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POCKET NEUTRON REM METER*

W. Quam, T. Del Duca, W. Plake,
G. Graves, T. DeVore, and J. Warren
EG&G, Santa Barbara Operations
130 Robin Hill Road
Goleta, California 93116

Summary

This paper describes a pocket-calculator-sized, neutron-sensitive, REM-responding personnel dosimeter that uses three tissue-equivalent cylindrical proportional counters as neutron-sensitive detectors. These are conventionally called Linear Energy Transfer (LET) counters. Miniaturized hybrid circuits are used for the linear pulse handling electronics, followed by a 256-channel ADC. A CMOS microprocessor is used to calculate REM exposure from the basic rads-tissue data supplied by the LET counters and also to provide timing and display functions.

The instrument is used to continuously accumulate time in hours since reset, total counts accumulated, rads-tissue, and REM. The user can display any one of these items or a channel number (an aid in calibration) at any time. Such data are provided with a precision of ±3% for a total exposure of 1 mREM over eight hours.

Introduction

Portable instruments used for personnel neutron dosimetry have historically beam large, heavy, and cumbersome, with virtually all their weight invested in polyethylene moderators that enable the fluence measuring detector, usually a BF_3 tube or a LiI crystal, to respond to incident neutrons in a manner similar to tissue. However, where neutron spectra are quite different from those for which the instrument was optimized, serious errors may result, because the polyethylene thickness must lie within certain ranges for each spectrum if the detector is to have a tissue-like response.

The instrument described here operates on a different principle: its tissue-equivalent (TE) detectors produce pulses proportional to the energy deposited in TE plastic. This energy deposition is directly related to rads-tissue. Both gamma- and neutron-caused events deposit energy. A lower level discriminator set near the maximum dE/dX that an electron from a gamma-ray event can have is used to minimize gamma response. This eliminates some of the neutron-caused events but in practice works well for portable instruments. Another compromise in design is the assumption that the detector output can be used to calculate average dE/dX of all particles traversing its sensitive volume. Spherical detectors yield simple algorithms[1] but are awkward to package. Complex algorithms[2-7] exist for cylindrical detectors, but it is not clear they are necessary for integral measurements in contrast to LET spectral work. In this instrument we have chosen the simplest of algorithms, and tests conducted so far have shown adequate accuracy has been obtained.

General Description

The instrument described here is a pocket-calculator-sized, neutron-sensitive, REM-responding personnel dosimeter (REM meter) which uses three TE cylindrical proportional counters as the neutron-sensitive detectors. These are conventionally called LET counters (LET is Linear Energy Transfer or approximately dE/dX). Miniaturized hybrid circuits are used for the linear pulse handling electronics followed by a 256-channel ADC. A Motorola 6805E2 CMOS microprocessor is used to calculate REM exposure from the basic rads-tissue data supplied by the LET counters, and it also provides timing and display functions.

The REM meter continuously accumulates time in hours since reset, total counts accumulated, rads-tissue, and REM. At any time the user can select and display on the LCD any of these items plus a channel number (an aid in calibration). The instrument provides these data with a precision of ±3% for a total exposure of 1 mREM over eight hours.

Figure 1 shows the top and front views of a REM meter constructed for field testing. It is powered by a 9-volt transistor radio battery, and employs energy-

Figure 1. Pocket REM meter prototype

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efficient circuitry. Three cylindrical LET counters used as detectors are positioned along its axis. Each counter is a stainless steel cylinder with a TE plastic liner and is filled with TE gas. The counters are ~3/4-inch in diameter and ~5-inches long.

The top-mounted controls operate the instrument in any of its display modes. The front panel readout is a dual LCD which indicates the reading in an engineering type display; namely, mantissa and a signed exponent. A rotary switch on the top allows hours, counts, rads or REM to be displayed on this readout. The decimal and signed exponent change appropriately. The display has a low battery indicator. Turning the instrument off results in loss of all data in memory. Upon turn-on the instrument waits a fixed time for HV stability and then starts accumulating from zero in all memory locations. The display is updated every two seconds.

Processing the Data

This instrument uses a simplified algorithm to calculate the Dose Equivalent in REM from the dose in rads-tissue. Both these quantities are calculated on a per pulse basis to minimize RAM storage. The dose in rads in the jth quality factor interval (see below) is obtained from:

$$(\text{rads})_j = k \sum_{i=n_j}^{m_j} n_{e,i}\, \Delta e \;\, e_i \qquad (1)$$

where k is a constant, n_j and m_j are boundaries of the jth interval (in keV/μ), and $n_{e,i}\ \Delta e$ is the number of counts within the Δe interval at e_i keV/μ. Δe, the conventional channel width is usually set to 1 keV/μ. The Dose Equivalent is similarly calculated on a per pulse basis as:

$$\text{REM} \simeq \sum_{j=1}^{4} (\text{rads})_j\ Q_j(e) \qquad (2)$$

where the $Q_j(e)$ are Quality Factors in the jth interval, as given in the table below.

	Boundaries, $e_{n,m}$,	
Interval, j	keV/μ	Qj(e)
1	4-6.9	2
2	7-22.9	5
3	23-52.9	10
4	>53	20

Electronics

Detectors

The detectors used in this device are cylindrical proportional counters. The outer housing is thin-wall (0.016 inch) stainless steel tubing, with a 0.050-inch-thick TE plastic liner whose inside diameter is 0.5 inch. The counting gas is methane-based TE gas at 2.5 cm Hg. The low gas pressure simulates a cavity approximately 1 micron in diameter in unit density tissue. The active length of the detector is 4.2 inches and is defined by field-shaping electrodes at either end.

Proper operation of the overall instrument depends critically on the detector's gain stability. We have optimized this by carefully processing the TE plastic to yield a very low outgassing product. Tests over the past three years with identical plastic in similar detectors have shown gain changes of <20%, with only 5% of that occurring in the last 33 months. All vacuum seals on the detector are either brazed or TIG welded. The evacuation and filling tube is pinched off after initial tests have been completed.

Detector gain is also dependent upon stability of the high voltage supply. Care has been taken to provide adequate regulation with respect to supply voltage and temperature while maintaining low current drain. The oscillator-type supply used contributes some noise to the system, but it is small compared to the LLD setting.

Analog Circuits

In the analog portion of the instrument, shown in Figure 2, the preamplifier serves as a charge-to-voltage converter. The post-amplifier shaping circuit and base line restorer are simplified versions of the usual NIM electronics. The LLD uses a regulated reference voltage.

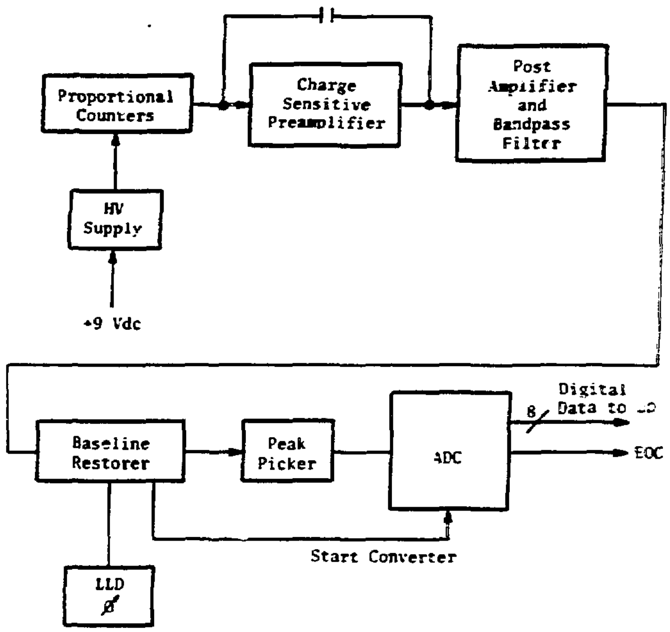

Figure 2. Analog circuitry

A National 0804 8-bit ADC is used. This is a low-power chip (7 mW) that requires ~200 microseconds for conversion, is a successive approximation type circuit, and contains its own internal comparator and clock oscillator.

Digital Circuits

The digital portion of the circuit (Figure 3) uses a Motorola 6805E2 microprocessor. As shown on the block

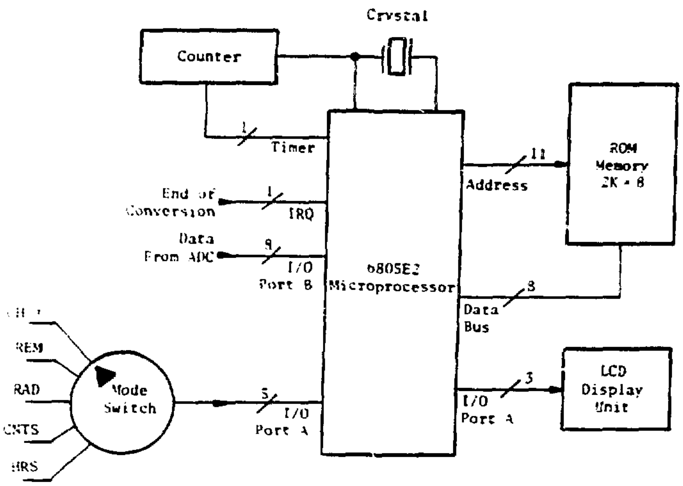

Figure 3. Digital circuitry

diagram, a 5-position rotary switch allows various data to be displayed on the LCD. The first position is elapsed time in hours after initial turn-on. An internal crystal time base is divided appropriately and stored in memory. Position number 2 displays accumulated counts, with four digits provided plus exponent. Position 3 displays the sum of counts per channel times channel number scaled to yield rads-tissue. Position 4 displays the REM data, obtained as shown earlier, with four digits provided plus an exponent for both rads-tissue and REM. Switch position 5 allows display of ADC channel number, which is used as part of the calibration procedure and allows precise setting of the ADC zero, amplifier gain, and lower level discriminator (LLD).

The LCD has four decimal digits plus a switched decimal point in the mantissa. The signed exponent has one digit.

The software for instrument operation is contained in a 2K byte EPROM.

Sensitivity and Spectral Response

Considerable experimental work indicates REM meter sensitivity is $\sim 5.7 \times 10^5$ counts per REM or 576 counts/hr per mREM/hr (neutron) from a bare ^{252}Cf source. System noise is 3.2 counts per hour (15.1 micro REM/hr) in a source-free environment at sea level. Thus the S+N/N ratio is $\sim$180 in a nominal 1 mREM/hr neutron field. The average Q.F. for the background is 12 to 15 and indicates that residual alpha contamination is the major contributor to the background. In addition, chi-square tests of individual meter background counts versus time show that they occur randomly.

Calibrations have been performed at the LLNL Low Scatter Neutron Facility,[8-10] and the results are given in Table 1.

The REM response is within ±11% if the bare ^{252}Cf data are allowed to over-respond to equal the 25 cm D_2O shielded under-response. This accuracy is adequate for most measurement needs and implies that more sophisticated unfolding algorithms may not be necessary.

This instrument combines advanced circuitry and tissue equivalent detectors yielding accurate REM measurements from a wide range of neutron spectra. These

Table 1. Calibration data from Low Scatter Neutron Facility

Source and Shield	Pocket REM Meter Response
^{252}Cf bare	1.00 (normalization point)
10 cm CH_2	0.87
15 cm D_2O	0.90
25 cm D_2O	0.78
20 cm Aℓ	0.99
^{239}PuBe bare	0.99
10 cm CH_2	0.97
15 cm D_2O	0.91
25 cm D_2O	1.00
20 cm Aℓ	0.91

features have been incorporated in a package small enough to be worn on the person, and thus yield a better approximation to an individual's exposure. Complete specifications are given in Table 2.

Table 2. Pocket REM meter specifications

1. Uses tissue-equivalent plastic detectors. Individual detectors have similar calibration factors (to within ±16% at one sigma).
2. Integrates dose and dose equivalent. Displays integration time in hours, total counts analyzed, rads, and REM. Display is a 4-digit mantissa plus signed exponent. Auto ranging in all modes.
3. Measures dose equivalent within ±11% for spectra from bare ^{252}Cf to ^{252}Cf shielded with 25 cm D_2O.
4. Overall angular response within ±10% for all directions (except directly through battery at bottom of instrument) as determined with a point source in a scatter-free environment.
5. Response is -3% at 50°C and -8.2% at 0°C referred to 25°C, including the LCD display and alkaline battery. Effects of relative humidity negligible up to 85%.
6. Gamma-ray response is <1% in fields of 1 to 10 rads per hour.
7. Zero drift less than 2 parts out of 256. Overall calibration stability better than 5% per year, based on experience with similar detector construction practices.
8. Software controlled warm-up or stabilization time automatically effected at turn on.
9. Readings updated every 2 seconds. Instrument response 100% of full reading within this 2-second update time.
10. Battery life approximately 40 hours using alkaline 9-volt transistor radio batteries. Low battery sign on LCD indicates approximately 8 hours of operation remaining.
11. Weight: 630 grams (1.4 pounds); size: 2 × 3 × 8 inches.

Project Funding

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