Can a Detector in Live-Time Mode Give a True Count Rate?

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Count rate in the live-time mode of a nuclear detection system should ideally be directly proportional to the disintegration rate of the sample assayed. We examine the linearity of the relationship by measuring the deadtimes using two different detection systems. For the sodium iodide (NaI) crystal detector system, iodine-125 (^{125}I) was used with the two-source method and the results were confirmed by the decaying-source method in which indium-113m (^{113m}In) was employed. For the cadmium telluride (CdTe) semiconductor detector system, the decaying-source method and ^{113m}In were used. In both systems, we found that nonlinearity at a high count rate could be significant.

Well-type gamma counters for in vitro assay and detector probes for in vivo assay can have significant count loss due to the deadtime. The instruments usually allow for the choice of real-time or live-time counting mode. Live-time is the counting interval in which radiation interaction in the detector can be recorded. The live-time counting mode is designed to exclude the deadtime from the interval of counting and yields a count rate that is directly proportional to the rate of disintegration of the sample. In the calibration of our counting system, we examined the linearity of the relationship by measuring and comparing the deadtimes of the two modes. The apparent "dead-time" measured in the live-time mode can be interpreted as the premature on-time of the clock, which monitors the live-time interval, before the recovery from the detection of an x-ray or gamma photon.

MATERIALS AND METHODS

In this investigation, we employed the two-source method and the decaying-source method to measure deadtime. The two-source method has been previously described by others (*1–3*). The configuration consisted of placing two sources at 12 cm from the detector and symmetric to its axis. Three successive measurements were made: first with source 1, then with both source 1 and 2 together, and finally by removing source 1 and leaving the configuration of source 2 unchanged. Background counts were taken after completion of the three source countings. From these four measurements, the deadtime of a nonparalyzable system can be calculated by the following equation, from Knoll (*1*):

$$\frac{m_{12}}{1 - m_{12}\tau} + \frac{m_b}{1 - m_b\tau} = \frac{m_1}{1 - m_1\tau} + \frac{m_2}{1 - m_2\tau}, \qquad \text{Eq. 1}$$

where m_b is the measured background count rate, m_1, m_2, and m_{12} are the measured count rates from source 1, source 2, and both sources in combination, respectively.

We followed the prescription of Knoll (*1*) in the use of the decaying-source method. The true count rates after a set time period can be expressed as follows:

$$n = n_0 e^{(-\lambda t)} + n_b, \qquad \text{Eq. 2}$$

where n is the true count rate, n_0 is the initial count rate, n_b is the background count rate, and λ is the decay factor. True count rates can be determined from the measured counts by correcting for the deadtime of the system. The relationship between the true and measured source counts is:

$$n = \frac{m}{1 - m\tau}, \qquad \text{Eq. 3}$$

where n is the true count rate, m is the measured count rate, and τ is the deadtime. If the background (n_b) is negligible, a useful equation can be derived by substituting Eq. 3 into Eq. 2 and the final form is as follows:

$$me^{\lambda t} = -(n_0\tau)m + n_0. \qquad \text{Eq. 4}$$

This equation defines a straight line relating $me^{\lambda t}$ to m. A determination of slope ($-n_0\tau$) and intercept (n_0) would yield the value of deadtime (τ).

Lengthy measurements entailed in the two-source method require an isotope with a long half-life. Therefore, we used ^{125}I in two capsules as sources. Each capsule had an activity of 10 μCi (0.37 MBq). In the decaying-source method, the condition of the detector system and the background should be stable for the duration of the experiment. Such stability is more likely to be achieved if a short-lived radionuclide is used as the source. In our laboratory, ^{113m}In with a half-life of 99.5 min was available for this purpose. The ^{113m}In source was obtained by eluting a ^{113}Sn source in our laboratory.

Two types of detector systems were studied. The first system consisted of a 2M2 detector,* which has a photomultiplier tube and a 5 × 5 cm NaI crystal, a high-voltage power supply,†

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a preamplifier,‡ an amplifier,§ and a nuclear personal computer analyzer (PCA) interface card.¶ The detector has a removable flat-field collimator which is 5 cm in length with inside diameter of 2.5 cm.

The second system consisted of a RMD detector** which has a CdTe semiconductor with a 10-mm diameter and 2-mm thickness, a compact circuit box for the power supply, preamplifier, and amplifier, and the same PCA interface card described previously. The analyzer circuit is installed in a microcomputer to serve as a multichannel analyzer of 1,024 channels. It also has a Wilkinson-type of analog-to-digital converter at 100 MHz clock frequency.

RESULTS AND DISCUSSION

The result of the use of the two-source method to measure the deadtime of the NaI(Tl) detector system was found to be dependent on the distance between the sources. The value initially increases with distance and reaches a plateau. It is our conjecture that, at close distances, the low-energy radiation from ^{125}I scattered from the capsules into the detector. This systematic error decreases with increasing distance between the sources. Therefore, we assume that the plateau approximates the true deadtime. The deadtimes of the NaI(Tl) crystal detector system in the real-time and live-time modes are 22 μsec and 1.5 μsec, respectively. To confirm the validity of the two-source method and the usage of a low-energy isotope, the decaying-source method with short-lived ^{113m}In was used to measure the deadtime in the live-time mode. Figure 1 illustrates an application of Eq. 4 to the results. The deadtime was determined to be 1.3 μsec, which is in agreement with the two-source method.

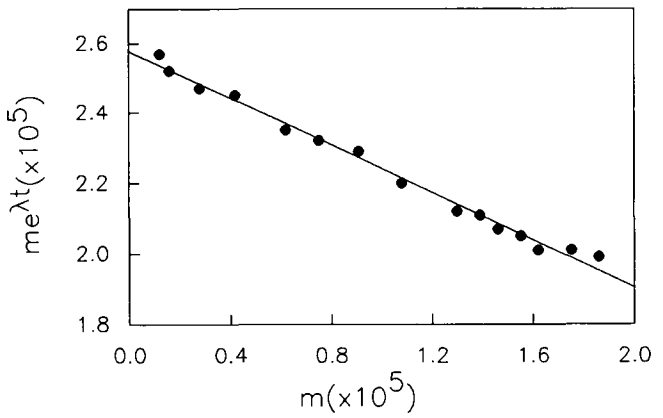

FIG. 1. The relationship of measured count rate m and $me^{\lambda t}$ for a decaying source (^{113m}In) and a NaI detector in the live-time mode. A straight line with the best fit is shown. Units on both axes are counts per second.

The deadtimes of the CdTe detector system in the real-time mode and live-time mode were found to be 2.8 μsec and 0.7 μsec, respectively, with the decaying-source method. These results are consistent with the expectation that a solid-state detector can accommodate a higher counting rate than a sodium iodide crystal.

CONCLUSIONS

In summary, we have shown that in our detector systems, deadtime of the instrument is substantially removed from the determination of count rate when live-time mode is used. For our NaI(Tl) detector, 1.5 μsec is not removed from the live-time clock. This can lead to as much as a 3% loss at the counting rate of 20,000 cps. Therefore, we caution readers that the selection of live-time mode operation for assay may not necessarily remove nonlinearity in the relation of measured count rate to the activity in the sample.

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NOTES

* Bicron 2M2 detector, Bicron, Inc., Newbury, OH.
† ORTEC 556 H high-voltage power supply, ORTEC EG & G, Inc., Oak Ridge, TN.
‡ ORTEC 113 preamplifier, ORTEC EG & G, Inc., Oak Ridge, TN.
§ ORTEC 575 amplifier, ORTEC EG & G, Inc., Oak Ridge, TN.
¶ Nuclear Personal Computer Analyzer interface card, Nucleus, Inc., Oak Ridge, TN.
** RMD detector, Radiation Monitor Devices, Inc., Watertown, MA.

REFERENCES

1. Knoll GF. *Radiation detection and measurements.* New York: Wiley and Sons; 1979:95.
2. Sorenson JA, Phelps ME. *Physics in nuclear medicine,* 2nd ed. Orlando, FL: Grune & Stratton; 1987:256.
3. Evans RD. *The atomic nucleus.* New York: McGraw-Hill, 1982:785.