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REM METER FOR PULSED SOURCES OF NEUTRONS

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ABSTRACT

We have built a rem meter specifically for measuring neutrons produced by fusion experiments for which the source pulses last 10 ms or longer. The detector is a ^{6}Li glass scintillator, 25.4 mm in diameter and 3.2 mm thick, surrounded by 11.5 cm of polyethylene. This detector has a sensitivity of 8.5×10^{4} counts/mrem. The signals from this fast scintillator are shaped using a shorted delay line to produce pulses that are only 10 ns long so that dose equivalent rates up to 12 mrem/s can be measured with less than a 1% counting loss. The associated electronic circuits store detector counts only when the count rate exceeds a preset level. When the count rate returns to background, a conversion from counts to dose equivalent is made and the results are displayed. As a means of recording the number of source pulses that have occurred, a second display shows how many times the preset count rate has been exceeded. Accumulation of detector counts and readout can also be controlled manually. The unit will display the integrated dose equivalent up to 200 mrem in 0.01 mrem steps. A pulse-height discriminator rejects gamma-ray interactions below 1 MeV, and the detector size limits the response above that energy. The instrument can be operated from an ac line or will run on rechargeable batteries for up to 12 hours.

INTRODUCTION

In response to a request, we built a rem meter for use around the LLNL Magnetic Fusion Test Facility (MFTF). The initial design parameters required an instrument that could measure the dose equivalent for a minimum source pulse length of 50 ms, a maximum dose per pulse of 100 mrem and an average pulse repetition rate of 1.25/hr. This implies a dose equivalent rate of 2 rem/s (7200 rem/hr). A typical sensitivity for a commercially available rem meter is 3000 counts/mrem. We needed a resolving time of 2 ns to measure the required dose equivalent rate with counting losses below 1% (~19 ns for 10% losses). This resolving time is about a thousand times shorter than that of a commercially available rem meter. In addition, the low pulse-repetition rate prevented the use of silver-activation systems such as those described by Slaughter and Pickles[1] or Brown, et al.[2]

The relatively long pulses prompted us to solve the problem by using a standard rem meter configuration with the thermalized neutrons detected by a fast ^{6}Li-loaded glass scintillator. This detector is capable of a 10 ns resolving time that, coupled with a 3000 count/mrem sensitivity, would allow us to measure 2 rem/s with a 6% counting loss. The electronics chosen allow pulse repetition rates up to 10/s, considerably higher than the design requirements.

Scintillator size is the main parameter affecting the sensitivity of this instrument, so the rem meter could be designed with a wide range of sensitivities. We chose to make the prototype a high sensitivity system with the result that the maximum dose equivalent rate that can be measured with a 1% counting loss is 12 mrem/s. This sensitivity is considerably greater than that specified by the design criteria, but even with the resulting decrease in the maximum dose rate that can be measured, the unit has a number of applications.

Pulses of any length can be measured as long as the dose equivalent rate does not produce an unacceptable counting loss. Like most rem meters, this unit uses a thermal neutron detector mounted in a neutron moderator in which the minimum width of the neutron pulse seen by the detector will be on the order of 0.1 ms, regardless of the source pulse length, due to the time required for the neutrons to diffuse through the moderator.[3,4] For a detector sensitivity of 3000 counts/mrem and a resolving time of 10 ns, a minimum width pulse can be measured with a 1% counting loss for dose equivalents of 34 μrem per pulse. This small value is equivalent to 120 mrem/hr if the source pulses once per second. For the sensitivity of the prototype, these values are 1.2 μrem/pulse and 4 mrem/hr.

DESCRIPTION

The glass scintillator is 3.2 mm thick, 25.4 mm in diameter, and contains 6.6% lithium enriched to 95% ^{6}Li (NE905). It is shown, mounted on the photomultiplier, in Fig. 1. No light pipe is used because tests showed that

FIG. 1. Foreground: the glass scintillator mounted on the photomultiplier tube. Background: inside view of the associated electronics.

it did not improve the resolution. Normally, the scintillator is enclosed in a light-tight cap. To obtain an approximate dose equivalent response, the scintillator is operated in a 28.3-cm-diameter polyethylene sphere. The scintillator is mounted directly on the photomultiplier (PM) tube, requiring a 5.4-cm hole bored to the center of the sphere in order to accommodate the PM tube. This results in an 11.4-cm thickness of polyethylene surrounding the detector, except in the area occupied by the PM tube. The hole is large enough to allow electromagnetic shielding around the PM tube, although the shield has not as yet been used. The prototype instrument was made transportable by mounting the detector and the electronics on a dolly as shown in Fig. 2. The sphere is mounted on the dolly so that the hole for the PM tube faces down.

Figure 3 shows a block diagram of the electronics. The electronics documentation of the system is identified as LEA 79-1762.[5] A transistorized dynode bias string is used with the PM tube to ensure its proper operation at high counting rates. The anode signals are clipped to 10-ns lengths with a shorted delay line and are applied to a voltage comparator that functions as a pulse-height discriminator. Signals from the comparator provide the input for a 120-MHz divide-by-four prescaler. A count-rate circuit uses the output of the prescaler to produce a gate signal to indicate that a source pulse is under way. By counting the gate signals, a record is made of the number of source pulses over which the dose equivalents are integrated. This is done by a register with a liquid display (LCD) located on the front panel of the instrument (see Fig. 4). The instrument can also run in a manual mode in which the gate signal is produced by a fixed voltage level.

When a gate signal occurs, signals from the prescaler are sent to a storage register that consists of 6 cascaded scale-of-16 stages. Gating the storage registers keeps the system from recording background counts. When the source-pulse ends, the gate signal drops and initiates a readout cycle.

During readout, the storage register is run back down to zero by a fixed frequency oscillator and a readout register is run up by an adjustable frequency oscillator. The ratio of the frequencies is adjusted to convert detector counts to mrem. The number of mrem is displayed on a second LCD on the front panel of the instrument in 0.01 mrem units; however, dose equivalents as low as 0.0001 mrem will be integrated. A reset switch on the front panel zeros the readout, the storage register, and the source pulse counter (see Fig. 4).

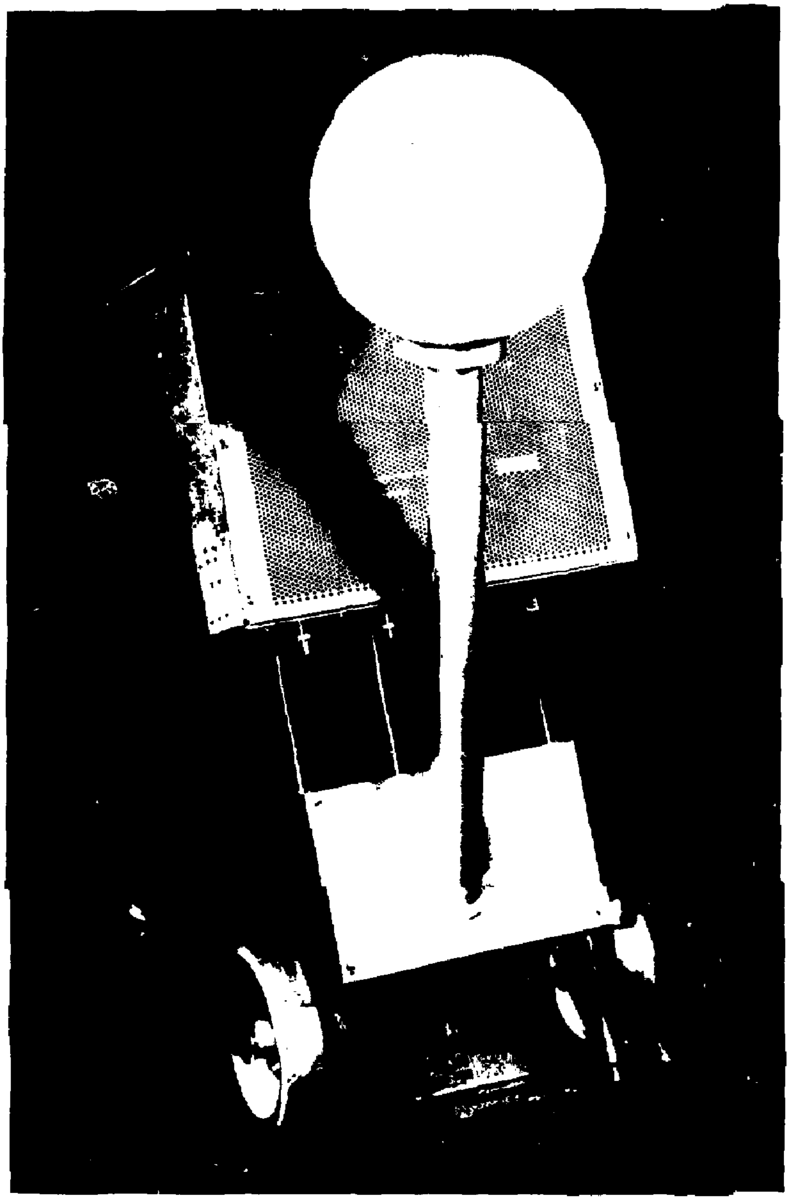

FIG. 2. Polyethylene sphere and electronics package mounted on a dolly.

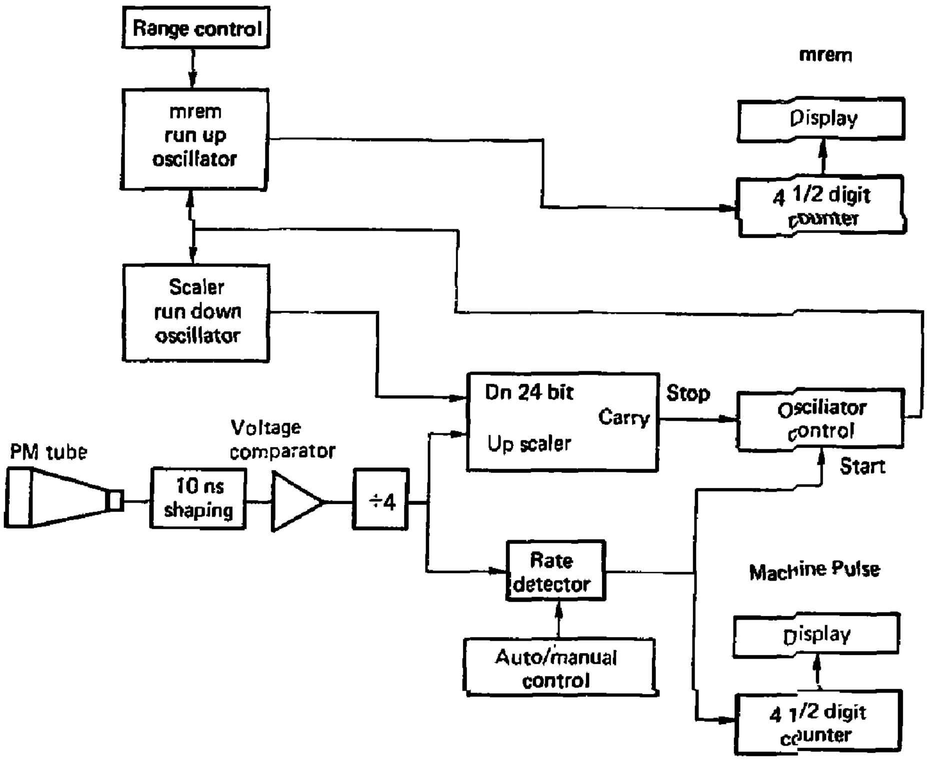

FIG. 3. Block diagram of the electronics.

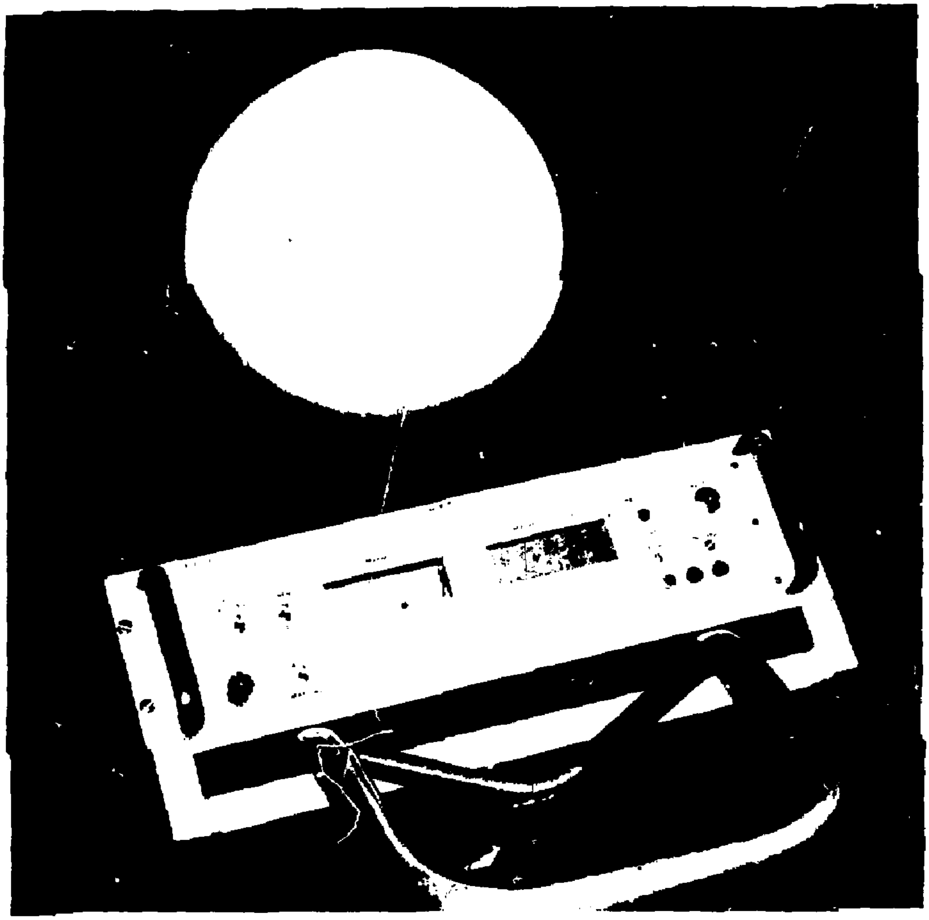

FIG. 4. Front panel showing readout displays and controls.

A dc-dc converter provides 1600 V for the PM tube. Two batteries and a battery-charging circuit allow the instrument to operate with or without a connection to a 110 V ac source. Fully-charged batteries will operate the unit for at least 12 hr.

Fabrication costs will depend upon where the work is done, but other costs involved in this rem meter can be estimated. The polyethylene for the ball costs $200, the scintillator $120, the PM tube $150 and the electronics $300, for a total cost of $800.

CALIBRATION

The system was calibrated by placing a 3.8×10^6 n/s ^{238}PuBe source 1 m from the center of the detector. We chose PuBe, rather than ^{252}Cf, because its spectrum is closer to that produced by a fusion source. An even better choice would have been a boron α,n source but it was not available. The dose equivalent rate at the detector was calculated to be 1.09×10^{-3} mrem/s.

Signals from the detector were sent via an external preamplifier and amplifier to a multichannel analyzer (MCA). Data was accumulated for 1000 s, a suitable pulse-height for a discriminator setting was chosen, and the counts above this pulse-height were integrated. This gave 84 600 counts/mrem.

A rear panel switch allowed the signal coming from the prescaler to be counted in the readout register normally used to record source pulses. Using this option, with the detector connected to the input of the rem meter, the discriminator was adjusted until the same count rate was obtained as indicated by the MCA measurement. The resulting threshold voltage measured at the front panel test points was 0.0504 V.

The variable oscillator was set to give the correct dose readout by replacing the detector signal with the output of a burst pulser set to give 8460 pulses/burst and by adjusting the oscillator to give a readout of 0.10 mrem/burst. After this calibration, a 1000-s run with the PuBe source at 1 m gave a measured value of 1.09 mrem. This verified the settings of both the discriminator and the readout oscillator. In addition, the counts recorded from a measurement of a PuLi source agreed with an MCA run made under the same conditions.

The threshold on the source-pulse gate circuit was set as low as possible for the circuit components used (0.555 V). A test with the PuBe source showed that this circuit is triggered unambiguously for dose equivalent rates of 2.7 mrem/s or greater. It will also be triggered when at least three detector counts occur within 50 ms.

The calibration should be stable for any reasonable range of temperatures (60 to 90°F). Tests have shown that the unit gives reproducible results if it is allowed to stabilize for about 5 min after being turned on.

OPERATION

Once calibrated, the operation of the pulsed-source rem meter is simple. The unit is rolled to the position where measurements are to be made and the power and high-voltage switches are turned on. The reset should be operated to clear any extraneous values that may be in the registers due to circuit startup. After five minutes of warmup, to allow the high voltage circuit and PM tube to reach stable operating conditions, the auto/manual switch can be put in the desired position and measurements can be made.

Generally, the automatic mode will be used, but steady-state sources or pulses with dose rates too low to operate the gate circuit can be measured for arbitrary times using the manual mode. An external clock is required if timing is required for a manual run. After the desired integrating time, switching back to the auto mode gives a readout of the dose equivalent that was accumulated provided that the dose equivalent rate of the neutron field does not exceed the level required to produce the automatic gate signal. The unit must be reset if subsequent pulses are not to be integrated.

PERFORMANCE

We chose the scintillator and moderator size so that the detector would produce 84 600 counts/mrem from a ^{238}PuBe source. With ~ 10 ns resolving time, this efficiency means that a 1% counting loss occurs for dose equivalent rates of 12 mrem/s. This corresponds to 0.6 mrem/pulse for machine pulses that are 50 ms long. As previously noted, the minimum width in the thermal neutron pulse seen by the detector is 100 μs for which the maximum dose equivalent that could be measured with a 1% counting loss would be 1.2 μrem.

A readout range of 0.01 to 199.99 mrem was chosen to be consistent with the detector sensitivity. Counts are recorded when the pulse-heights are above a threshold set just below the peak produced in the scintillator by its response to thermal neutrons, as illustrated in Fig. 5. This threshold corresponds to the pulse-height that would be produced in the scintillator by 1 MeV electrons. The peak occurs at the same pulse-height as a 1.8 MeV electron, and the width of the neutron-produced peak at half-height is about 20% of its pulse-height.

The chosen threshold will effectively suppress response to gamma-rays below 1 MeV. Only 88 counts resulted from a 6 min measurement of ^{137}Cs at a 1 R/hr exposure rate. Response to gamma-rays with $E > 2.5$ MeV is effectively limited by the size of the detector. At most, only 4% of the counts obtained from the PuBe source could be attributed to gamma-ray interactions (4.4 MeV gammas from the source and 2.2 MeV gammas from neutron captures in the polyethylene sphere). Higher sensitivities are obtained for gamma-rays between 1 and 2.5 MeV. For example, the response to ^{60}Co was equivalent to 1.5 mrem for an exposure of 24 mR given at an exposure rate of 1.5 R/hr. A comparison of the response to PuBe and ^{60}Co is shown in Fig. 6.

When it was calibrated with a $^{238}PuBe$ source, the rem meter responded about 15% low to a ^{252}Cf source and a few percent high to a PuLi source [E(avg) = 0.5 MeV]. Although a rem meter employing a polyethylene sphere of the dimension used has a reasonably energy-independent dose equivalent response, a detector of this type commonly over-responds to lower-energy neutrons. Tests of the prototype made in pulsed neutron fields that could contain a significant number of neutrons in this energy region gave a greater response than other rem meters that had more sophisticated moderators. Of course, the difference may have been due to the under-response of the other rem meters. Another comparison was made by exposing this rem meter, two commercially available rem meters, and a silver-activation detector to five steady-state neutron fields. The sources used were ^{252}Cf moderated by 25 cm of D_2O, ^{252}Cf moderated by 10 cm of D_2O, bare ^{252}Cf, PuBe and 14 MeV (D,T) neutrons. Runs were normalized with a long counter. Table 1 compares the detector responses of the various rem meters. The responses of the pulsed source rem meter to monoenergetic neutrons of 0.097, 0.[illegible], 1.42 and 2.19 MeV are also given in the table. Expected values of nrem/(n/cm^2) were obtained from ANISN calculations coupled with National Council on Radiation Protection (NCRP) values for the dosimeter intercomparisons and from the NCRP values for

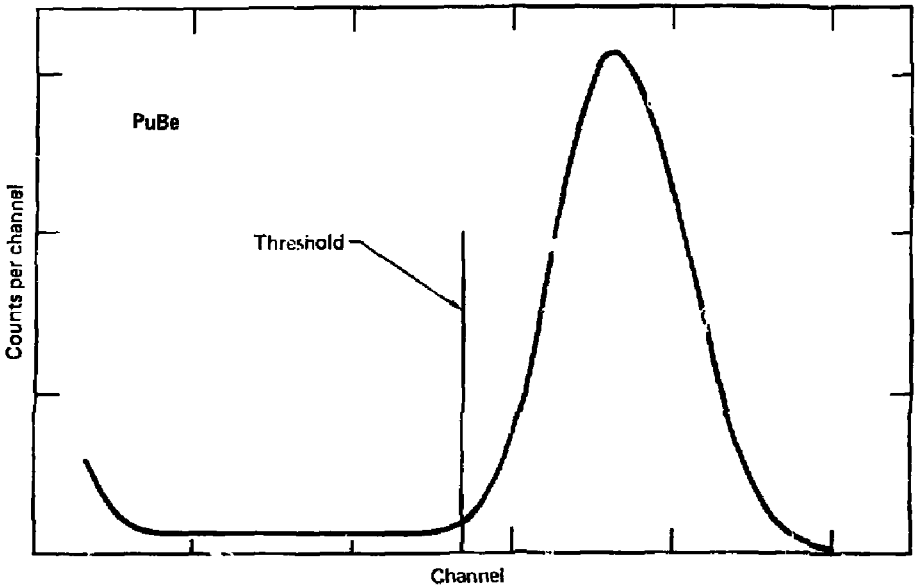

FIG. 5. Typical pulse-height response of the system to neutrons.

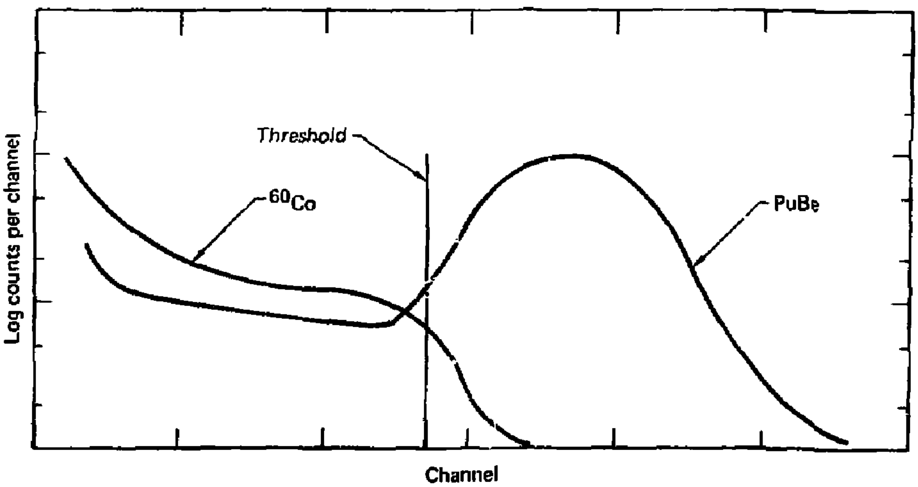

FIG. 6. Comparison of the pulse-height spectra produced in the detector by a PuBe neutron source and a ^{60}Co gamma-ray source.

TABLE 1. Comparison of PSRM responses with those for other rem meters[a].

Source	Average energy (MeV)	Response nrem/(n/cm^2)				
		Silver-activation detector	Anderson Braun	9-in. sphere (PNR-4)	Pulsed-source rem meter	Calculated values (ANISN/NCRP)
^{252}Cf + 10 cm D_2O	0.092	12.1	14.6	17.9	19.9	2.32
$^{7}Li(p,n)^{7}Be$	0.097	--	--	--	15.0	5.9
$^{3}H(p,n)^{3}He$	0.42	--	--	--	17.5	22.4
^{252}Cf + 10 cm D_2O	0.59	21.4	23.0	24.4	23.9	8.75
Bare ^{252}Cf	1.4	39.7	41.3	41.3	39.3	21.8
$^{3}H(p,n)^{3}He$	1.42	--	--	--	32.9	41.3
$^{3}H(p,n)^{3}He$	2.19	--	--	--	41.6	39.3
Bare $^{238}PuBe$	2.5	42.7	36.8	38.8	39.1	25.5
$^{3}H(d,n)^{4}He$	10.6	27.0	22.6	26.5	29.3	44.6

[a] ^{252}Cf, PuBe and d,T neutron average energies obtained from ANISN calculations.

the monoenergetic neutrons.[6] Except at the lowest energy, the detector response to monoenergetic neutrons was reasonable and it agrees well with the other rem meters for more complicated spectra.

The means chosen to calculate mrem from detector counts can be precise but it does require a finite time to perform the conversion. For oscillator frequencies used in the prototype, it requires about a second for each 10 mrem readout.

For long, manual runs, the background sensitivity is important. One run made in an area known to have few neutrons gave 6.8 counts/min above the discriminator level. A pulse-height analysis showed 1.3 counts/min were definitely due to neutron interactions. The remaining 5.5 counts/min may be due to alpha emitters in the glass. Data from the manufacturer indicate 4 to 8 counts/min of alpha background could be expected for a scintillator of this size. If a lower background is necessary, a more expensive version of the scintillator is available that has about 1/10 as much alpha activity.

CONCLUSION

We have built a rem meter that is useful for measurements of pulsed neutron sources whenever the dose equivalent rate does not exceed 12 mrem/s. Higher rates could be measured if the detector sensitivity was lowered, which may be done with only minor modifications. The rem meter also has use for measuring low-level continuous fields due to its high sensitivity and it has been used successfully to measure pulses much shorter than those for which it was designed. It is dependable, easy to operate, and rugged enough to have performed successfully through a recent earthquake.

Some improvements have already suggested themselves. A smaller, less sensitive detector seems desirable for several reasons: to reduce the gamma-ray sensitivity still further; to decrease the size of the PE sphere; and, to reduce the alpha background. Simplifications in the electronic circuits will result in a smaller size, in an increased ease of operation and readout, and in a major simplification in calibration. Smaller detector and electronics sizes could be coupled to make the system considerably more portable.

REFERENCES

1. D. R. Slaughter and W. L. Pickles, "A Highly Sensitive Silver-Activation Detector for Pulsed Neutron Sources," Nucl. Instr. and Meth. 160, 87-92 (1979).
2. D. Brown, R. J. Buchanan, and A. R. Koelle, "A Microcomputer-Based Portable Radiation Survey Instrument for Measuring Pulsed Neutron Dose Rates," Health Phys. 38, 507-522 (1980).
3. T. M. Jenkins, Neutron Thermalizing Time in 6.3 cm of Paraffin, Stanford Linear Accelerator Center, Palo Alto, CA, Appendix A in SLAC-HP-64-1 (1964).
4. H. Dinter and K. Tesch, Moderated Rem Meters in Pulsed Neutron Fields, Deutsches Elektronen-Synchrotron, Hamburg, Germany, DESY 76-08 (1976).
5. LLNL Internal Document LEA 79-1762; Readers outside the Laboratory who desire information on LLNL internal documents should address inquiries to the Technical Information Department, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94550.
6. Protection Against Neutron Radiation, National Council on Radiation Protection and Measurements, NCRP-38 (1971).

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