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AEC RESEARCH AND DEVELOPMENT REPORT

A PORTABLE MULTIPURPOSE RADIATION MONITOR

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Instruments
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A PORTABLE MULTIPURPOSE RADIATION MONITOR

by

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ABSTRACT

A basic electronic package for a portable multipurpose radiation monitor was designed, fabricated, and field tested. Transistorized plug-in circuits powered by rechargeable nickel-cadmium batteries, a readout meter, and an electromechanical register are contained in a 4" x 5" x 6" case. Three rate meter ranges, a battery check position, and a register integrator for low rates are provided. The circuitry contains seven silicon transistors on four plug-in cards. Neutron, alpha, beta-gamma, or alpha-beta-gamma detectors can be individually coupled to the electronic package. Calibration for each detector is simple and stable because the package is unaffected by temperature changes between 20 and 100°F. The monitor weighs about seven pounds, can be carried in one hand, requires no warmup period, and is easy to operate and service.

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* Du Pont's trade-mark for acrylic resins.

A PORTABLE MULTIPURPOSE RADIATION MONITOR

INTRODUCTION

Portable radiation survey instruments have been developed that use a single basic electronic package and various types of radiation detectors. This basic package with a series of detectors can measure alpha, beta, gamma (semiquantitatively), and neutrons. Plug-in electronic circuit cards and rechargeable batteries reduce and simplify maintenance and spare parts inventory. The instrument weighs about seven pounds, and the basic package is 4" x 5" x 6".

SUMMARY

Three electronic packages were designed and field tested with different types of detectors. All instruments performed satisfactorily. These prototypes demonstrated that a single electronic package can be used with four different types of radiation detectors. The life of the instruments in field use was greatly increased by using rechargeable batteries. During a 6-month field test, the three instruments required neither recalibration nor maintenance.

DISCUSSION

ELECTRONIC CIRCUIT OPERATION

The circuitry, Figure 1, uses a minimum of components and circuits. To further aid in quick and easy repair of the basic package, almost all components other than the meter, register, and selector switch are on plug-in cards that can be replaced as units. Silicon transistors minimize temperature-dependence effects.

The Dumont 6291 photomultiplier (PM) tube, which is used with three of the radiation detectors, and the high voltage divider network are in a detachable probe connected to the instrument case by a coaxial coiled cord. Bypass capacitors in the last two dynode stages of the PM tube ensure peak currents from a detector scintillation that exceeds the average dynode string current.

The preamplifier plug-in card contains the signal developing resistor, emitter follower, and two stages of amplification. The negative scintillation pulses developed across the PM tube anode

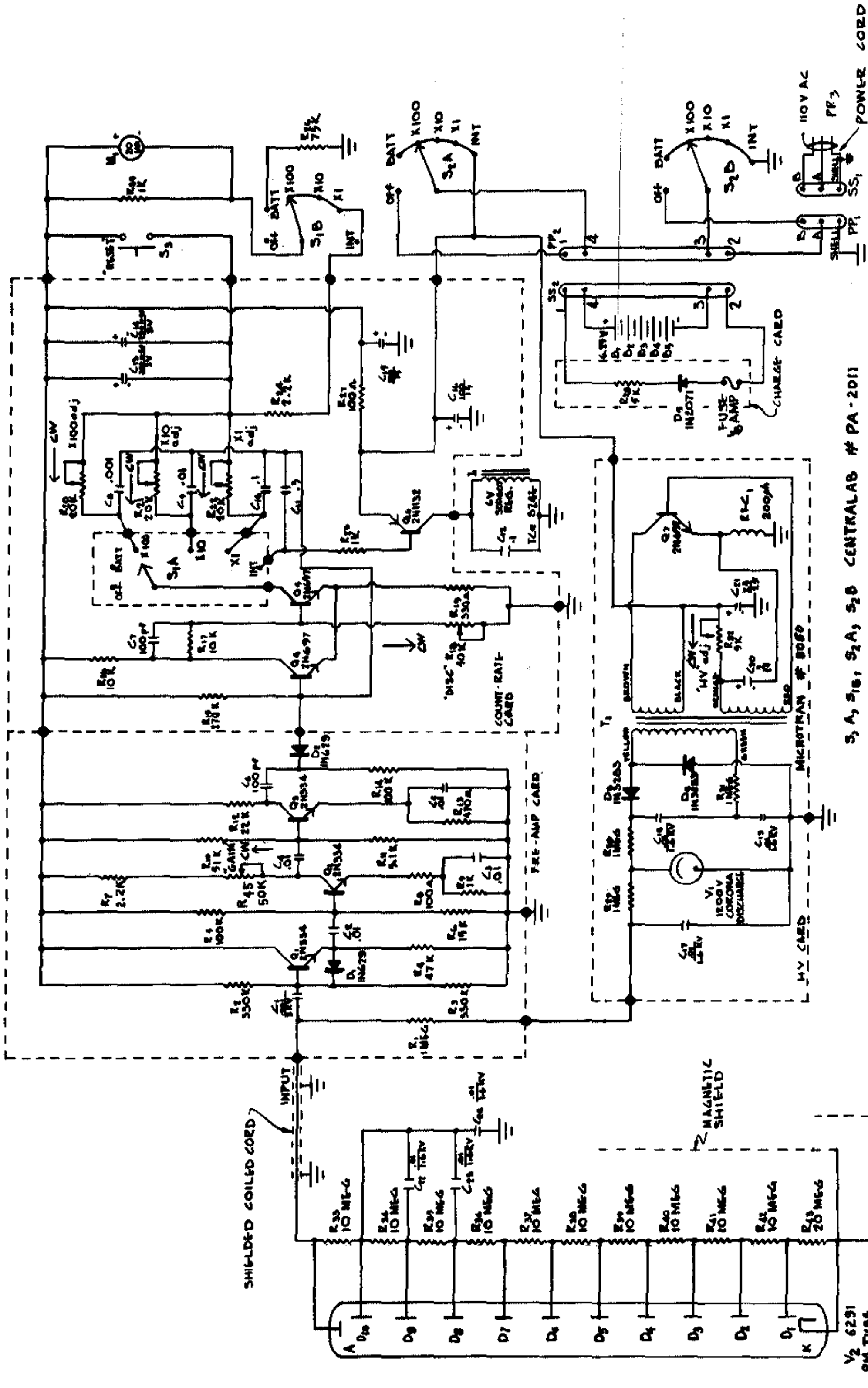


FIG. 1 BASIC ELECTRONIC PACKAGE CIRCUITRY

resistor R_1 are coupled to the base of Q_1, an emitter follower stage, via C_1. D_1 prevents burnout of the transistor by high voltage transients that are generated when the instrument is turned off. The negative pulses are coupled from the emitter follower to the first of two common-emitter amplifier stages, Q_2 and Q_3. The voltage gain in these two stages is approximately 60 and is controlled by potentiometer R_{45}; negative feedback in the emitters of both Q_2 and Q_3 ensures stability. The output of the preamplifier card through D_2 ensures that only negative pulses without any positive overshoot are coupled to the multivibrator stage.

The count-rate plug-in card contains a monostable multivibrator consisting of Q_4 and Q_5 and a register drive Q_6. In the monostable multivibrator, Q_4 is normally conducting and Q_5 is cut off by the voltage from the biasing network R_{16}, R_{17}, and R_{18}. Incoming negative pulses to the base of Q_4, a result of a scintillation, cut off Q_4, producing a positive pulse at the collector of Q_4 that is coupled to the base of Q_5 via C_7. Potentiometer R_{18} as a pulse height discriminator control allows the bias of Q_5 to be adjusted to reject the smaller scintillation pulses from gamma radiation and noise. The period during which Q_5 conducts is determined by the time required for the capacitor in the collector circuit of Q_5 to discharge sufficiently to bring the base of Q_4 back to a voltage bias point, thereby re-establishing conduction within Q_4. The negative pulse produced at the collector of Q_4 is then coupled via C_7 to cut off conduction within Q_5 and return the circuit to its initial state.

As a result of Q_5 being turned on, a negative square wave voltage pulse drawn through the meter circuit causes an up-scale reading. The meter deflection per pulse is determined by the value of the Q_5 collector capacitor used to gate the multivibrator. For higher counting rates, the use of a smaller value capacitor reduces the conduction time of Q_5 which reduces scale deflection per scintillation pulse. The meter movement is shunted by C_{13} and C_{14} to smooth out the Q_5 voltage pulses and to provide a uniform meter deflection. Potentiometers R_{20}, R_{21}, and R_{22} are used to calibrate the rate meter scales. Reset switch S_3 discharges C_{13} and C_{14} and allows the meter to be quickly returned to zero after a high meter reading.

In the register integrate position, PNP silicon transistor Q_6 replaces the meter circuit in the collector circuit of Q_5. Conduction of Q_5, as a result of a scintillation pulse, biases Q_6 into the conduction state. The collector circuit of Q_6 contains a Sodeco register that cycles for each gating of Q_6. Capacitor C_{11} determines the gating time of the multivibrator, which must be sufficient to allow the register to cycle mechanically.

The high voltage plug-in card contains a DC to DC converter which develops 1200 volts for the PM tube dynode string. Q_7 is used in a blocking circuit that oscillates at approximately 800 cycles per second. Potentiometer R_{32} is used to adjust the frequency of the oscillations to provide 1200 volts across the corona discharge tube V_1. This oscillator draws approximately 16 ma. The voltage generated in the secondary of T_1 is connected to a voltage doubler that develops slightly more than 1200 volts. Corona discharge tube V_1 regulates this high voltage to 1200 volts.

The charge plug-in card contains a fuse, halfwave rectifier D_5, and voltage dropping resistor R_{28}. Under normal charging conditions, the current is approximately 10 to 15 ma, depending on the voltage of the nickel-cadmium battery at the time of recharging. These batteries are never to be recharged for periods longer than 72 hours. Four 1.5-volt D-size flashlight batteries with a shorting wire across one of the five battery positions may be used to replace the five 1.25-volt nickel-cadmium batteries. A battery check position on the selector switch indicates the condition of the rechargeable batteries; the battery voltages are checked while under the normal operating current load, and the meter is switched across the batteries as a voltmeter.

Calibration of the instrument for a particular detector is simple and stable over long periods of time and remains unchanged between 20 and 100°F. The instrument with any of the four different detectors can be carried in one hand, is easy to operate and read, and requires no warmup.

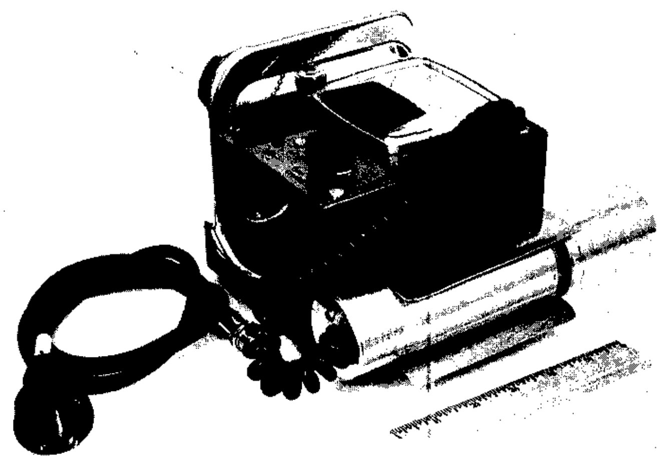
NEUTRON DETECTOR

The first prototype (see Figure 2) was a scintillation dosimeter for fast neutrons. Advantages over present instruments are:

- Low initial cost
- Effective discrimination against gamma radiation
- Convenient size and weight
- Nondirectional
- Sensitive to low neutron flux densities.

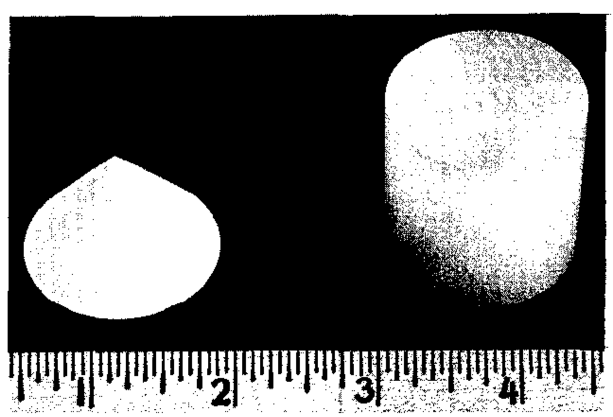
A unique feature of this instrument is the relatively simple fast detector which detects neutrons by the (n,p) scattering process. Because the radiation dose received by tissue exposed to fast neutrons is energy dependent, the detector was designed to attain a response proportional to that of tissue. This is

FIG. 2
NEUTRON DETECTOR



accomplished by a polyethylene moderating cylinder containing a "Lucite" cone-shaped light pipe in intimate contact with a Dumont 6291 PM tube (see Figure 3); the slanting surface of the cone is coated with silver-activated ZnS (9 mg/m^2). The high specific ionization of the recoil protons from the (n,ρ) reaction with hydrogen in the polyethylene produces scintillations within a ZnS(Ag) phosphor. Polyethylene has a relatively large cross section for the (n,ρ) reaction. The resultant recoil protons transfer their energy within a distance of less than 100 microns.[1] The conical scintillation surface compensates for faster neutrons by providing a greater scintillation area with increasing depth in the hydrogenous moderator. The shape and size of the detector were empirically determined to achieve an approximate tissue response for neutrons from 0.2 to 10 Mev. Larger light pulses from the proton interaction with ZnS(Ag) are counted, but the smaller pulses from the gamma radiation are electronically rejected. The symmetrical conical surface allows the detector to be relatively insensitive to directional effects.

FIG. 3
"LUCITE" CONE-SHAPED LIGHT PIPE AND POLYETHYLENE CYL.



In comparison with three commercially available neutron dose measuring instruments, the detector accurately measured neutron dose rates from a variety of complex neutron energy spectra over an energy range from 0.2 to 10 Mev. Three neutron dose rate meter ranges of 0 to 50, 500, and 5000 mRem/hr*, and a register integrator for low rates are provided. The detachable neutron detector probe (8" long x 1.75" diameter) can be used for glove port monitoring or in other limited spaces. With an electronic discrimination setting to allow only 10-20 c/m in a 5 R/hr gamma field, the fast neutron response is approximately 4 c/m/mRem/hr.

ALPHA DETECTOR

The second prototype was an alpha scintillation detector (see Figure 4) with a uniform response over the entire circular detection area of 100 cm^2. The detector is 4-1/2"-diameter x 1/32"-thick "Lucite" that is sprayed on one side with approximately 10 mg/cm of ZnS(Ag). The outward side of the scintillation area with the sprayed phosphor is covered with two layers of 0.00015-inch double aluminized "Mylar"**, which allows the detector to be used in direct sunlight. A 1-1/2" Dumont 6291 PM tube detects scintillations occurring on the fluorescent surface.

The high scintillation efficiency of ZnS(Ag) for alpha particles and its relative insentitivity to gamma rays allow electronic discrimination of the smaller gamma pulses. No light pipe is used in the two-inch distance between the scintillation surface and the PM tube to keep neutron response and probe weight to a minimum (the detector was designed for use in plutonium processing areas). Neutron response to a bare Pu-Be source is ~1 c/m/mRem/hr. By attaching the probe to the case, the instrument can be held in one hand for surface and smear-type monitoring, or it can be removed from the case for monitoring various locations and positions.

The only modification needed for the basic electronic package is a replacement meter faceplate which reads 0 - 500 c/m. This provides three count rate ranges of 500, 5000, and 50,000 c/m, and a register integrator for low count rates. The detector efficiency is 12%, with a complete insensitivity to gamma radiation up to about 5 R/hr.

** Du Pont's trademark for polyester film.
* Meter scale is marked in mRem/hr and calibrated by applying a dose-equivalent of 10 to the mrad/hr value measured by the neutron survey instrument.

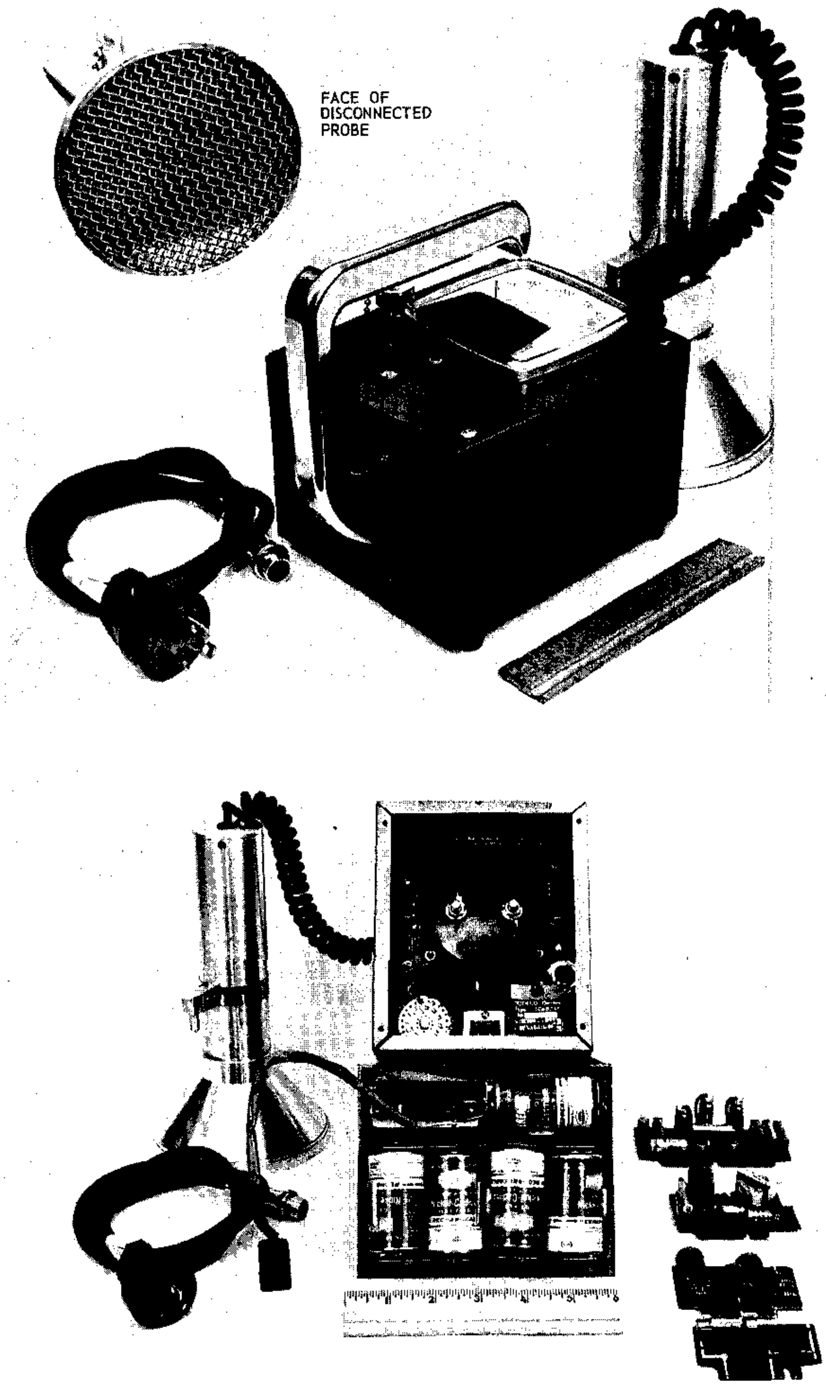


FIG. 4 ALPHA DETECTOR

BETA-GAMMA DETECTOR

A Geiger tube was used with the basic electronics, in place of the scintillation probe, to measure beta-gamma radiation (see Figure 5). Two minor modifications to the basic package made it compatible with the Geiger tube. To provide the 900 volts to place the tube on the Geiger plateau, a Victoreen type 5841 corona tube replaces V_1, the Victoreen type GV3A-1200 corona tube, and R_{32} is adjusted to provide 900 volts. The meter faceplate is modified to display readings of 0-500 c/m. This provides three count rate ranges of 500, 5000, and 50,000 c/m, and a register integrator for low count rates.

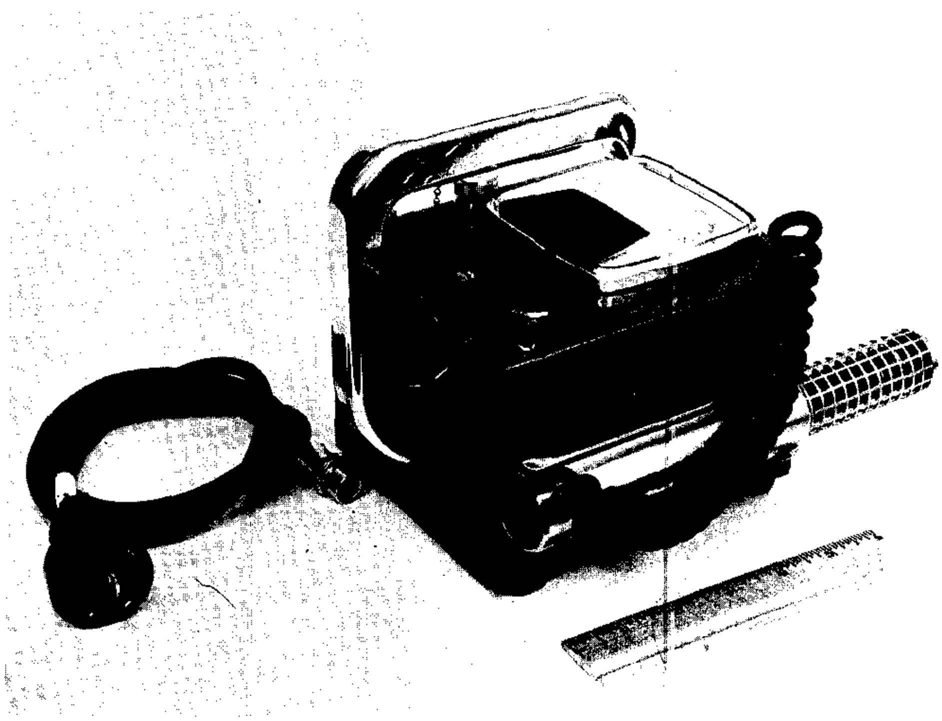


FIG. 5 BETA-GAMMA DETECTOR

ALPHA-BETA-GAMMA DETECTOR

An alpha-beta-gamma survey probe (see Figure 6) was also used with the basic electronics package. The probe is a 1/16"-thick x 1-1/2"-diameter NE-102 plastic scintillator (Nuclear Enterprises, Ltd.) sprayed on one side with 10 mg/cm^2 of ZnS(Ag). The combination of ZnS(Ag) and plastic scintillator provide scintillating material for alpha, beta, and gamma radiation. The plastic scintillator acts as a light pipe between the ZnS(Ag) surface and the PM tube. The outward side of the plastic scintillator sprayed with the phosphor is covered with a single layer of 1/4-mil double aluminized "Mylar", to make the end of the probe lighttight. A 1-1/2" Dumont 6291 PM tube in intimate contact with the NE-102 scintillator detects scintillations in both the ZnS(Ag) and the plastic scintillator. The probe can be removed from the case for monitoring, or the overall unit can be held in one hand for smear-type monitoring. Although this detector will not identify the type of radiation, it has the advantage of responding to single or mixed radiation when monitoring for possible contamination.

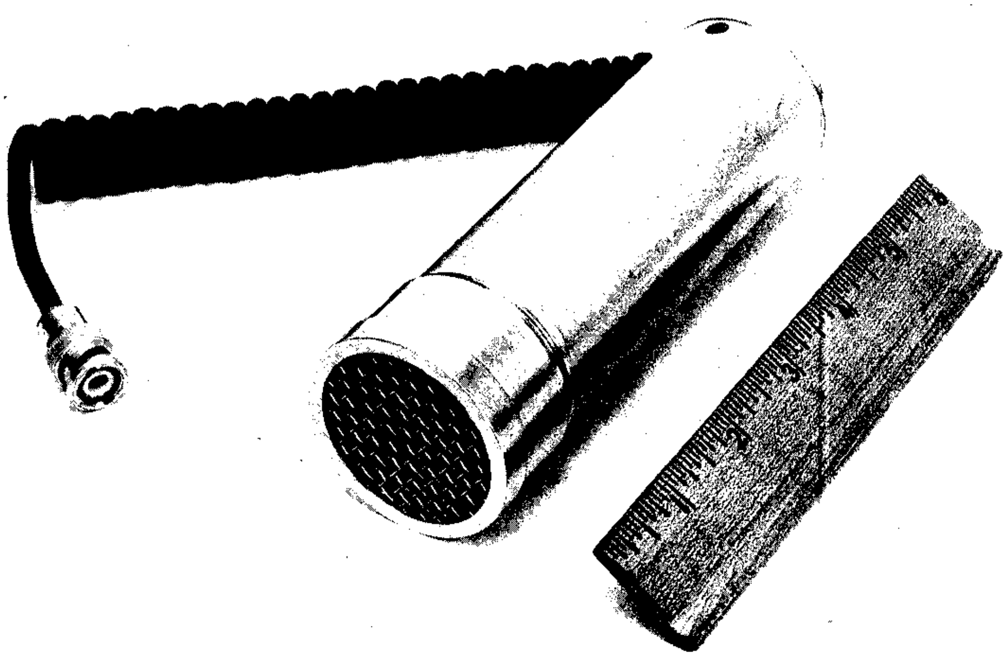


FIG. 6 ALPHA-BETA-GAMMA DETECTOR

The only modification needed for the basic electronics package is a meter faceplate which reads 0-500 c/m. This provides three count rate ranges of 500, 5000, and 50,000 c/m, and a register integrator for low count rates.

Conversion factors for this detector with the discrimination set to allow 1000 c/m/mR of gamma radiation are as follows:

	d/m/c/m
alpha (5 Mev)	5
beta ^{90}SrY	3
beta ^{204}Tl	15

REFERENCE

(1) W. F. Hornyak. A Fast Neutron Detector. Rev. Sci. Instr., 23, 264 (1952).