On Stability of Scintillation Detectors

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This paper describes how a photomultiplier tube in a scintillation detector changes pulse height with time, when the detector is exposed to a gamma-emitting source and high dynode voltage. The change in pulse height causes a "drift" of the spectral peaks out of the preadjusted energy window, and errors in counting rate of about 20% are detected. The drift is dependent on the photon flux, the level of the high voltage, and the energy of the source. The effect was not present in all detectors studied. It is thus important to check the stability properties of a detector before use.

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When using scintillation detectors for measurements of gamma radiation in various clinical applications, we usually assume that the measured object does not affect the measuring system. Unfortunately, this assumption is not always valid.

When studying gamma spectra before and after a counting session, we observed that the channel number of the photopeak had increased, sometimes as much as 20%. At first we believed that this drift was due to amplifier electronics. After a systematic exclusion procedure, the phenomenon was localized to the photomultiplier tube of the detector. Drifting could be demonstrated even after the power supply had been switched off. We therefore classified it as a "memory" effect in the photomultiplier due to exposure to gamma radiation. It was soon obvious that the drift was dependent on both the activity of source and the level of high voltage.

We therefore decided to investigate this drift as a function of time at various levels of photon flux and high voltage. The nuclides used were Tc-99m, I-125, and I-131.

METHOD

For the data acquisition we used a multichannel analyzer, equipped with a minicomputer and plug-in modules, analog-to-digital converter (linearity > 0.025%, stability > ± 0.01%/day), and linear amplifier (gain range 8–1024, gain stability > 0.01%/°C). A graphical terminal was used for the display of the spectrum, for which purpose there were 256 channels. Four 5-yr-old NaI(Tl) detectors* (S-11 phosphor, 10-stage venetian-blind dynodes) supplied with high-voltage power supply (stability > 0.007%/°C) were studied. All detectors had energy resolutions of about 9% at 662 keV. A conical lead collimator was used, 110 mm long, external opening 75 mm, internal opening 50 mm, outer diameter (cylindrical) 120 mm). A cylindrical source was placed in the center of a 10-cm homogeneous Plexiglas cube, and the distance from the detector front to the middle of the source was 160 mm.

Two brand-new NaI(Tl) detectors† with an energy resolution of 8% were also studied (bialkali cathode, 10-stage venetian-blind dynodes).

After several days without exposure to gamma activity, the photopeak was located in channel No. 132. All measurements started with the photopeak in this channel. One detector required higher dynode voltage than the other three to get the same pulse heights from the PMT.

The increase of channel number for the photopeak was then recorded after exposure to various levels of gamma activity, high voltage, and source energy. Every study lasted 5 hr. During the last

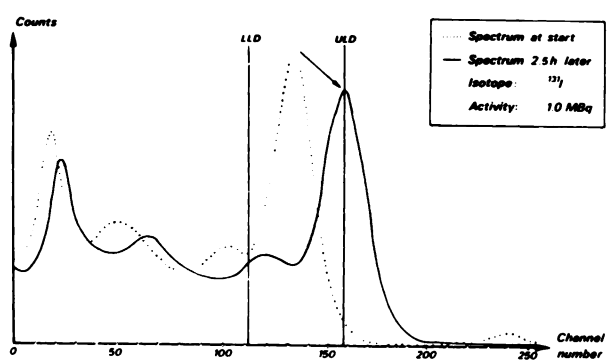

FIG. 1. Spectrum from I-131, with energy window shown. LLD = lower level discriminator, ULD = upper level discriminator.

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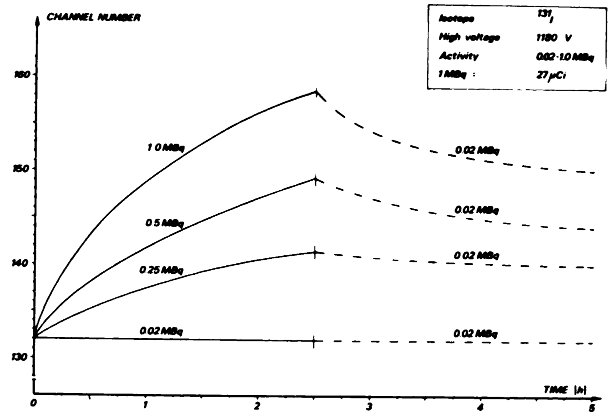

FIG. 2. Time-dependent shift of photopeak with variations in source activity level. (Max. count rate 1800 cps.)

2.5 hr, a low-activity source (0.02 MBq, 0.54 μCi), giving a count rate 40 cps, was used to show how the photopeak returned toward its original channel. We had previously observed that this low activity did not move the photopeak from its zero-input position.

RESULTS

All results, given below, refer to measurements of the detector with the most pronounced changes. To get an appropriate output signal this detector required a higher dynode voltage than the other detectors tested. This first brought the problem to our attention because, as we will see later, high dynode voltage intensifies the changes.

The shift of the whole spectrum and the increase with time of the photopeak's channel number are illustrated in Fig. 1. The dotted curve shows the initial spectrum. The detector was exposed to 1.0 MBq (27 μCi) I-131 (resultant count rate 1800 cps) for 2.5 hr, and the new spectrum recorded then is shown by the solid curve. The photopeak's channel number increased from 132 to 159. This signals an increase in pulse height from the photomultiplier tube (PMT).

Figure 2 shows the effects of various gamma activities on the shift of the photopeak, with fixed high voltages, The first 2.5 hr show the increase with time of the photopeak channel number during exposure to a source in front of the detector. The shift of the photopeak was most marked at high levels of gamma activity.

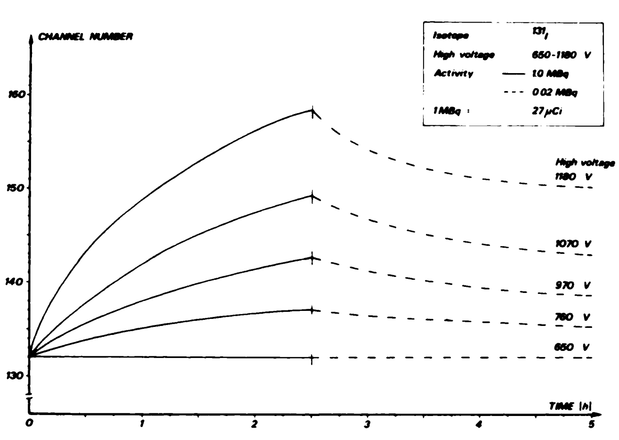

FIG. 3. Time-dependent shift of photopeak with variations in high voltage. (Max. count rate 1800 cps.)

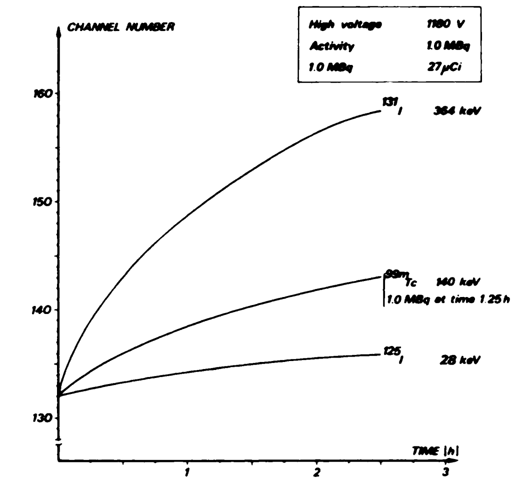

FIG. 4. Time-dependent shift of photopeak with several emitters. (Max. count rate 1900 cps.)

The second part of the graph (dashed) shows the slow recovery to the initial condition. For a given source activity, the return is much slower than the initial drift, taking several hours. Switching off the high-voltage power supply had no effect on the return time, which shows that it is an internal phenomenon in the photomultiplier tube. This was already shown by Gaeta and Manera in 1958 (*1*).

Figure 3 shows the effects of several high voltages on photopeak drift with fixed initial source activity. The shift of the photopeak was most marked at the higher voltages and was zero at the lowest.

Figure 4 shows the dependence of photopeak shift on the gamma energy of the source, with constant source activity and high voltage. High-energy emitters are seen to cause a more marked shift of the photopeak than low-energy nuclides.

Finally, the two brand-new detectors† were tested under the conditions described above, but no changes (<1%) in pulse height with exposure time were detected.

DISCUSSION

The drift of the photopeak thus depends on the high-voltage

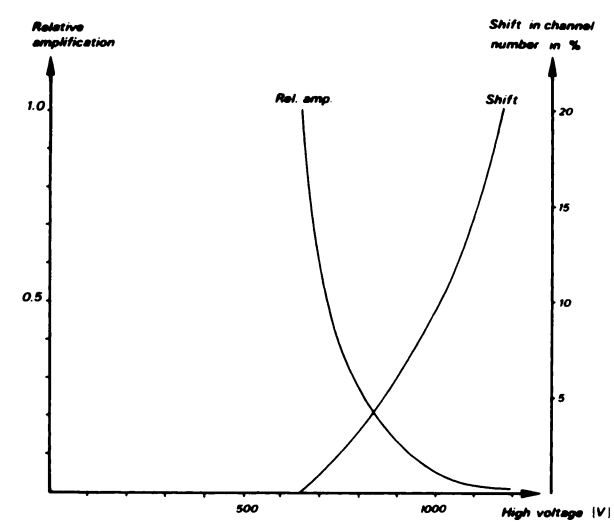

FIG. 5. Shift of photopeak channel in percent and relative demand for amplification as function of the dynode voltage. Relative amplification 1.0 denotes a factor of 360.

level, the gamma activity, and the energy of the source. It is evident that this effect is due to the PMT and not to amplifier electronics. The photopeak shift is a multiplicative phenomenon due to an increased photocathode sensitivity (*1*). The stability of a PMT should therefore be checked before use in all detectors where this effect might be important. Different types of PMTs seem to have different stability properties, but obviously even two identical PMTs from the same manufacturer show differences. This effect does not seem to be due to aging, for our records show that we observed similar behavior in this same detector 4 yr ago.

We can see from Fig. 1 that a loss in count rate results from the mismatch of the preadjusted energy window. Because of photopeak drift, there is a substantial loss of counts (>20% in Fig. 1) represented by the area lying to the right of the upper discriminator, while the area gained at the lower discriminator is insignificant. With other settings of the discriminator levels, other effects on the count rate would be seen. For the detector studied, it is evident that when low dynode voltage is used, the drift decreases. In practice, one must instead increase the gain of the linear amplifier of the detector system radically, as shown in Fig. 5. To minimize the drift, the highest gain of the linear amplifier should be used, and the required high voltage is then adjusted to get appropriate pulse height. In high-precision experiments an electronic pulse-height stabilizer would minimize the effect.

FOOTNOTES

* Teledyne Isotopes, 2″ × 2″ model S-88-1, PMT type EMI 9656 B.

† Harshaw 2 in. × 2 in. type 8S8/2A 2 in. × 2 in., PMT type EMI 9856.

REFERENCE

1. GAETA R, MANERO F: Characteristics of Dumont 6292 photomultiplier tubes. *Int Conf Peaceful Use At Energy* 14: 331–334, 1958