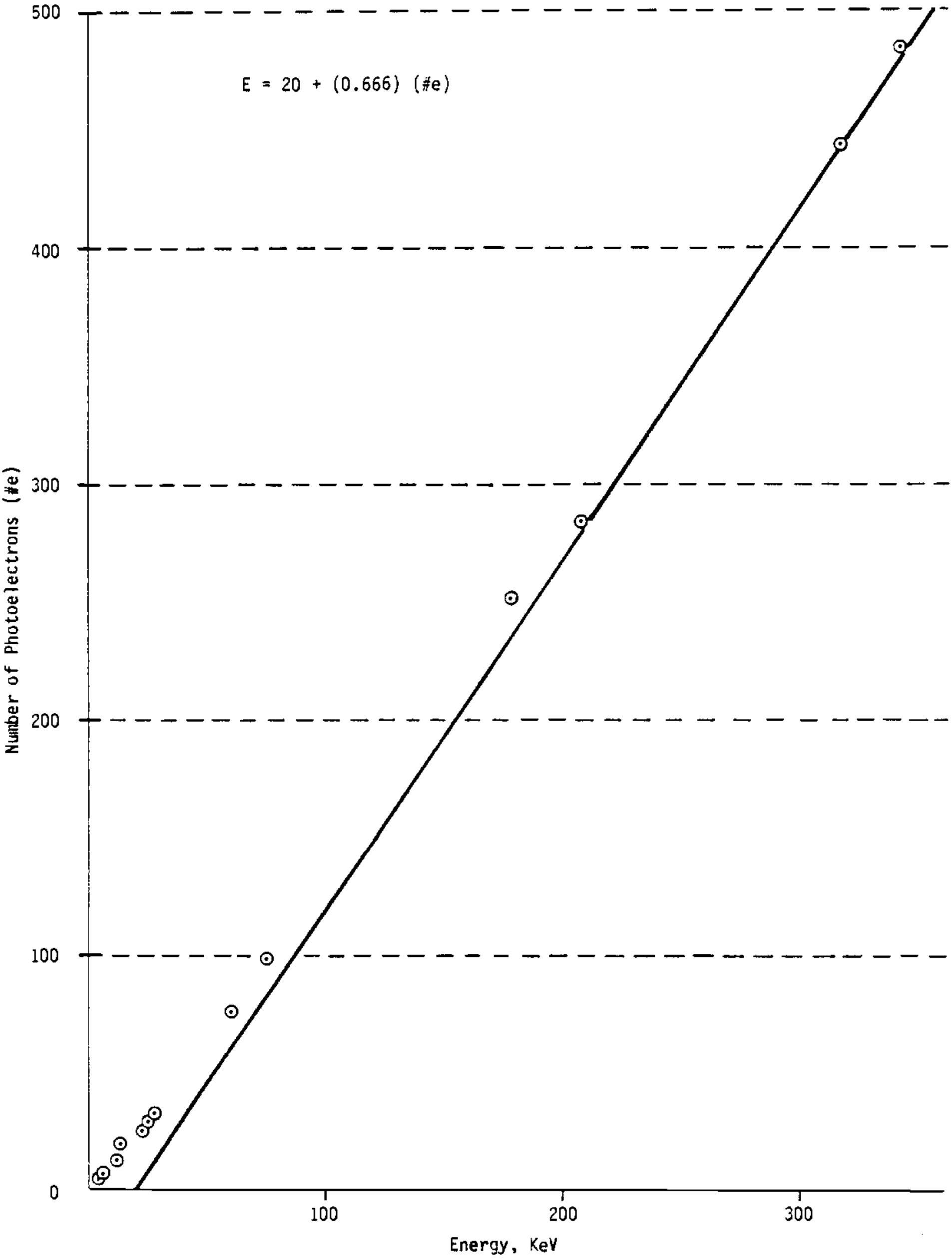

Figure 7. Electron energy vs calculated number of photoelectrons at low energy (below 300 keV) to show variation from high energy relationship.

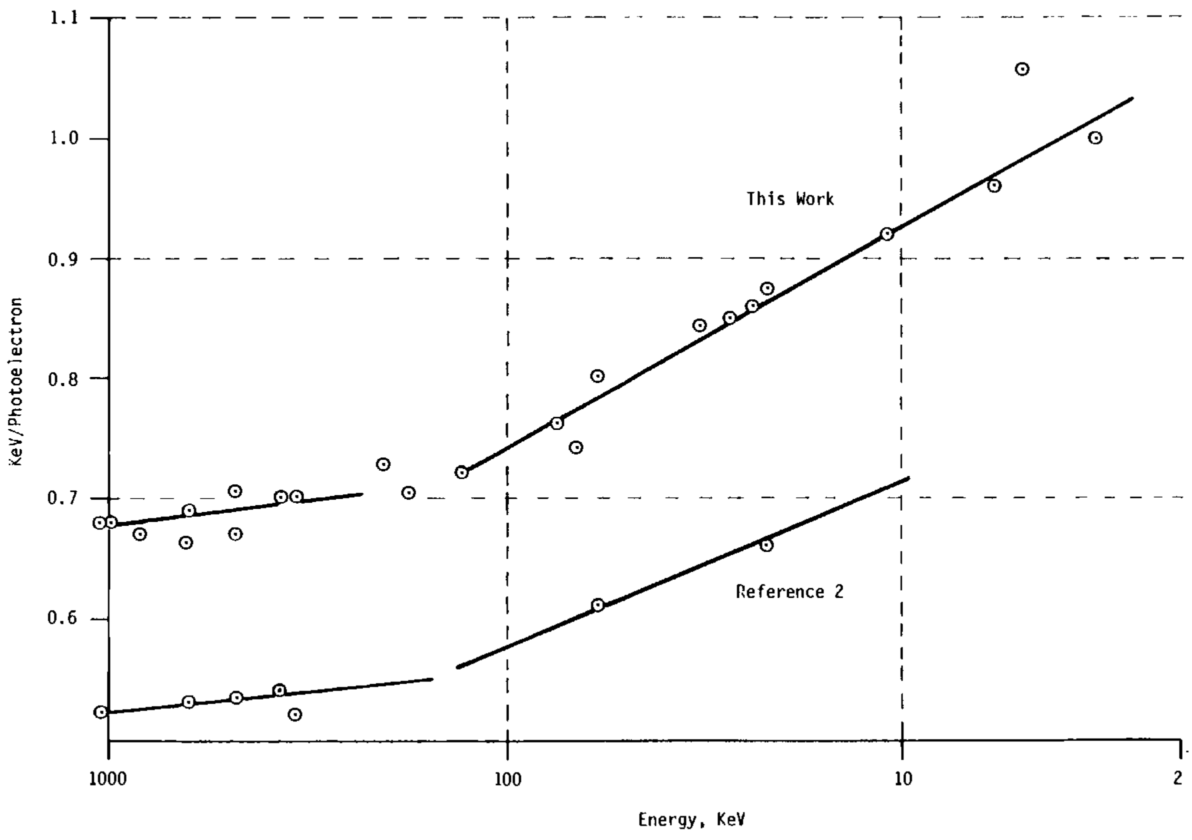

Figure 8. Calculated keV/photoelectron as function of energy (log scale) comparing this work with reference 2 (single MPT).

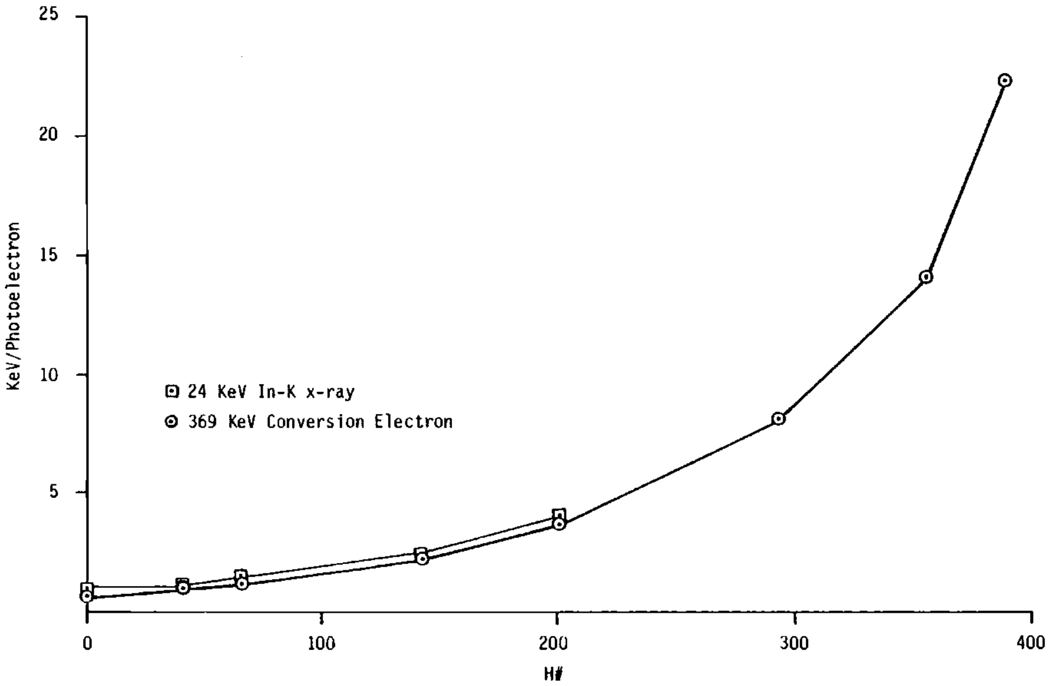

Figure 9. Effect of quench upon keV/photoelectron for 369 keV conversion electrons and 24 keV in K x-rays from ^{113}Sn-^{113m}In in liquid scintillator solutions quenched with nitromethane.

photoelectron over the electron energy range measured. This difference may be in part due to the difference in the quantum efficiency of the MPT's. Also, the coincidence system splits the light between two MPT's which may lead to small losses of photons from the scientific event. Each MPT has a certain threshold of detection and the total threshold for the summed pulses in the coincidence system is greater than the threshold in the single MPT system. The energy per photoelectron was essentially constant in the coincidence

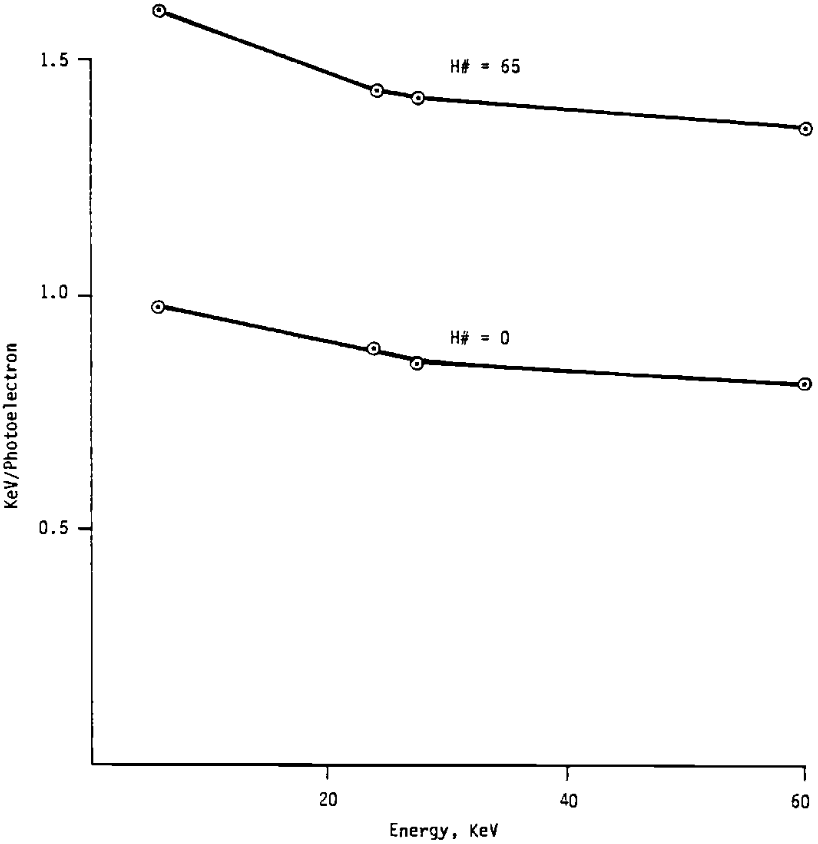

Figure 10. Effect of quench upon keV/photoelectrons as function of electron energy over low energy range (5.9 - 59.5 keV) showing unquenched samples (H# = 0) and a quenched sample (H# = 65).

system for electron energies greater than 300 keV at between 0.66 and 0.70 keV. Below 300 keV electron energy the energy per photoelectron increases as the electron energy decreases. It requires approximately 1 keV to produce a photoelectron at electron energies of 5.9 to 3.4 keV. The data used for Figure 8 were corrected for quench to give the pulse height response for an unquenched scintillation solution. When quenching is present in the sample, the energy per photoelectron increases. Figure 9 shows the keV/photoelectron change for the 369 keV conversion electrons and 24 keV In-K x-ray responses as a function of quench as measured by H#. Figure 10 shows the effect of quench on the keV/photoelectron versus energy curve. The two curves are parallel, i.e., quench effects the same change in keV/photoelectron, over the energy range 5.9 to 59.5 keV.

CONCLUSIONS

The data presented show that for a commercial coincidence system the energy required to produce a photoelectron at the face of a MPT is a function of the energy of the electron producing the scintillation event. Above 300 keV energy, the energy per photoelectron is essentially constant between 0.66 and 0.70 keV/photoelectron for an unquenched scintillator solution. The effect of increasing quench is to produce an increase in the energy required to produce a photoelectron. As the energy of the exciting electron decreases below 300 keV, the energy per photoelectron increases. In an unquenched scintillator solution it requires about 1 keV of energy to produce a photoelectron at electron energies between 3-6 keV.

REFERENCES

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