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《Original》

A Method for Determining Dead Times of a G.M. Detector as a Function of the Count Rate

Seung Gy Ro

Health Physics Division, Atomic Energy Research Institute

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Abstract

A method for determining dead times of a G. M. detector as a function of the count rate has been investigated using the Mn^{56} radioactive sample.

The formula, $\mathscr{T}(N_1)=\frac{N_t-N_1e^{-\lambda t}}{N_1N_t}$, seems to be useful for determining a relation between the dead time and the count rate. Here $\mathscr{T}(N_1)$ is the dead time for the count rate N_1, N_1 is the count rate at time zero, N_t is the count rate at time t, λ is the radioactive decay constant of the sample used, and t is the time between the first and second runs. When all the counting data were corrected for the dead times evaluated with this formula and then a variation of these corrected counting data with time was observed, the results showed quite a good agreement with the published data for the radioactive decay of Mn^{56}.

Besides, it appears that the dead time decreases as the count rate increases in a dead time-to-count rate relation obtained by the same formula.

요 약

Mn^{56} 방사성 물질을 이용하여 방사능 측정계수율에 따라 변화되는 한 가이가 검출기의 불감시간을 결정하는 방법을 탐구하였다.

식 $\mathscr{T}(N_1)=\frac{N_t-N_1e^{-\lambda t}}{N_1N_t}$는 이 검출기의 불감시간과 방사능 측정계수율과의 한 관계를 결정할 수 있는 유용한 공식으로 생각되었다. 여기에서 $\mathscr{T}(N_1)$는 방사능측정계수율 N_1에 대한 불감시간이며 N_1은 첫 측정시각(이 시각을 0시로 잡는다)에서 방사능측정계수율이고 N_t는 첫 측정시각으로 부터 t라는 시간후에 얻어진 계수율이며 λ는 방사능붕괴상수이고 t는 두 측정시각의 시간차를 의미한다. 이 공식에 의하여 얻어진 불감시간에 따라 모든 방사능 측정자료를 교정하고 시간에 따른 그 계수율의 변화를 관찰한 결과 이미 보고된 Mn^{56}의 방사능 붕괴형식을 잘 따르고 있음을 보여주었다.

한편 이 공식을 이용한 결과를 보면 방사능 계수율 대 불감시간과의 관계로 부터 얻은 불감시간은 방사능 측정계수율이 증가함에 따라 감소현상을 나타냈다.

1. Introduction

In determining precisely high counting rates, one has to make a correction for the counting loss that is not measured by the detector system within dead time. An accurate correction can be made if the dead time is known well. There are serveral methods of determining the dead time. In many articles reported,[1~5] the dead time was determined on the assumption that it is independent of the count rate. It is doubtful, however, that the dead time obtained on this assumption can be used for a correction for all the counting data regardless of the count rate.

Brinkman[4] found that the dead time of a G.M. detector varies depending on the count rate. However, there remains an unclear point in his article: he determined the dead time by directly using the customarily adopted formulae. Actually these formulae can be used in the case only that the dead time does not depend upon the count rate.

Therefore, if the dead time varies as a function of the count rate, the representative formula for a dead time correction of G.M. detectors may have to be modified to account for this fact as follows:

$$N_0=\frac{N}{1-\mathscr{T}N(N)} \quad \cdots\cdots(1)$$

where N_0 and N are the true and measured count rates, respectively, and $\mathscr{T}(N)$ is the dead time as a function of the measured count rate N. The dead time $\mathscr{T}(N)$ in this formula cannot be simply determined by the commonly used methods, e.g., the two samples method, the method of a series of calibrated samples, etc.

In this article, a method of determining $\mathscr{T}(N)$ of a G.M. detector (Tracerlab, type TGC-2, serial No. 48310) as a function of N is thus suggested using Mn^{56}. According to the results obtained by this method, all the counting data were corrected and a variation of these corrected count rates as a function of time was observed to be compared with the value reported[6] for the decay of Mn^{56}.

2. Method

If the activities of a radioactive sample were measured at a certain time interval, a relation between these two measurements would be given by

$$\frac{N_1}{1-N_1\mathscr{T}(N_1)}e^{-\lambda t}=\frac{N_t}{1-N_t\mathscr{T}(N_t)} \quad \cdots\cdots(2)$$

Here N_1 is the count rate at time zero, N_t is the count rate at time t, $\mathscr{T}(N_1)$ and $\mathscr{T}(N_t)$ are dead times for the count rates N_1 and N_t, respectively, λ is the radioactive decay constant of the sample used, and t is the time between the first and second runs. This formula implies that the dead time depends on the count rate. It is also understood that the dead time cannot be easily determined in this formula. To solve this equation, an assumption is thus made: low count rate may be little influenced due to the dead time. The validity of this assumption is supported by the fact that a variation of low count rate with time follows exactly the decay rule of a radicactive sample in question of interest even if any dead time correction is not made.

Therefrom, N_t was taken to be a count rate from the points (cf. Fig. 1) for which the dead time correction is negligible, and Eq. (2) is simplified by the form

$$\frac{N_1}{1-N_1\mathscr{T}(N_1)}e^{-\lambda t}=N_t \quad \cdots\cdots(3)$$

The dead time $\mathscr{T}(N_1)$ as a function of N_1 can be derived from equation (3)

$$\mathscr{T}(N_1)=\frac{N_t-N_1e^{-\lambda t}}{N_1N_t} \quad \cdots\cdots(4)$$

By this formula [Eq. (4)] the dead time as a function of the count rate is obtained.

3. Choice of Sample

It is of importance to choose an appropriate radiation source and its activity as far as the

working time required is concerned. For this study, the following should be taken into consideration:

a) short-lived radioactive material whose half-life is well known must be chosen;

b) the irradiated sample should emit only the radiation of interest, i.e., when the sample is produced in a reactor no disturbing radioactive materials except the favorable radiation source are produced;

c) the activated sample should have a simple decay scheme;

d) relatively high activity is necessary. Although it depends on many factors, the total activity of the order of 0.5-1μCi is needed at the time zero. These activities are, in part, related to the working time as will be discussed later.

There are many radiation sources which are available for this purpose. Among them, Mn^{56} with a half-life of 2.58 hrs is one of the most promising radiation sources. This can be easily produced by irradiating Mn^{55} with thermal neutrons in such facilities as reactors. Since the natural isotopic abundance of manganese-55 is 100%, there is no problem of contamination due to foreign radioactive materials when this manganese sample is bombarded with neutrons. If the sample is irradiated in the neutron field where there exist fast neutrons, some competing reactions such as the (n, n'), (n, 2n) and (n, α) reactions[7] on Mn^{55} with fast neutrons can occur, and subsequently the resultant radioactive materials may interfere with the precise measurements of the Mn^{56} activity. In fact, these competing reactions present no problem because the cross section for the Mn^{55} (n, γ) Mn^{56} reaction with thermal neutrons is appreciably high compared to that for the competing reactions on Mn^{55} with fast neutrons. On these accounts, Mn^{56} was chosen for this study.

4. Experimental

4.1. Sample Irradiation

A small amount of pure manganese powder were irradiated for 5 min in the pneumatic transfer tube of the Korean TRIGA Mark-II reactor, of which thermal and fast neutron fluxes are known as 3×10^{12} n's/cm^2-sec and 5×10^{12} n's/cm^2-sec, respectively.[8]
In the pneumatic tube, Mn^{56} with a half-life of 2.58 hrs is mainly produced through the (n,γ) reaction on Mn^{55} with thermal neutrons. Of course, undesirable radioactive materials can be produced through the (n, n'), (n, 2n) and (n, α) reactions on Mn^{55} with fast neutrons. Accordingly these can give rise to spurious variation of the Mn^{56} activity as a function of time, leading to an error in determining the dead time. However, the contribution due to these undesirable activities may be negligible compared with the Mn^{56} activities because the activation cross section for the Mn^{55} (n, γ) Mn^{56} reaction is several hundred times as large as that for the competing reactions as discussed before. By observing gamma-ray spectra from the irradiated sample with the help of a 100 channel pulse height analyzer (Technical Measurement Corp., Gammascope II, Model 102), no contamination was found.

4.2. Measurement of the Sample Activity

With giving a cooling time of about 2 hrs after irradiation in order to minimize the possible influence of the short-lived foreign radioactivities, the activity of the irradiated sample was measured by means of a shielded G.M. detector (Tracerlab, TGC-2, Serial No. 48310) associated with an electronic decade scaler (Nuclear Chicago, Model 186).

It is not necessary to determine the absolute disintegration rate of the sample, except for some quantity proportional to the disintegra-

tion rate. The sample was thus placed with fixed solid angle at an appropriate distance from the G.M. detector, and the measurements of its activity were carried out at a 30 min interval during 4.5 half-lives of Mn^{56}. The average count rate (in cpm) was taken from counting the sample for two minutes in each run. During the run, the counting system has been found quite stable.

5. Results and Discussions

A variation of the measured count rate N_1 as a function of time was plotted on a semi-log paper and is shown in Fig. 1. Together with the experimental values, the extrapolated line drawn from the points for which the dead time corrections are negligible is indicated in the figure as well.

Table I

N_1 (cpm)	N_t (cpm)	τ (μs) calculated by Eq. (4)
33,520±130	1,952±27	400±18
21,577±104	1,952±27	457±23
16,799± 92	1,952±27	528±30
10,273± 72	1,952±27	580±32
4,979± 50	1,952±27	680±47

The activities of the sample were measured during 4.5 half-lives of Mn^{56}, being 33,520± 130 cpm at the first run and 1,952± 27 cpm at the last run. With fixing N_t by the value of the last run, dead times of a G.M. detector (Tracerlab, TGC-2) for the various values of N_1 were calculated from Eq. (4) and in Table I are presented some of these results. The errors in the count rates as shown in Table I and Fig. 2 are standard deviations and were obtained by compounding quadratically the following sources of errors; the statistical counting errors of the sample and an uncertainty in the background counting. The standard deviations in the dead times consist of the systematical

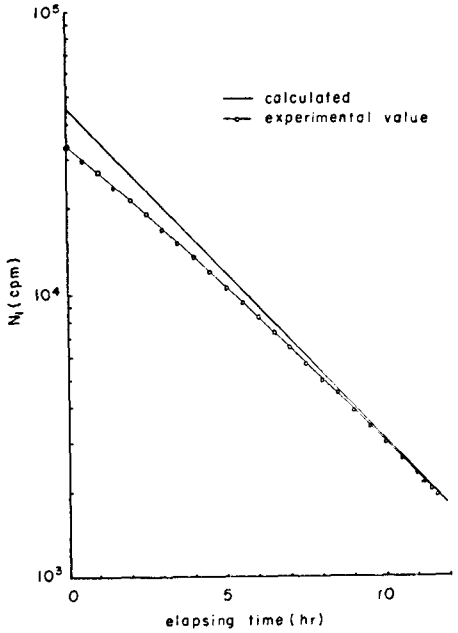

Fig. 1. N_1 as a function of time in the decay of Mn-56

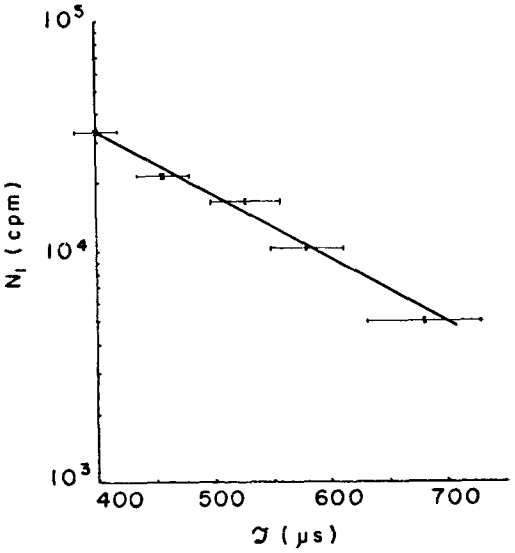

Fig. 2. Dead time as a function of the measured count rate

error from Eq. (4), a 0.1% round-up error in calculation and a 0.5% uncertainty in the decay constant of Mn^{56} given in the literature.[6]

Also a relationship between the dead time and the count rate is graphically shown in Fig. 2. As shown in Table I and in Fig. 2, the dead time is not independent of the count rate, and

decreases as the count rate increases. The reason for this is not clearly known yet, and hence a further theoretical investigation is extremely preferred.

For the convenience' sake, a mathematical expression for a dead time-to-count rate relation was derived from an analytical fitting of the experimental data. This expression obtained by a least-squares method is given by

$$\mathscr{T}(N) = 1,973 - 347.2 \log N \quad \cdots\cdots (5)$$

where $\mathscr{T}(N)$ is dead time in μs and N is the measured count rate in cpm.

In order to test the validity of this relationship [Eq. (5)], another manganese-56 sample (53,053± 163 cpm at time zero) which was different from that used before was prepared, and the activities of this sample were counted as a function of time. All the measured counting data were corrected for the dead time calculated from Eq. (5). The half-life of Mn^{56} was determined by a least-squares fitting of these corrected data and it turned out to be 2.58± 0.05 hrs. In this value, the standard deviation is comprised of the errors from the counting statistics, the background counting and the dead time determination. This value of the half-life is in good agreement with the published data.[6]

In general, a relatively long time run of counting is required for obtaining a dead time-to-count rate relation. If a very short-lived sample, is used, the time required may be shortened but this is not very recommendable because there is a difficult problem in the counting technique. Therefore, it is desirable to choose a radioactive sample as short as possible but such a difficult counting technique is not encountered. In view of this, Mn^{56} may be the most promising one for this purpose because no special counting technique is needed.

In addition, the activity of sample chosen is an important factor for determining a dead time-to-count rate relation during a short period. In the case of Mn^{56}, at least 12 hr run may be required if the measured count rate at time zero is about 33,000 cpm. Although it depends on many factors, this count rate can be obtained from measuring 0.3 μCi by means of a counter with an overall counting efficiency of 5%. From this, it may be stated that an optimum activity for this purpose is about 0.5–1 μCi.

6. Conclusions

The dead time determined by the commonly adopted methods as already mentioned may not be used for correcting all the counting data regardless of the count rate. If the dead time is dependent on the count rate as experimentally proved by Brinkman and also in this work, the well-known formula for a dead time correction may have to be modified as Eq. (1). The formula [Eq. (4)] proposed here may be a useful one for determining a relation between the dead time and the count rate.

Since the reason that the dead time increases with decreasing count rate is not clear yet, a further theoretical investigation is very desirable.

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