Chirper
Monitor

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PERSONAL RADIATION MONITOR

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OAK RIDGE NATIONAL LABORATORY

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Instrumentation and Controls Division

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R. H. Dilworth and C. J. Borkowski

Abstract

A Personal Radiation Monitor instrument has been developed that weighs 3-1/2 ounces and has the size of an ordinary fountain pen. Worn in the pocket of the user, the device provides immediate audible and visual indication of gamma dose rate. Indications are given by the simultaneous flash of a neon lamp and a burst of audible warning tone best described as a chirp. The repetition rate of the chirp and flash is proportional to gamma dose rate. The proportional range of indication extends from background to about 2 r/hr for instruments set to the normal range of sensitivity. An optional less sensitive range extends the upper limit of proportional indication to 200 r/hr. In either range the maximum indications do not block in overloading radiation fields short of that which would damage the components. To insure continuous protection, there is no on-off switch. Operation for one month is obtained from a four volt mercury battery.

The instrument uses a miniature halogen filled Geiger counter as the radiation detector. Generation of 500 volts to operate the counter is done by a transistor blocking oscillator, transformer, and semiconductor diode voltage quadrupler. Feedback through two transistor emitter followers increases the rate of the oscillator in proportion to Geiger tube current, and a fourth transistor amplifies this tone into a hearing aid earphone with resonant air column. The electronic assembly is encapsulated in epoxy resin for protection and housed in a tubular stainless steel case fitted with a pocket clip.

1. Introduction

The instrumental protection of personnel from accidental radiation exposure is usually accomplished by area monitoring instrumentation. However, when it is realized that protection is desired not for areas but for people, the possibility of providing radiation monitoring instruments that can be worn on the person becomes very attractive. Another advantage of personal monitors lies in the fact that few people work alone in those areas most susceptable to radiation accidents, and the simultaneous alarm of monitors worn by several workers will add the credence of multiple coincidence to the warning.

Radiation detectors worn on the person are in widespread use in the form of film badges, pocket ion chamber dosimeters, and self-reading quartz fiber pocket dosimeters. None of these types of monitors gives any immediate warning to the user of an abnormal radiation level; they merely give after-the-fact information on dosage already received. There has been some use of personal warning instruments of the accumulating dosimeter type, notably the R-Vox, developed by F. M. Glass of the Oak Ridge National Laboratory in 1953, and the PTW Monitor, a recent German development. These instruments are worn on the belt of the user, and they emit a loud tone alarm when a chosen dose — typically 100 mr — has been accumulated since they were last reset. Instruments of this category are particularly useful in preventing overdose to workers in areas of known radiation. However, they have inherent disadvantages when used as warning instruments in normal environments because of the uncertainties of when in the accumulating period the dangerous field was encountered and where the encounter took place.

These and other considerations point to the need of an on-the-person radiation monitoring instrument that is sensitive not to accumulated dose but rather to the dose rate or intensity of radiation. Such an instrument can provide immediate warning if the radiation intensity rises abnormally. Furthermore, a rate sensitive instrument can be made to give a proportional indication of intensity and can aid the user in locating the source of radiation or in choosing a safe evacuation route.

The Personal Radiation Monitor - PRM - to be described is an attempt to satisfy the needs just expressed. It has been specifically designed to provide immediate warning of an abnormal radiation intensity. Although it can be used for quantitative measurements, surveying, or contamination monitoring; it should be remembered that the limitations imposed on the design by the primary objectives will necessarily restrict the suitability to these corollary purposes.

In considering the design of a dose-rate-sensitive monitor to be worn on the person, the question of size is of paramount importance. There has been some objection by workers to instruments whose size required that they be worn on the belt or carried in some special harness. Such seemingly minor objections actually have a drastic effect on the user's acceptance of the instrument and his probability of using it when he needs it. On the other hand, there is little if any objection to the use of ion chamber or quartz fiber instruments that have the shape of a fountain pen and a clip for wearing in a shirt or coat pocket. Therefore, it was decided to confine the new instrument to the size and shape of a fountain pen as nearly as possible.

Another design philosophy for the PRM was that of not trying merely to miniaturize with tiny components some existing monitoring circuits, but rather to devise new circuits and methods which inherently used few components of small size and which insofar as possible made multiple use of those components and circuits. Further aims were to obtain exceptional battery life without the use of a detrimental on-off switch, and to keep the cost of the instrument at a minimum so as to make widespread use practical.

2. General Description

The external appearance of the PRM is shown in Fig. 1. It is 5-3/4 inches long and just under 3/4 inch diameter. The weight with battery is 3-1/2 ounces. The case is of polished stainless steel for ease of decontamination, and a spring clip is provided for holding the instrument in a pocket. An opening in the case just above the pocket clip communicates through a resonant air chamber to the hearing aid earphone that generates the audible alarm sound. A flashing neon lamp for visible warning is under a protective red plastic cover at the top of the instrument.

Removing a screw cap at the bottom of the PRM allows removal of the inner assembly as shown in Fig. 2. The 4 volt mercury battery provides one month of continuous operation; there is no on-off switch. The captive contact for the lower battery terminal eliminates the problem of poor contact through the spring and cap, and both battery terminals are made of gold-plated silver to eliminate terminal corrosion. The electronic assembly is fitted into a plastic outer shell which is then completely filled with clear epoxy resin. This encapsulation provides not only mechanical stability for the components but also affords humidity protection to the extent that operation while immersed in water is possible.

Warning indications given by the PRM are in the form of simultaneous audible "chirps" and flashes of the neon lamp. The repetition rate of these chirps and flashes is proportional to gamma dose rate. The pitch of each chirp is always the same - about 2800 cycles per second, and information is conveyed only by variation in the rate of recurrence. The apparent brightness of the neon lamp varies from barely visible in low fields to a steady orange glow in a dangerous dose rate. The standard model of the instrument is provided with two possible ranges of sensitivity. A given instrument must be set to the desired range semi-permanently. Conversion from one range to the other can be made at will in a few minutes, but access to the proper tools and materials is necessary.

The choice of range to which an instrument is set is determined by the amount of capacitance in the neon lamp scaler circuit. Two capacitors are built into the instrument with their leads run close to the outer surface of the encapsulated assembly. As fabricated, both capacitors are in the circuit and the lower sensitivity range is obtained. To obtain the normal higher range of sensitivity, the larger of the two capacitors is removed from the circuit by drilling into the encapsulant a small diameter hole that opens the lead so placed for the purpose. The hole is then sealed with Duco cement. It is possible to reconnect the capacitor by drilling out the cement and tamping the hole with conductive silver paint or dentists amalgam. Since the joint so made is at ground potential, no further insulation is required. The range changing procedure can be done many times without damage to the instrument.

The more sensitive of the two ranges is considered to be the normal range most suited to general use. The low sensitivity range is intended for specialized use with instruments clearly marked as such. A tabulation of typical chirp rate response to gamma dose rate from Cobalt 60 is given in Fig. 3. It should be remembered that the prime objective of the instrument is to indicate a change in dose rate; the circuit does not provide for exact duplication of such calibrations from instrument to instrument. However, a single instrument will retain an individual calibration.

An important characteristic of the Personal Radiation Monitor is that the maximum indications persist even in dose rates that far exceed the range of proportional indication. Verification has been made by actual exposure up to 3×10^6 r/hr, and there is no reason for indication to cease until the components fail due to radiation damage. This non-blocking characteristic is operable in either of the two ranges of sensitivity.

The radiation detector is a miniature halogen filled Geiger counter, the Philips 18509-02. This counter tube can be seen in the left center portion of the encapsulated assembly shown in Fig. 2. Previously reported versions of the instrument[1] have used the GM tube in an unorthodox mode involving the discharge of a large external capacity in order to obtain a large charge transfer per GM pulse. In the interest of long term reliability, the present instrument has reverted to conventional self-quenching of the GM tube with a high value resistance, and an additional transistor has been provided to recompense the lower charge transfer per pulse.

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1. R. H. Dilworth and C. J. Borkowski, Instrumentation and Controls Division Ann. Prog. Report, July 1, 1960, ORNL-3001, p 22.

3. Basic Circuit Operation

The basic operation of the circuit is illustrated in the block diagram of Fig. 4. High voltage for operation of the GM tube is obtained from a transistor blocking oscillator whose output passes through a step-up transformer to a voltage-quadrupling rectifier having a 520 volt output. The radiation induced current pulses from the GM tube are accumulated in either of two range setting capacitors. In the normal more sensitive range, only the smaller capacitor is connected; and its capacity is chosen such that about 10 pulses of the GM tube are required to cause one discharge of the neon lamp in a steady state condition. (More than 10 pulses are required to obtain the initial neon discharge when an instrument is first started.) Each neon lamp discharge drives the first emitter follower with a short voltage pulse. The output of this emitter follower charges a capacitor to the same voltage as the input pulse. A shunt resistor discharges the capacitor, but it does so with a much longer time constant so that the chirp to be generated will be of suitable duration.

This fast-rising, exponentially falling pulse is fed into a second emitter follower whose output feeds the same pulse shape to both the blocking oscillator and the audio amplifier. The effect of this pulse on the blocking oscillator is to abruptly increase its repetition rate from the idling value of about 100 pps up to a peak frequency of about 2800 pps. The rate then falls exponentially as does the trailing edge of the driving pulse. This controlled repetition rate in response to radiation accomplishes two desired effects: First, it increases the duty cycle of the power supply as the current demand of the GM tube requires, thus allowing a low idling rate in the absence of radiation that conserves the battery. Second, it provides the source of the distinctive "chirp" sound used as the audible alarm. The audio amplifier to which the blocking oscillator pulses are fed has a threshold control actuated by the drive pulse from the second emitter follower. The amplifier is muted in the absence of radiation, but with each neon scaler discharge it is turned on to amplify the burst of pulses of the blocking oscillator as they increase abruptly to 2800 pps and then decay exponentially in repetition rate. The output of this amplifier is fed to a hearing aid earphone having an air coupling column dimensioned for resonance at the peak frequency of 2800 cps. In this manner the transistor blocking oscillator is used both as a power oscillator and as an alarm tone generator with the obvious saving of additional components and battery power.

This method of securing an audible alarm by means of a burst of tone in the center of the region of best response for the human ear is distinctly advantageous over the simpler method of merely amplifying the sharp pulse from the GM tube or the neon discharge. These narrow pulses do not have appreciable energy content in the audible spectrum, and most of the sound obtained in such systems comes from the shock excitation of the transducer in the audible range. This is an inefficient process. The use of a burst of tone of suitable length together with acoustical resonance in the transducer allows the production of a remarkably loud alarm with peak power input to the transducer of 20 milliwatts or less.

Operation in the less sensitive range is identical except that the larger scaling capacitor is also connected and about 250 GM pulses are required for one neon discharge.

4. Circuit Details

The complete schematic diagram is shown in Fig. 5. Four germanium transistors and five silicon diodes are used. Operation of the circuit is not conventional in several respects in which the properties of the semiconductor devices are used for multiple purposes. Detailed explanations of some aspects of the circuit follow.

The blocking oscillator, transistor Q1, is held in a cut off condition between oscillations by charge placed on capacitor C1 during the previous oscillation. The discharge path for C1 through resistors R1 and R2 is to the emitter of Q2 so that the repetition rate of the blocking oscillations will be proportional to the voltage of the Q2 emitter. While cut off, the Q1 collector voltage rests at the supply voltage of -4 volts. When the cut off charge is depleted, Q1 turns on regeneratively due to the feedback from the center-tapped transformer primary, and the collector voltage drops nearly to zero in saturation. This saturation period, determined by transformer characteristics, is about 180 microseconds. At the end of this period the transformer flux will begin to collapse, and Q1 is turned off regeneratively. The flyback effect of collapsing flux would cause a large negative voltage excursion at the Q1 collector if unchecked. However, this is limited by clamping in the transformer secondary circuit.

The turns ratio of the transformer is such that the initial 4 volt positive going pulse in the collector half of the primary induces a 130 volt positive pulse in the secondary. During this pulse, capacitor C3a is charged through the forward conductance of diode CR2 to the 130 volt amplitude with a polarity of plus toward the transformer winding. Now as the flyback causes the secondary voltage to swing negative, the 130 volt charge on C3a is added to the amplitude of the secondary voltage. If not clamped, this negative flyback would reach 200 to 300 volts. However, the reverse breakdown voltage of CR2 is selected for about 260 volts, and the sum of the secondary and C3a voltage is clamped to this value by the breakdown. Since the C3a voltage was 130, the secondary voltage also clamps at 130; and the secondary waveform is nearly symmetrical with excursions of plus and minus 130 volts. The primary voltage waveform is a reflection of the secondary with symmetrical excursions up to zero and down to minus 8 volts about the minus 4 volt supply. The reverse breakdown voltages of the other three quadrupler diodes are chosen higher than that of CR2 so that they do not enter into the clamping action. The output voltage of the quadrupler is twice the peak-to-peak amplitude of the secondary voltage, or about 520 volts. Tolerances allowed in the selection of the reverse breakdown voltage of CR2 will be reflected doubly in the output voltage. Current specifications allow a ±10 volt variation at CR2 with a consequent variation of at least ± 20 volts in the output at no load.

The current output of the GM tube is allowed to charge the selected range setting capacitor, C5 or C9. When the voltage across this capacitor reaches the firing potential of the neon lamp, it will discharge through emitter follower Q4. Successive GM current pulses will then recharge it, and the repetition rate of the neon lamp discharge is proportional to the output current induced in the GM tube by radiation.

The plastic cover over the neon lamp is colored red in order to filter out the shorter wavelength light from ambient illumination. If this were not done, the photocurrent so caused would discharge the accumulated charge as rapidly as it accumulates in radiation intensities less than about 10 mr/hr with bright sunlight ambient. Even with the red cover, there is some variation in the chirp rate at very low dose rates due to changes in ambient illumination of the neon lamp.

During this rapid rise time of the neon lamp discharge, the Q4 collector will fall as much as the Q4 emitter rises because of the equal 1 mf capacitors that each must charge. The emitter will therefore rise to half the supply voltage, or to 2 volts. Capacitor C8 is discharged by R10 and capacitor C6 is discharged by R9 and the input current required by Q2. Thus each neon lamp discharge produces a fast rising, exponentially decaying pulse at the base of Q2. This pulse is duplicated at the emitter of Q2 where it controls the blocking oscillator repetition rate and trips the threshold of the audio amplifier.

In very high radiation fields where the current output of the GM tube is so large as to cause a continuous DC discharge through the neon lamp into Q4, the DC voltage produced at the Q4 emitter is about 2 volts. It is for this reason that the C8-R10 network is used so that the peak alarm frequency caused by an overloading radiation level is the same as that obtained in single chirps at low levels.

In order to maintain the high voltage output of the quadrupler in the absence of appreciable radiation, it is necessary to have the blocking oscillator run at a continuous low idling rate. This is secured by setting the required minimum DC voltage at the Q2 emitter by the voltage divider R4 and R8. Further idling input that is temperature dependent is supplied by resistor R6 and thermistor R7 at the Q4 base. The combined effect of the two sources operates the blocking oscillator at a rate of about 100 pps at room temperature. The loss of collector leakage current at colder temperatures causes a drop in this rate that is compensated by the increase in the thermistor resistance. Similarly the increase in leakage currents at higher temperatures is partially offset by a decrease in the thermistor resistance. The overall temperature compensation is such that useful indications with the instrument are possible from -20 to +120°F. At the higher temperatures the increased DC output at the Q2 emitter will begin to overcome the threshold of audio amplifier and a steady hum is heard. This is easily distinguished from the radiation induced chirps.

Drive signal for the audio amplifier transistor Q3 is available at the proper level from the base of the blocking oscillator transistor and is coupled through capacitor C2. Base bias for Q3 is obtained from the Q2 emitter through R3. A silicon diode CR1 is in series with the Q3 emitter. This diode is used as a threshold element to mute the audio amplifier between chirps by virtue of the fact that such diodes have negligible forward conduction until the voltage across them exceeds about 0.5 volt. The idling voltage at the Q2 emitter is less than this threshold, and therefore the base and emitter voltage of Q3 will likewise be below that required for conduction in CR1. When discharges of the neon lamp produce pulses at the Q2 emitter as previously described, the diode threshold is exceeded and the amplifier is activated to amplify the blocking oscillator pulses. These pulses have been increased in rate by the same Q2 emitter pulse as previously described, and the resultant chirp is so obtained. The miniature earphone used as the transducer is of the type intended for use in eyeglass frame hearing aids.

During construction of the instrument it is necessary to choose the required values of R1 and R2 that will tune the peak frequency of the chirp exactly to resonance with the air column. The frequency is approximately 2800 cycles per second. Resistor R6 is also chosen at assembly to compensate for variations in the collector leakage of the transistors and set the idling battery current at room temperature to 1.4 milliamperes. This value has been determined to provide a safe margin of operation over the temperature range previously stated. The battery is rated at 1000 milliampere-hours of service; therefore, about 714 hours of operation -- almost one month -- is indicated.

The effect of temperature on the radiation indication is shown in Fig. 6. The regulation of the high voltage supply with load current is shown in Fig.7.

5. Prototype Experience

Approximately 130 prototype instruments of similar design to that just described have been built at ORNL. Early types were not encapsulated, and the lifetime was short due to breakage. As failures developed, the causes were noted so that unreliable components and methods could be eliminated. The present design incorporates the benefit of this considerable experience in the choice of every component with the possible exception of capacitors C5 and C9 which are recent additions. It is unlikely that these will be troublesome. Based on this experience, the only significant possibilities for failure lie with the GM tube and the earphone. The previously mentioned unorthodox high capacity discharge mode of GM tube operation was used in all but the most recent instruments, and there has been a considerable history of GM tube failure. However, the data is confused by the fact that the manufacturer has recently experienced some abnormal batches of tubes which failed with conventional self-quenching circuits in the same way - namely the occurrence of spurious pulses not radiation induced. The present mechanical layout separates the GM tube from other components to allow for possible destructive removal, replacement, and re-encapsulation. Since the present circuit is exactly that recommended for the GM tube, the expected reliability will be no different from that in more conventional applications. There have been two earphone failures in instruments that were in heavy field use. The failures were mechanical and not electrical.

There is another recurrent failure caused by shorting of the neon lamp electrodes if the instrument is dropped repeatedly. The soft wire supports allow repositioning of the electrodes during the swift decelleration of impact. It is felt that this problem is amenable to correction best through careful use and handling of the instrument rather than the considerable expense and effort of obtaining a shock-proof neon lamp.

Reports of the usefulness of the Personal Radiation Monitor in field experience have been uniformly good. The device can be placed in the pockets of workmen with only the most rudimentary instruction and yet be useful in warning of an unexpected dose rate. It is particularly useful to personnel around reactors or other shielded sources in helping them to choose the areas of least dose rate in which to perform necessary operations. Significant reductions in dose for given operations have been obtained in these cases. A calibrated instrument in the hands of a knowledgeable user becomes a useful means of measurement of unknown radiation levels. The greatest general value of the device is the "sixth sense" of constant awareness of the radiation level that it affords the wearer.

The assistance of R. J. Fox in the development of many aspects of the mechanical design of the PRM is gratefully acknowledged.

Fig. 1. External Appearance of PRM.

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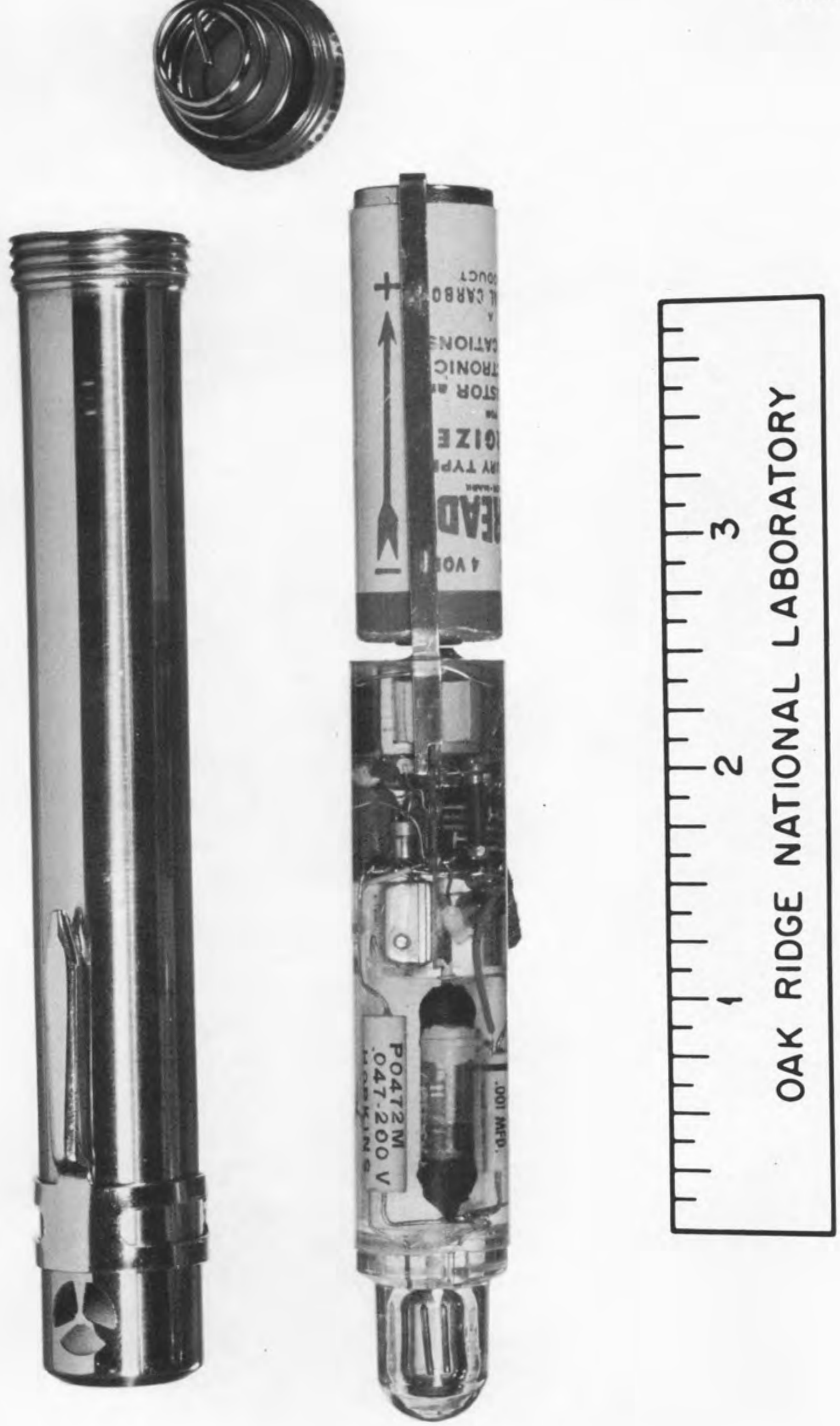

Fig. 2. PRM Disassembled.

Normal Range

1 mr/hr	12 chirps/min
2	26
5	68
10	183
100	578
1 r/hr	Chirps merging
2	Steady tone

Low Sensitivity Range

10 mr/hr	13 chirps/min
100	69
500	151
1 r/hr	204
10	1481
100	Chirps merging
200	Steady tone

Fig. 3. Table of Dose Rate vs. Chirp Rate

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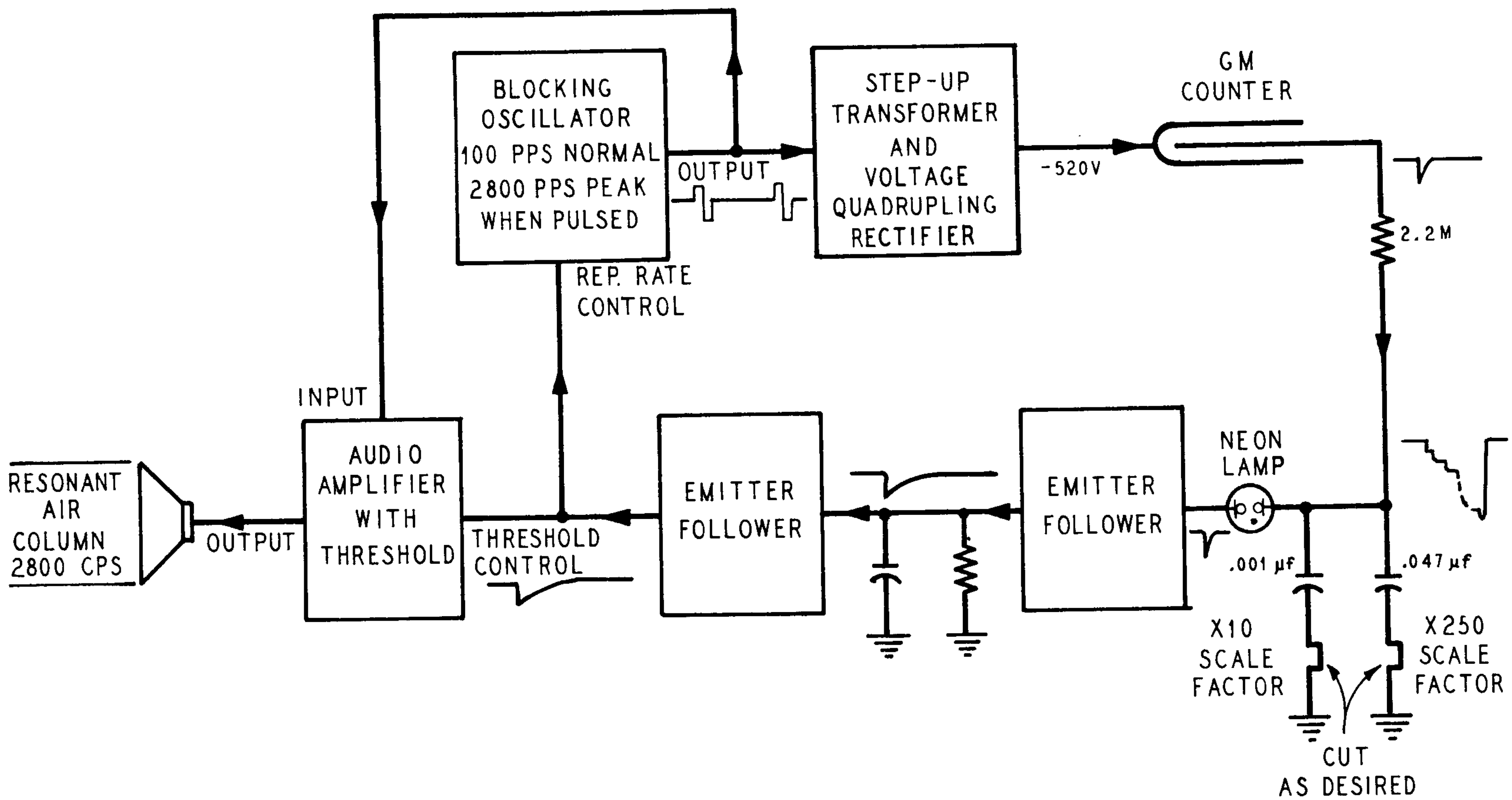

Fig. 4. Block Diagram Personal Radiation Monitor.

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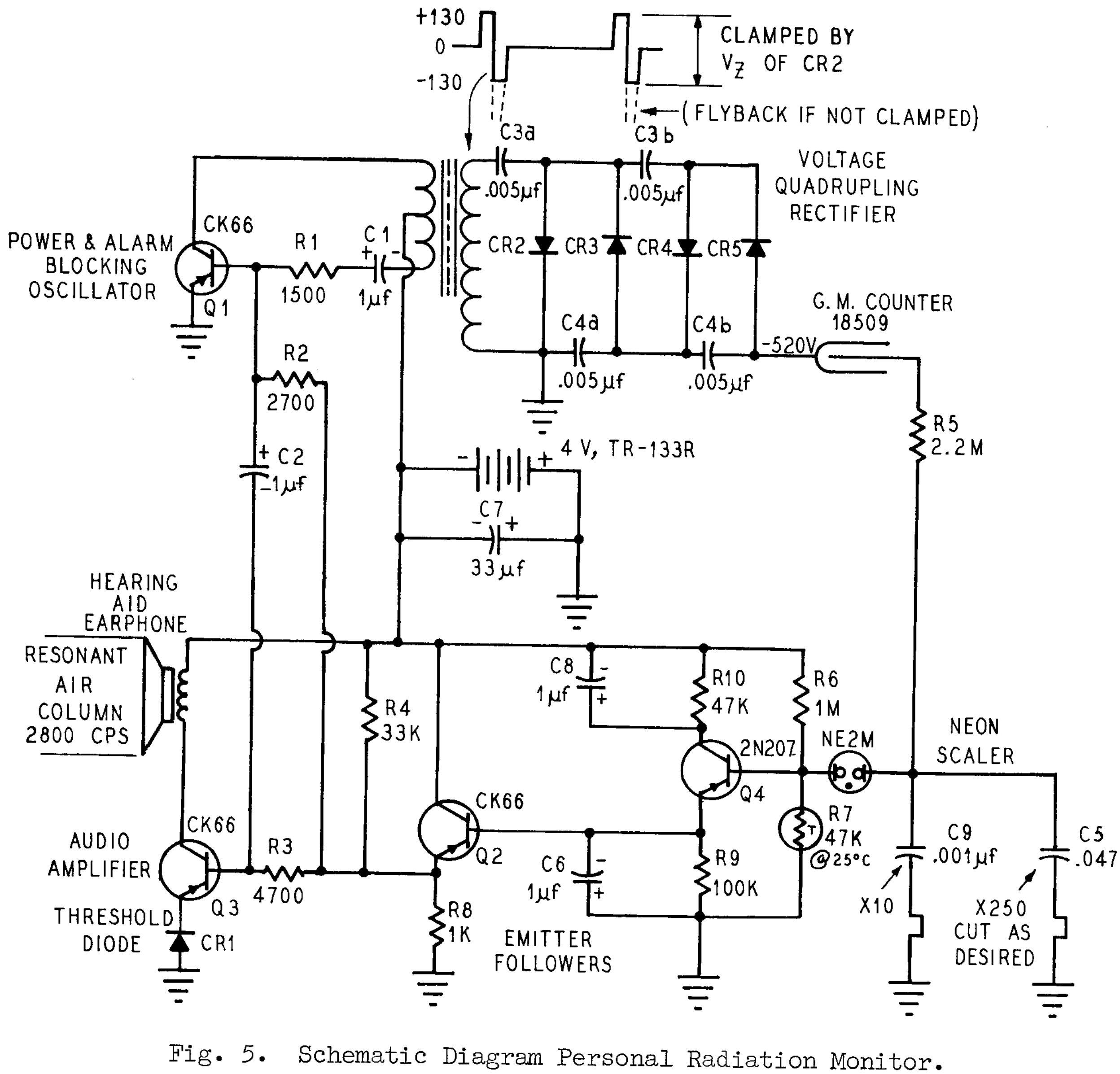

Fig. 5. Schematic Diagram Personal Radiation Monitor.

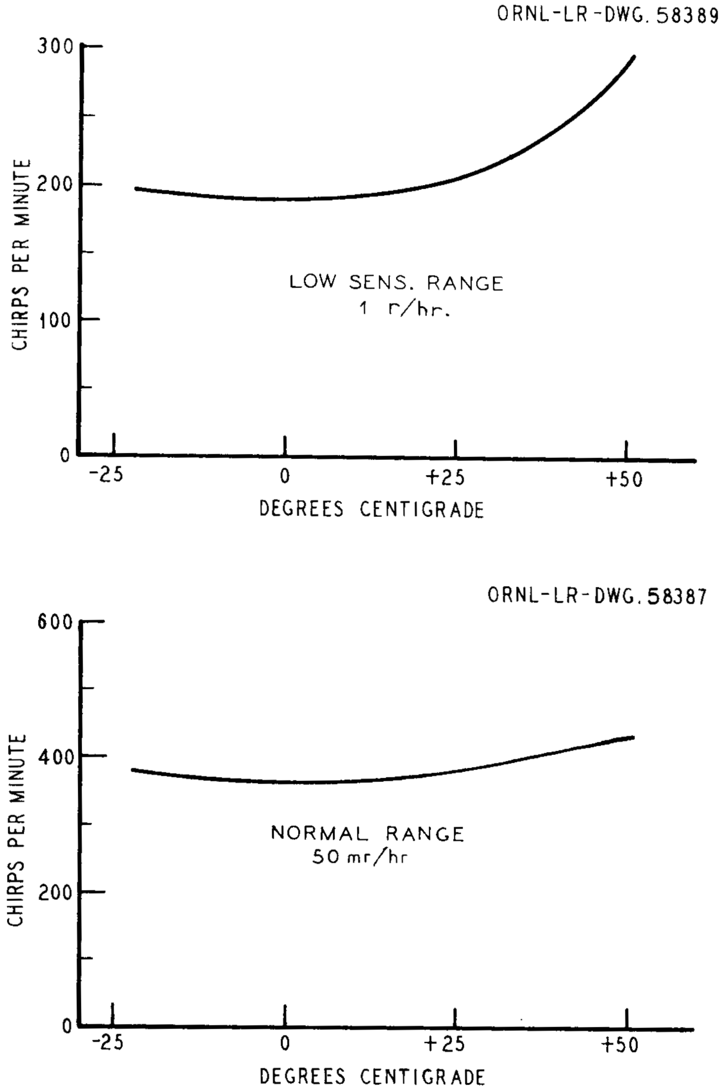

Fig. 6. Indications vs. Temperature.

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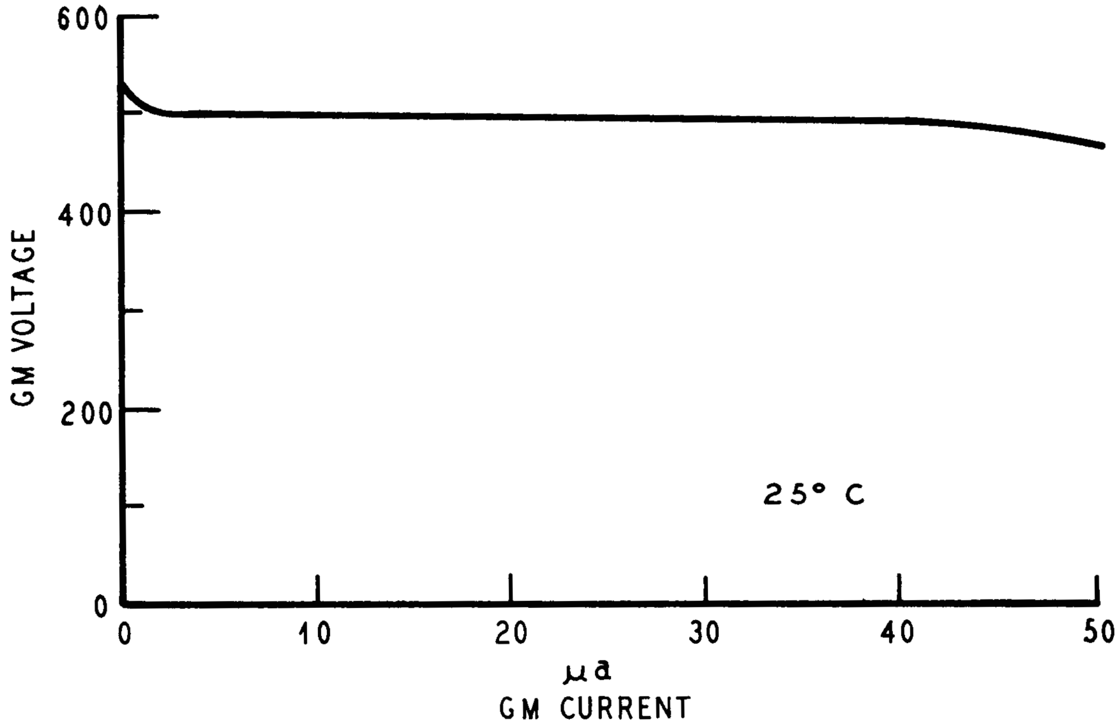

Fig. 7. High Voltage Regulation Against Load Current.

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