A PORTABLE ABSORBED DOSE MEASURING INSTRUMENT WITH GAMMA DISCRIMINATION

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INTRODUCTION

Dose absorbed in tissue may be measured by several types of detectors, e.g., tissue-equivalent ion chambers, Hurst proportional counters, and Rossi-type proportional counters. The latter device, designed and developed by H. H. Rossi[1], enables the experimenter to measure the spectrum of absorbed dose in LET and, with suitable electronics, the dose absorbed in tissue. These two characteristics imply that some means of discrimination of dose delivered in various LET intervals exists in this type of detector and that this capability can be applied to a relatively simple dose measuring instrument. This paper describes a suitable detector and some of the electronics necessary for its operation as a dose measuring instrument.

THE DETECTOR

The detector, shown in Fig. 1, is a sphere of tissue-equivalent plastic[2], with a single wire electrode located on a diameter of the sphere. The inside diameter of the detector described here is 2.2 inches. The sphere, together with appropriate connectors and fittings, is fastened on an aluminum base plate. A vacuum-tight aluminum cover completes the assembly. In use, the detector volume is filled to a low pressure (2 to 20 cm Hg, typically) with a tissue-equivalent proportional counting gas. The low-pressure gas in the spherical volume thus simulates a tissue cavity having linear dimensions of 1 to 10 microns. For the present design, operation at 1700 volts between the shell and the central wire is used. With this voltage gradient, ions formed in the volume are collected with a multiplication of 3 to 4 thousand.

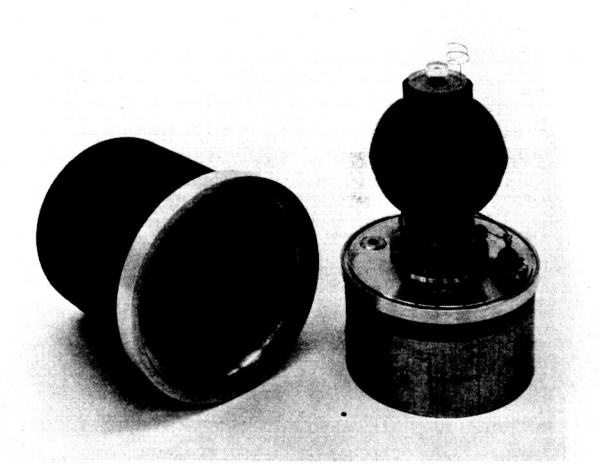

Fig. 1. Spherical Tissue Equivalent Proportional Counter

A spherical cavity with an axially arranged central wire does not collect with equal efficiency from all parts of the cavity. A solution to this problem has been pointed out by P. W. Benjamin[3]. He recommends specially shaped insulator and conductor penetrations. These recommendations have been employed in this detector; however, plastic is used for insulators and the gradient determining structures, and three-terminal construction is employed at each penetration.

The assembled detector is contained in a right circular cylinder 3.5 inches in diameter and 4.25 inches high and weighs 560 grams. Spheres with internal diameters as small as 0.5 inch or as large as 5.0 inches can be readily constructed.

The detector is a direct coupled device, i.e., it has no series coupling capacitor in its signal lead. It may thus be used as a current source with an electrometer readout, or as a pulse producing device with an a-d converter or pulse-height analyzer readout. If used as a current source, the detector produces 1×10^{-14} A per μrad/hr. This can be restated as 3.6×10^{-5} A per rad/sec or 1×10^{-8} A per rad/hr. The leakage current in the absence of high voltage is of the order of 1-2 $\times 10^{-15}$ A. The three-terminal construction prevents high-voltage leakage from appearing on the signal lead.

An internal source is usually used with detectors of this type. We have employed ^{241}Am as an alpha source for pulse-height analyzer calibration. Using this technique, the alpha peak may be adjusted to a known channel number on the pulse-height analyzer, thus providing a known keV/micron calibration per channel. This determines the overall system gain. A similar technique (with a stronger alpha source or a ^{55}Fe source) can be used to generate a known current to enable an electrometer to be calibrated.

Since the detector is a tissue-equivalent system, it responds to gamma rays, neutrons, π mesons, etc., just as tissue does. In other words, it can be calibrated to yield ergs per gram tissue or rads-tissue. If an a-d converter or pulse-height analyzer is used as a read-out, and if system gain is set with the internal alpha source, no calibration is required and rads-tissue may be determined directly.

DETECTOR USED AS A CURRENT SOURCE

A useful instrument can be constructed using the detector as a current source. With the parameters outlined before, 1700 volts and 20 cm Hg fill pressure, the detector has a sensitivity comparable to an 80-liter ion chamber, and background of 20 μrad/hr is $\sim 2 \times 10^{-13}$ A.

Figure 2 shows a block diagram of a workable system. The electrometer is an all solid-state varactor bridge device. Its input noise current is $\sim 1 \times 10^{-14}$ A. The high-voltage supply is an oscillator voltage doubler circuit. It has a special regulator so that the high voltage can be varied to adjust the system gain and still maintain good stability.

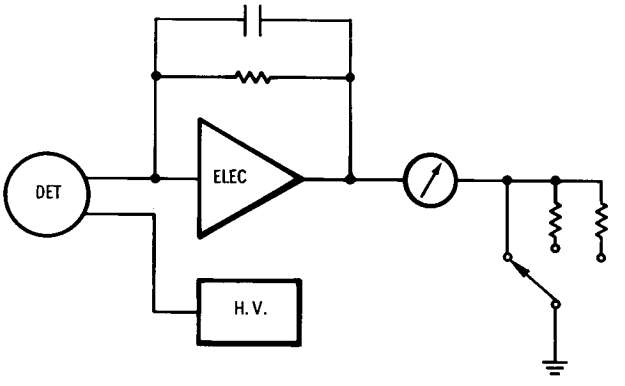

Fig. 2. Direct Coupled Absorbed Dose Measuring Instrument

Figure 3 is a photograph of a portable system following the block diagram of Fig. 2. This particular unit employs ± 18 volts for the electrometer operational amplifier and + 9 volts for the high-voltage supply. The electrometer operates well down to ± 7 volts and the high-voltage supply down to + 7 volts. Presently, simple transistor radio batteries are used with a lifetime of ~ 100 hours.

This system has full-scale ranges of 60, 600 and 6000 μrad/hr. A less sensitive instrument would require current division at the input or a lower overall detector multiplication, both of which are realizable.

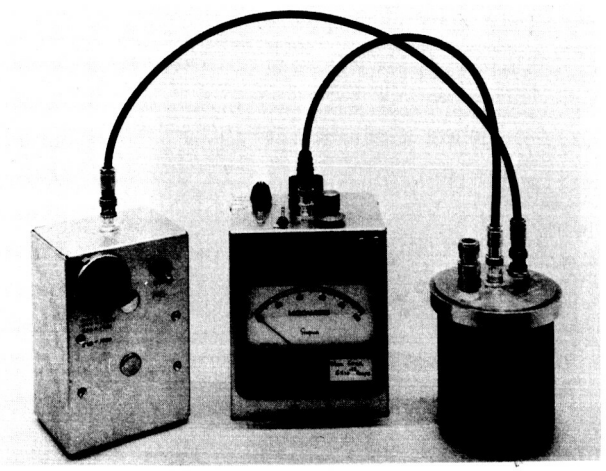

Fig. 3. Portable Battery Operated Absorbed Dose Measuring Instrument

In use, the system gain is set by turning on the internal source and adjusting the high voltage until the calibration reading is reached. The calibration may be verified by exposure to a known gamma or neutron source, or the detector output may be connected to an a-d converter or pulse-height analyzer and an independent calibration performed.

DETECTOR USED AS A PULSE SOURCE

This same detector may also be used as a regular proportional counter and thus as a source of pulses. These pulses may then be amplified in the usual manner with an FET input preamplifier, followed by a linear amplifier. Circuitry suitable for absorbed dose measurements is shown in Fig. 4. Spectroscopy uses would take the linear amplifier output and feed it into an a-d converter or a pulse-height analyzer.

Figure 4 shows a discriminator that enables a lower level to be placed on the signals fed to the meter circuit. Since pulse linearity must be preserved if an accurate dose measurement is to be obtained, the discriminator is used to control a linear gate at the amplifier output. The pulses that pass the linear gate are summed in the charge-sensitive rate-meter circuit. The rate-meter output is then proportional to the absorbed dose (rads-tissue) per unit time deposited in the detector. Such circuitry has been suggested by J. W. Baum,[4,5] and improves upon the simple rad responding instrument by addition of nonlinear electronics to produce a REM response.

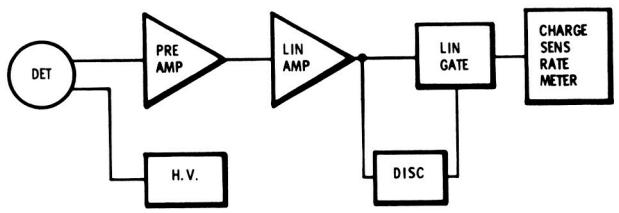

Fig. 4. Absorbed Dose Measuring Instrument With Discriminator

PULSE DETECTOR NEUTRON AND GAMMA RESPONSE

If the linear amplifier output is connected to a pulse-height analyzer, an X-Y plot such as shown in Fig. 5 is produced. The data in Fig. 5 were obtained by exposing the detector to a ^{252}Cf neutron source of ~ 0.8 micrograms at 5 cm for 40 minutes. The detector diameter was adjusted to 1 micron. The internal ^{241}Am alpha source was used to measure the system gain which was adjusted to 400 keV/micron full scale on the X axis. The usual proton "edge" may be clearly seen at ~ 90 keV/ micron. Figure 6 shows a ^{60}Co spectrum with a full-scale value of 40 keV/micron, i.e., a factor of 10 increase in gain over Fig. 5. The gamma contributions are seen to extend only to ~ 3 keV/micron. Obviously, if a linear gate were set to pass only pulses above ~ 3 keV/micron, only neutron induced events would be measured. Some percentage of the dose would be lost, of course, due to neutron induced events below the bias level.

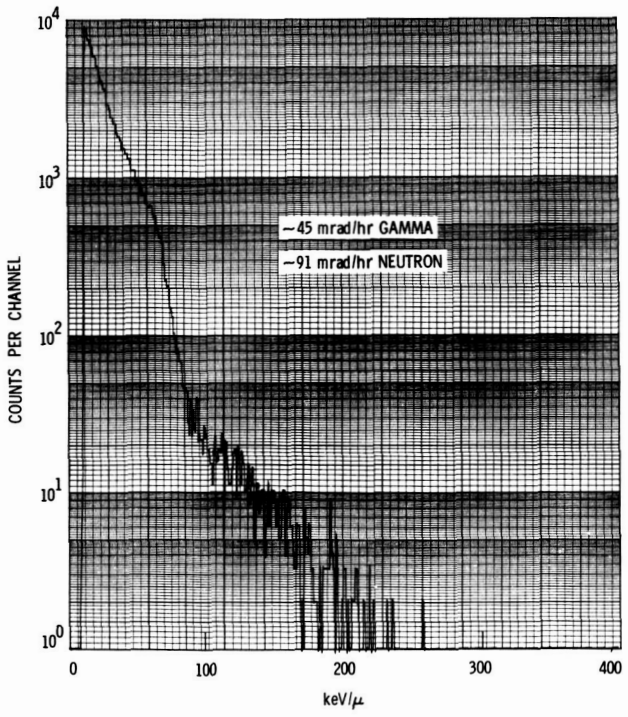

Fig. 5. ^{252}Cf Spectrum

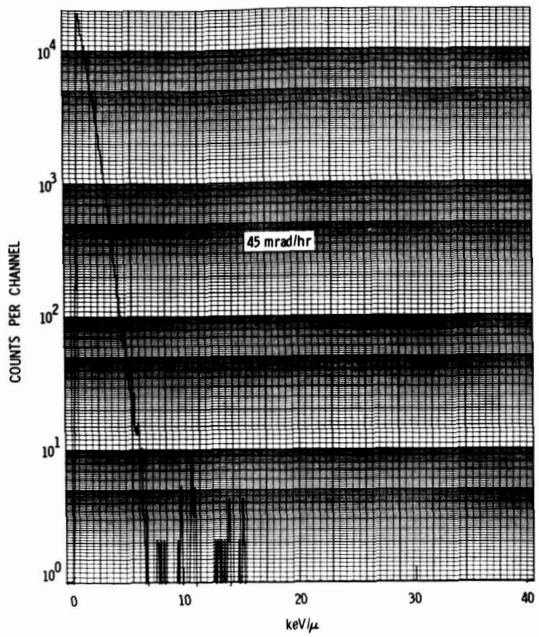

Fig. 6. ^{60}Co Spectrum

This is discussed below. System noise is shown in Fig. 7. The gain has been increased a factor of 100 over Fig. 6 and thus full scale is 0.4 keV/micron. The electronic noise is seen to become noticeable at about 0.05 keV/micron. The remainder of the "noise" is due to background activity in the detector and the room. The noise is clearly very small in comparison to the neutron dose rate and small even if ^{60}Co gammas alone are considered.

If one measures the rads-tissue per hour from ^{60}Co as registered by a circuit such as that shown in Fig. 4 versus discriminator setting, the results shown in Table 1 are obtained. It is clear that 98% of the absorbed dose is delivered at LET values of 3 keV/micron or less. Table 2 presents similar data for ^{252}Cf. Here only 50% of the absorbed dose is from events having LET values below 3 keV/micron. If a particular bias level is selected, such as 3 keV/micron, the meter reading will correspond to neutron induced events only. For the conditions of this experiment, the <u>total</u> absorbed dose rate was 133 m rad-tissue per hour

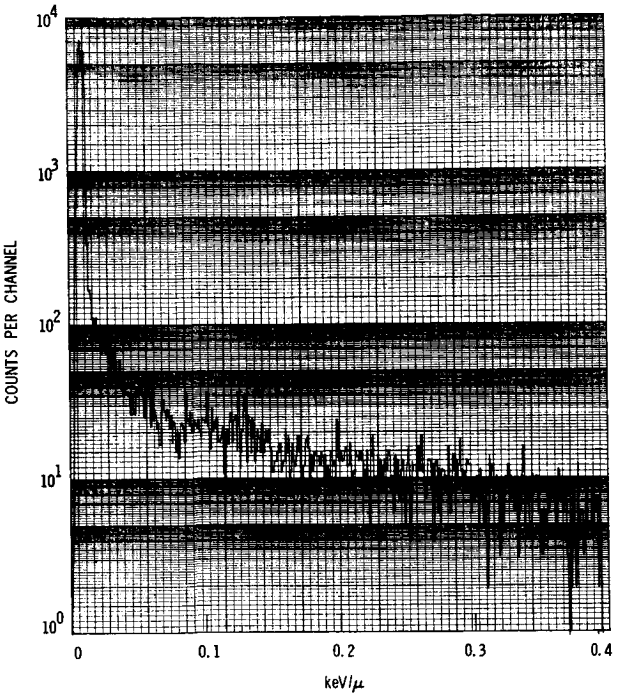

Fig. 7. Noise Spectrum

which corresponds[6] to 45 m rad-tissue per hour from gammas and 88 m rad-tissue per hour from neutrons. Thus 64 m rad-tissue per hour were measured (see Table 2) at 3 keV/micron bias level and represents about 73% of the neutron caused absorbed dose. While these data are restricted to similar source-detector configurations, a bias curve may be run for other radiation environments, the total dose measured with the direct coupled detector, and a similar analysis performed.

In conclusion, it can be seen that a simple rad-tissue responding absorbed dose-rate measuring instrument can be constructed. It uses a single wire spherical tissue-equivalent proportional counter as a current source detector. Readout is accomplished with a solid-state electrometer circuit. A further elaboration may be introduced that allows discrimination levels to be set at various levels of LET. This will provide the ability to selectively measure neutron and gamma plus neutron events. In all cases the detector size may be adjusted to be between 1 and 10 microns.

TABLE 1. CUMULATIVE FRACTIONAL ABSORBED DOSE RATE VERSUS keV/μ BIAS FOR ^{60}Co GAMMA RAYS

L, keV/μ	Absorbed Dose Rate (keV/μ ≥ L) Rad/hr	Cumulative Fractional Absorbed Dose
.322	3.83 (-3)	0.47
.483	3.46 (-3)	0.52
.638	1.75 (-3)	0.76
.685	1.75 (-3)	0.75
1.087	1.10 (-3)	0.85
1.356	0.88 (-3)	0.88
1.49	0.857 (-3)	0.88
1.89	0.579 (-3)	0.92
2.15	0.400 (-3)	0.94
2.95	0.128 (-3)	0.98
3.75	0.021 (-3)	0.99
4.55	0.018 (-3)	0.99

TABLE 2. CUMULATIVE FRACTIONAL ABSORBED DOSE RATE VERSUS keV/μ BIAS FOR ^{252}Cf

L, keV/μ	Absorbed Dose Rate (keV/μ ≥ L) Rad/hr	Cumulative Fractional Absorbed Dose
0.322	102.0 (-3)	0.23
0.483	86.2 (-3)	0.35
0.638	82.0 (-3)	0.38
0.685	78.6 (-3)	0.41
0.957	76.7 (-3)	0.42
1.36	72.9 (-3)	0.45
2.15	66.9 (-3)	0.50
3.75	62.0 (-3)	0.53
8.54	53.3 (-3)	0.60
9.53	48.8 (-3)	0.63
13.5	39.9 (-3)	0.70
16.51	34.9 (-3)	0.74
21.4	28.7 (-3)	0.78
37.3	13.5 (-3)	0.90
85.0	1.36 (-3)	0.99
164.4	0.22 (-3)	0.99