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DOW

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Abstract. A compact integrating neutron-flux counter using a solid-state detector and mercury microcoulometer is described. The counter provides a visual indication of the number of pulses detected.

A description of the field use and the limitations of the counter for personnel neutron-dose estimation are included.

INTRODUCTION

Neutron dosimetry lags far behind other measurement techniques used by health physicists. An improved means for measuring neutron dose to individuals is needed to adequately assess the biological dose associated with neutrons. A small counter, useful for dose estimations, should be of value toward the development of a small dose meter to be worn by an individual.

Described herein is a pocket-size counter, not a true dose meter, which may lead to improved future developments. The counter is similar to other particle counters[1] which utilize semiconductor detectors.[2,3] The primary difference of the counter is in the utilization of an electrochemical element[4] which stores pulses and provides a visible indication of the number of neutrons detected.

Counters utilizing semiconductor detectors have been used to count neutrons by detecting fission fragments, reactions in the silicon of the semiconductor itself, and by detecting charged particles from materials in contact with the semiconductor detector.

Dose histories of a few hundred millirems per year are important in work operations, because records must be kept to show avoidance as well as absorption of dose. Under current circumstances, a small dose implies a large inaccuracy by the emulsion method because only a few tracks are recorded. Relief from the statistical errors associated with small numbers may be the principal advantage to be gained from use of the counter. Disagreement between dose estimates based on film data and dose meter readings led to consideration of a counter to replace the film.

DISCUSSION

Description:

The counter is contained in a 5.4 by 1.9-centimeter round can and weighs 42.5 grams.

A clip is attached to the outside case to provide for carrying the counter. An identification number is placed on the front surface of the can for personal employee identification.

Counter Electronics:

A one-square centimeter (cm) diffused window particle detector is used as the detector with a lithium-6 (^{6}Li) foil mounted on the surface of a cadmium foil adjacent to the entrance window. The arrangement provides neutron detection by the ^{6}Li*(a, n)* reaction. The circuit consists of a three-stage amplifier with a sensitivity control and a monostable multivibrator to produce a fixed-pulse shape for the output integrator circuit. The integrator circuit includes a current amplifier for a mercury microcoulometer.

The current pulse causes a small quantity of mercury to transfer across the electrolyte-filled gap between mercury columns in the capillary tube of the microcoulometer, causing a displacement of the position of the gap. The net displacement of the gap is proportional to the number of events detected. Thus a visible indication can be provided of the number of pulses accumulated.

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[1] Solid State Radiations, Incorporated, Los Angeles, California. (Model 703.)
[2] Molechem, Incorporated, a subsidiary of The Harshaw Chemical Company, Cleveland, Ohio.
[3] Oak Ridge Technical Enterprises Corporation, Oak Ridge, Tennessee.
[4] Curtis Instruments, Incorporated, Mount Kisco, New York.

The microcoulometer has a limited gap-movement rate. Gap movement is limited to 1.2 cm per hour at 5 milliamperes, longer at lesser currents. The gap displacement per count can be adjusted over a wide range by varying the value of the series resistor.

The quiescent battery current of the circuit is 80 microamperes at 1.3 volts. The current drain permits a maximum of 16 weeks of operation from a single mercury battery (RM 625RT2).

The circuit configuration is shown in Figure 2.

The detector provides a positive output pulse for the three-stage amplifier system. Although the quiescent transistor collector current through the amplifier is low, a gain of approximately 10 is obtained from each stage. A potentiometer is used as a gain control to set the pulse amplitude triggering the monostable multivibrator.

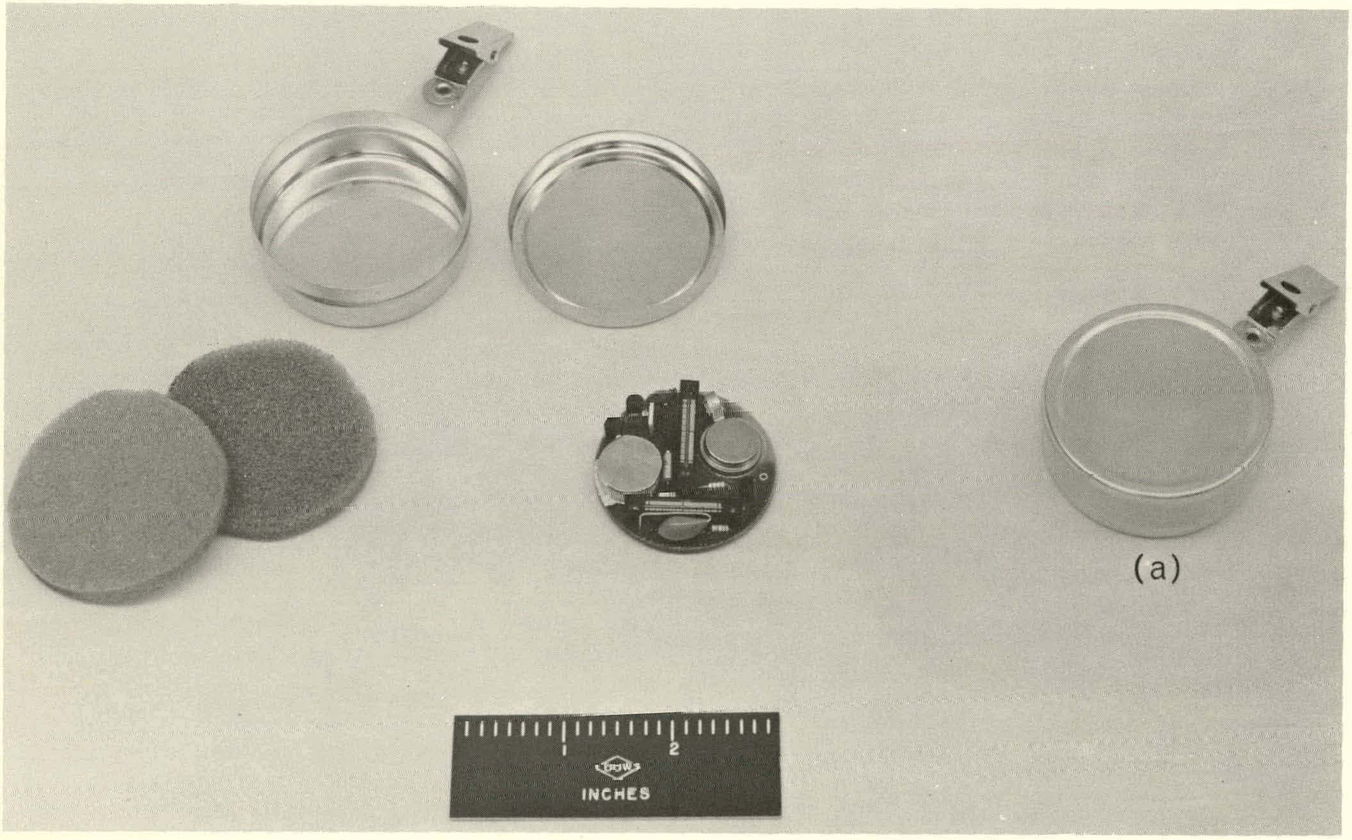
The pulse width of the univibrator was set to produce a pulse width of 10 milliseconds. This produced a full-scale deflection of the mercury microcoulometer of one million pulses. Subsequent field testing of the counter determined that there was insufficient gap displacement for short-term observations. Later models have a 240-millisecond pulse width producing a full scale displacement with 40,000 pulses. The process is reversible which permits a digital readout of the column by pulsing the column backwards to the zero position.

The counter circuit is mounted on a printed circuit board and suspended within the can with a polyurethane pillow. The circuit is completely self-contained with no connection to the can. The circuit boards including the detector and Li foil have been built for $57.

EXPERIMENTAL EVALUATION

The counter was tested in various experiments to determine the operating characteristics and possible uses as a neutron dosimeter. The experiments were conducted in two parts: (1) Laboratory tests in which the counter was exposed to known dose rates from standard sources, under various controlled conditions; and (2) Field tests in which the counter was exposed to unknown fluxes in relatively uncontrolled conditions. The performance of the counter was then compared to nuclear emulsions and survey dose-rate meters.

FIGURE 1. Pocket-Size Counter (a) and Component Parts.



Laboratory Tests:

Laboratory tests were conducted to determine the relative counter sensitivity as a function of the neutron energy, the effect of backscattering from a phantom backing, the effect of cadmium in front of and behind the detector, background and gamma response, electrostatic noise problems, instrument ruggedness, and microcoulometer fragility. In some experiments, the output of the counter was modified to drive a mechanical scaler. This was useful in making measurements of pulses per millirem (mrem) or pulses per neutron per square centimeter.

Results of Laboratory Tests:

1. Counter Response as a Function of Neutron Energy.

The relative sensitivity of the counter as a function of neutron energy was measured using calibrated plutonium fluoride (PuF_4) and plutonium-beryllium (Pu–Be) sources with various thicknesses of moderators. This yielded neutron fluences covering an *average* energy range from about 0.2 million electron volts (MeV) (PuF_4 moderated with 7 cm of polyethylene) to 4.5 MeV (unmoderated Pu-Be). (See Table I).

The relative sensitivity of the counter to moderated neutrons was thus reduced by the addition of 0.040 inches of cadmium over the detector. Even with the cadmium over the detector the sensitivity of the counter increased as the *average* neutron energy decreased. The use of cadmium adhering to the front of the detector was incorporated into the counter design. A water-filled, plastic-lung phantom was used as a backing medium for the counter.

No significant change in the relative counter response as a function of neutron energy was found for comparisons of air and phantom backing, with or without cadmium interposed between the backing and the detector, for an *average* neutron energy range from 0.2 to 4.5 MeV. Backscattered neutrons from the phantom did contribute to an increase in the counts per mrem by a factor of 5, compared to the cadmium and air backing throughout the energy range investigated.

2. Background and Gamma Response.

The background response of the counter was from 2 to 3 pulses per hour. At a typical counter sensitivity of 50 pulses per mrem, the background resulted in an accumulation of an equivalent dose of 1.4 mrem per day. The semiconductor detector became somewhat affected by electromagnetic radiation, including light. A gamma dose rate from cobalt-60 (^{60}Co) of 8 roentgens (R) per hour produced a count rate of 1.6 pulses per minute or an apparent neutron response of 2 mrem per hour. The counter was adequately shielded from electrostatic noise by the metal container. A count rate of 250 pulses per minute in an electrostatic noise area was reduced to background by enclosure in the metal container.

3. Instrument Fragility.

The mercury microcoulometer is sensitive to mechanical shocks causing a displacement of the gap in the mercury column, or a fragmentation or disintegration of the gap. Twenty-eight drops from 2.5 feet resulted in an average gap displacement of 0.04 of full scale per drop. Vibrations, such as from a Burrell[5] wrist-action shaker set at maximum vibration for a one-hour duration, caused no effect on either the microcoulometer or the circuit.

[5] Burrell Corporation, Pittsburgh, Pennsylvania.

FIGURE 2. Circuit Configuration.

Legend

1. Silicon-diffused window detector (1 square centimeter).
2. Amplifiers, three-stage system.
3. Monostable multivibrator.
4. Current amplifier.
5. Integrator cell.

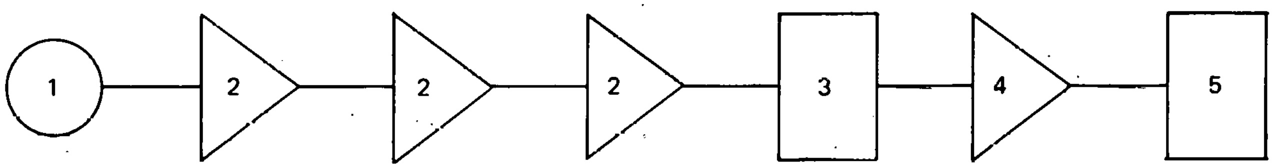


TABLE I. Detector Energy Response

*Sources	Moderation	Counter Response Relative to Unmoderated PuF_4 (phantom backing)	
		Bare Detector	Cadmium-Covered Detector
PuF_4	Unmoderated	1.0	1.0
PuF_4	2.5-cm polyethylene	3.6	2.2
PuF_4	4.0-cm polyethylene	4.2	3.6
PuF_4	5.0-cm polyethylene	6.4	4.2
PuF_4	7.0-cm polyethylene	16.7	6.9
Pu-Be	Unmoderated	0.6	0.9
Pu-Be	9.5-cm Lucite	2.4	2.3

*Calibrated plutonium fluoride (PuF_4) and plutonium-beryllium (Pu-Be).

Field Tests:

Field tests were conducted to determine the applicability of the counter as a neutron dosimeter in field conditions. These tests consisted of: (1) The measurement of the counter sensitivity to the neutron fluences for various shielding conditions and operations; and (2) The evaluation of the counter response when worn by personnel exposed to neutron fluences during routine operations.

Results of Field Tests:

The counter sensitivity (pulses per mrem) depends on the energy spectrum which can vary in a work area depending on the shielding or moderating conditions in the area. At locations where little or no shielding existed, counter sensitivities were within a factor of 2 for the 11 work areas tested and were within 30 percent for 8 of the 11 areas. Counter sensitivity changed as much as a factor of 4 for work areas containing neutron shielding. An additional factor of 3 was measured when the glove port was open or closed. Since the counter is more sensitive to moderated neutrons, doses from unmoderated neutrons through open glove ports or shields tended to be masked by the counter response to moderated neutrons in the vicinity.

Field tests for personnel wearing the counter during routine operations were conducted in two parts: (1) Tests with personnel working in specified work areas with the counter calibrated for the *average* neutron energy spectrum in that area, and (2) Tests with personnel working in various general work areas with the counters using an average calibration factor. Under Part 1 conditions, agreement of the counter dose with doses indicated by neutron dosimetry film and with doses calculated from survey dose-rate measurements were consistently within a factor of 2, and were within 30 percent in approximately two-thirds of the cases. Under Part 2 conditions, agreement with film or survey doses was inconsistent. Discrepancies of greater than a factor of 3 occurred in almost 25 percent of the readings. The normalized counter response (net column deflection per dose per counter sensitivity) varied by as much as a factor of 10, depending on the degree of moderation of the neutrons. Loss of data from the counter occurred with a frequency of 5 to 10 percent, usually because of column-gap fragmentation.

SUMMARY

An electronic integrating neutron counter, using a detector and mercury microcoulometer pulse integrator, has been built. The counter uses a ^6Li foil to produce alpha particles and provides 240-millisecond pulses from the electronic circuit to operate the integrator.

The dose meter is useful in controlled field operations, but has serious limitations in normal process area environments. The unit provides only approximate neutron dose indications and also contains a fragile pulse integrator. In addition, this system has now been superseded by a simpler and less expensive thermoluminescent dosimeter process.