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NEW METHOD OF PROPORTIONAL COUNTER FEEDBACK BIASING FOR WIDE-RANGE RADIATION DOSE-RATE MONITOR*

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Abstract

A prototypic wide-range radiation dose-rate monitor for civil defense applications has been developed and tested. The specified dose-rate range (0 to 500 R/h) was displayed on a single readout scale by using feedback-controlled biasing of a proportional counter. This new method is based on controlling the avalanche multiplication factor (gas gain) of the counter by varying its bias voltage in response to its measured output current (i.e., detected dose rate). The counter output current varies between 0 and 1.5 nA in a quasi-logarithmic response to dose rates between 0 and 500 R/h. The corresponding values of gas gain and bias voltage range from 1 to 300 and 200 to 1900 V respectively.

Introduction

A method of feedback-controlled biasing of proportional counters was developed and tested in a wide-range dose-rate monitor for civil defense applications. Proportional counters are a good alternative to Geiger Mueller counters for this application because, in conjunction with feedback-controlled biasing, they offer wider range capabilities and a longer life expectancy.

The main purpose of this research was to investigate the properties of feedback-controlled biasing in connection with a program aimed at developing a portable monitor with a nonsaturable, monotonic response and capable of measuring exposure rates in the range 0 to >1 kR/h on a single scale that does not require switching.

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Feedback-Controlled Biasing of Proportional Counters

To extend the range capability of a dose-rate monitor with a gas proportional counter, the output current of the counter is used in a feedback circuit to control its own bias voltage (Fig. 1). For a small detected dose rate, the bias voltage--and, consequently, the counter gas gain--are at their maximum values; that is, the counter operates at its highest sensitivity. As the detected dose rate increases, the bias voltage and gas gain decrease, thereby reducing detection sensitivity.

This dose-rate-dependent sensitivity characteristic results in a compression of the readout scale and extends the dynamic range of the proportional counter from pulse counting at background radiation levels to ionization current measurements at dose-rate levels up to 1 kR/h. Also, the proportional counter life expectancy is greatly extended by operating it at low values of gas gain (<1) during high exposure rates (>500 R/h).

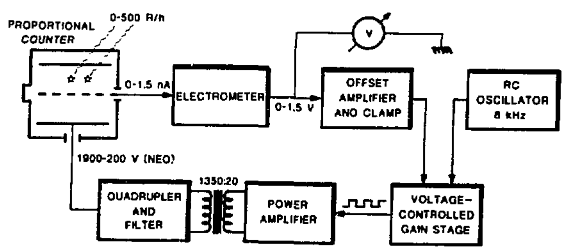

Fig. 1. A detected dose rate ranging from 0 to 500 R/h generates an ionization current in the proportional counter (0 to 1.5 nA) that drives the readout meter V (0 to 1.5 V) and controls the detector bias voltage in the range 1.9 to 0.2 kV.

For the prototypic monitor, we measured functional relationships between dose rate, ionization current, gas gain, and bias voltage (Figs. 2 and 3) as follows:

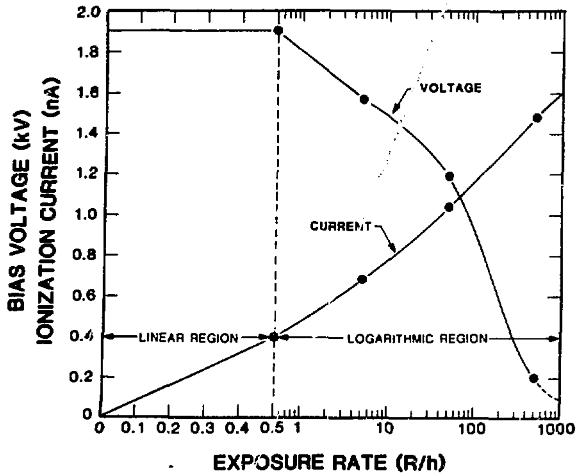

Fig. 2. The ionization current of the proportional counter varies linearly from 0 to 0.4 nA and quasi-logarithmically from 0.4 to 1.5 nA in response to exposure-rate variations from 0 to 0.5 R/h and 0.5 to 500 R/h respectively. The bias voltage is held constant at 1.9 kV in the linear range and decreases under feedback control from 1.9 to 0.2 kV in the logarithmic range of the exposure-rate scale.

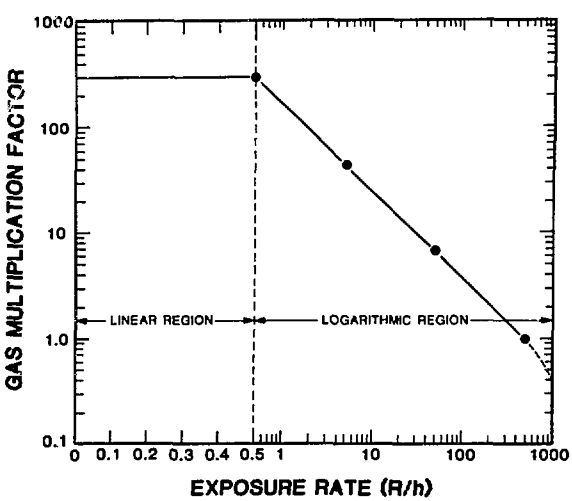

Fig. 3. The gas multiplication factor is held constant at 300 in the linear region and follows the decrease in bias voltage (Fig. 2) from 300 to 1 in the logarithmic region of the exposure-rate scale.

In response to an increase in dose rate from 0 to 0.5 R/h, the ionization current increases linearly from 0 to 0.4 nA while the bias voltage and the gas gain are held constant by the clamp circuit at 1.9 kV and 300 respectively. For a detected dose rate increase from 0.5 to 500 R/h, the ionization current increases in a quasi-logarithmic mode from 0.4 to 1.5 nA, the bias voltage decreases from 1.9 to 0.2 kV, and the gas gain decreases from 300 to 1. Beyond 500 R/h the response is highly compressed; that is, as the ionization current approaches 1.7 nA for large values of detected dose rate (>1 kR/h), the bias voltage (and therefore the gas gain) approach zero. Consequently, the response of this monitor neither saturates nor exhibits foldback.

Proportional Counter

The proportional counter was filled with 90 mg of 80% Ar + 20% CF_4 at atmospheric pressure to deliver an ionization current of 1.5 nA at unity gas gain when exposed to a 500-R/h gamma radiation field.[1] We did not expect this gas mixture to have an air-equivalent response below 100 keV, but its dielectric properties made it a good choice for the proof-of-principle monitor. A gas envelope with 3-mm-thick aluminum walls was used for compensation to make the response nearly air equivalent for gamma energies between 0.1 and 2 MeV.[2]

The active counter gas volume is a 40-mm-high, 40-mm-diam cylinder. The anode wire (25-µm-diam stainless steel) and the envelope are operated at ground potential, while the cathode cylinder is operated at negative bias voltage. This arrangement has two advantages: The ionization current can be measured with a ground-referenced electrometer connected to the anode, and the envelope is a guard structure that mitigates leakage-current effects across the anode insulators. The gas multiplication factor ranges from 0 to 6×10^3 in response to anode-to-cathode biasing between 0 and 2.5 kV; no breakdown or spurious pulses were observed in this range.

Electronic Circuit

The measurement and control functions of the electronic circuits are generated by two integrated circuits (TL094 and CA3053) and one transistor (2N5089) for the high-voltage transformer drive. The readout used for the prototypic monitor is a 50-µA panel meter (Fig. 1). The circuit is powered by a 6-V battery and consumes 72 mW.

The four amplifier sections of the TL094 Quad amplifier are used as follows:

- The first section is used as an electrometer of 10^9-Ω transresistance; its output drives the 50-μA panel meter.
- The second section is used as a voltage-gain and offset amplifier stage; its output voltage controls the gain of the CA3053 amplifier stage.
- The third section is an 8-kHz RC oscillator; its output is connected to the voltage-controlled gain stage for amplitude modulation.
- The fourth section of the TL094 and the 2N5089 transistor are used as a power amplifier to drive the primary of the high-voltage transformer.

The dc-bias voltage at the output of the high-voltage quadrupler ranges between 0.2 and 1.9 kV in response to an electrometer input current ranging from 1.5 to 0.4 nA.

Experimental Results

The prototypic dose-rate monitor was calibrated at exposure levels of 0.4, 4.0, 40, and 400 R/h using a ^{137}Cs source. The time constant of the response to a step function change in exposure rate was 1 s in the range 0.4 to 400 R/h. The energy response curve was measured at the facilities of the Federal Emergency Management Agency and showed a strong peak in the range 30 to 60 keV as compared to an air-filled ionization chamber. More uniform energy response will be obtained in future designs by using more nearly air-equivalent gas mixtures. Preliminary tests with Ne-CH_4 show promising results.

Discussion

Preliminary data obtained with the prototypic wide-range radiation dose-rate monitor indicate that the feedback-controlled biasing of proportional counters is a practical method for monitoring exposure rates from background levels up to 1 kR/h. These data provide an adequate basis for the design of an engineering model of such a monitor and indicate several modifications that should be incorporated into an instrument for fallout shelter applications:

- To measure low-level exposure rates between 0 and 1 R/h with greater accuracy, a 6-digit LCD readout, calibrated directly in μR/h and gated by a 10-s clock, will be incorporated.
- To facilitate interpretation of the exposure rate in an emergency situation, an indicator of increasing or decreasing exposure rate will be provided, and a bar-graph LCD will replace the panel meter readout.
- To make the response to exposure rate nearly air equivalent, gas mixtures containing a high concentration of neon will be used.
- To reduce the power requirements, low-current amplifiers will be used; in addition, neon requires lower exitation voltages than argon, which further reduces the power requirements.

With these modifications, a wide-range dose-rate monitor is feasible for operation as a fallout shelter instrument for the measurement of exposure rates ranging from background levels to 1 kR/h. The use of the feedback biasing method of the proportional counter provides a rugged instrument with long life expectancy. In addition, sensitivity and scale configurations for special-purpose instruments are easily achieved by selecting appropriate ranges of gas gain (from 0 to 10^4) and feedback circuit transfer functions.

Acknowledgments

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2. Ibid., p. 167.