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CHARGE TRANSPORT TACTICAL DOSIMETER,(U)
JAN 77 S KRONENBERG, R A LUX, R PFEFFER

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CHARGE TRANSPORT TACTICAL DOSIMETER

ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

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CHARGE TRANSPORT TACTICAL DOSIMETER

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January 1977

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The charge transport dosimeter, an instrument capable of measuring doses of gamma rays and fast neutrons delivered to personnel, is intended as a second generation Army tactical dosimeter, replacing the present IM185. The instrument's response to gamma rays is based on the tendency of high atomic number materials to reflect the energetic electrons produced within matter by gamma rays, causing a positive charge to collect on a thin central conductor surrounded by a low atomic number insulator. It is made sensitive to fast neutrons

20. Abstract (contd)

as well by surrounding the collector with a hydrogenous radiator. By proper selection of collector and radiator dimensions and compositions, its quantum energy response and neutron-to-gamma response ratio can be tailored to match a wide choice of desired characteristics.

A number of experimental models of the charge transport dosimeter have been built and successfully tested on gamma rays and fast neutrons at various dose delivery rates. Results show that the instrument promises to satisfy all Army requirements for a tactical dosimeter while substantially reducing both production and maintenance costs.

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CHARGE TRANSPORT TACTICAL DOSIMETER*

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INTRODUCTION

The purpose of tactical dosimetry is to provide a troop commander with data about the current levels of nuclear radiation exposure of his troops during the conduct of a battle in which tactical nuclear weapons are used. To be suitable for this purpose, dosimeters must be easily portable, rugged and capable of accurately indicating both the gamma ray and fast neutron doses delivered by a prompt initial radiation burst and ~~the~~ gamma ray doses delivered by the subsequent fallout field. Although an acknowledged need for a tactical dosimeter exists (1), the Army does not yet have such an instrument in the field. The tactical dosimeter IM185 now under advanced development appears capable of meeting all of the rigid requirements set for such an instrument. It is, however, a technologically sophisticated instrument which will be costly to produce and will require considerable depot and field maintenance. The IM185 operates by collecting secondary electrons ejected by neutron or gamma radiation from surfaces within a vacuum chamber and indicates the quantity of accumulated electrons by discharge of an electrometer. The instrument requires a charger for the electrometer and a power supply for the internal vacuum pump.

By taking advantage of the recently investigated phenomenon of radiation-induced charge buildup in insulators (2), it has become possible to develop a dosimeter which meets all of the requirements of the Army tactical dosimeter while avoiding the technological complexity of the IM185. This new instrument, the charge transport

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dosimeter, is intended as a second generation replacement for the IM185. Its design promises several significant advantages:

1. It is entirely self-contained.

2. It requires no external power sources such as batteries.

3. Elimination of the vacuum system reduces maintenance.

4. Unit production costs are expected to be low.

5. There is no residual electrical leakage in the package during pre-exposure storage.

PRINCIPLE OF OPERATION

Detection of Gamma Rays

The detection of gamma rays by the charge transport dosimeter is based upon the nonuniform charge distribution induced by gamma rays in the vicinity of thin layers of high-atomic-number (Z) materials embedded in low-Z media (3).

The physical basis for this effect may generally be described as follows: Consider a slab of low-Z material much thinner than the absorption length of the gamma rays but thicker than the maximum range of the electrons produced within it by the gamma rays. Monodirectional irradiation of such a slab will produce a current of photo- and Compton electrons which travel in the general direction of the incident radiation beam. Placing a perturbing layer of higher-Z material perpendicular to the beam within the low-Z medium will alter the electron current in the medium on both sides of the layer. On the "upstream" side, i.e., the side between the layer and the radiation source, the current is significantly reduced because of the large number of electrons produced in the medium which have undergone large-angle scattering in the perturbing layer. On the opposite side of the layer, the backscattered electrons are removed from the current but additional Compton and photoelectrons produced in the layer are added. Depending on which effect predominates (a function of gamma ray energy and of both thickness and composition of the perturbing layer), the net effect may be either an enhancement or a reduction of electron current. In all cases the effect is restricted to a region of medium no farther from the perturbing layer than the maximum range of electrons produced by the gamma rays. The interior of the medium, away from such boundary regions, is the "equilibrium region" where incoming and outgoing currents exactly cancel.

We have observed that for hard x-rays and gamma rays in the MeV range, the net result of this effect is a loss of electrons from the perturbing layer. If the perturbing layer is electrically isolated by a layer of low-Z insulator (thin compared to a typical electron range) and completely enclosed by a low-Z Faraday cage (whose thickness exceeds the electron range), gamma irradiation will cause the perturbing layer to acquire a positive charge.

We have already exploited this effect to construct dose rate meters which are capable of sensing the direction from which gamma rays arrive (3). However, by appropriately shaping the collecting electrode it is possible to achieve an isotropic response.

Detection of Neutrons

The detection of fast neutrons by the charge transport dosimeter involves the accumulation within a high-Z collecting layer of recoil protons produced in a surrounding hydrogenous radiator. When a hydrogenous medium is irradiated by fast neutrons, energetic recoil protons are produced by the elastic scattering of neutrons from hydrogen nuclei within it. If a high-Z layer is embedded in this hydrogenous medium and is electrically insulated from it, some of these protons will penetrate and stop within the layer. Protons suffer much less backscattering in the high-Z layer than do electrons; those that enter it are likely to remain, causing it to acquire a positive charge. The layer can lose charge only through the escape of (a) high-Z ions produced within the layer through neutron elastic scattering, and (b) protons and alpha particles produced within the layer by neutron-induced inelastic nuclear reactions. We have found that neither of these mechanisms is sufficient to overcome the positive charging: the range of high-Z ions is too short to allow the transport of any significant charge through their escape, and the pertinent inelastic reaction cross sections are small compared to the elastic (n,p) scattering cross section. The magnitude of the accumulated positive charge can be determined as in Reference 4.

FEATURES OF INSTRUMENT

The basis of the charge transport dosimeter is a thin layer of high-Z electrical conductor, such as lead, surrounded completely by a very thin layer of low-Z high-quality insulator, such as polyester. Enclosing this insulator is a Faraday cage of low-Z material whose thickness is greater than the maximum range of relevant recoil protons or electrons as shown in Figure 1. By making the Faraday cage of hydrogenous material (i.e., a shell of polyethylene between an

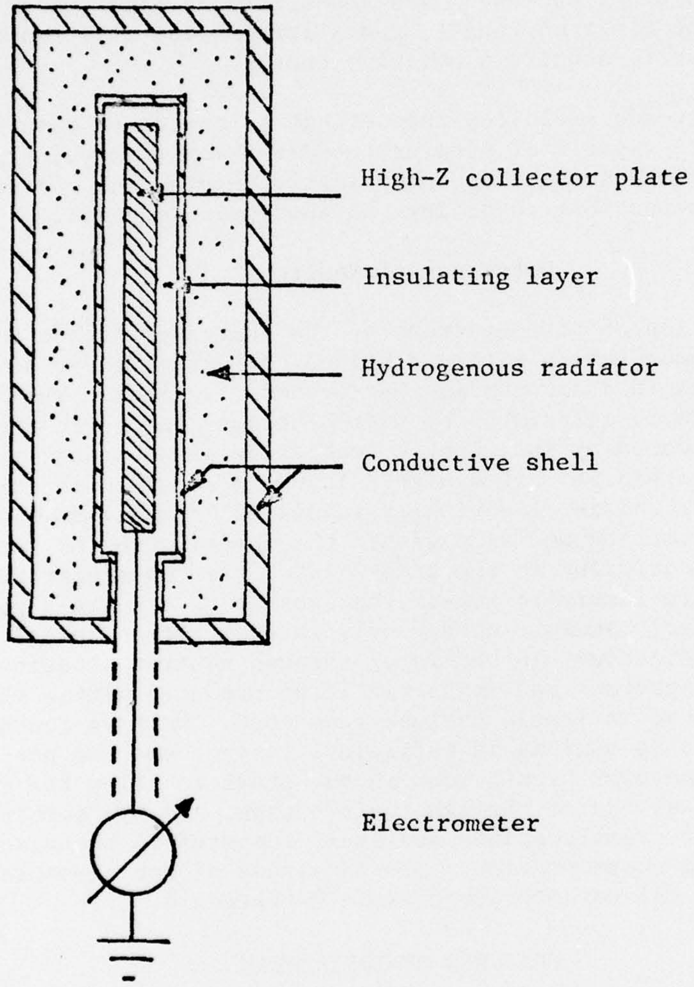

Figure 1. Cross Section of Charge Transport Dosimeter.

outer aluminum conductor and a thin inner layer of Aquadag conductor), the same dosimeter can be made sensitive to both gamma rays and fast neutrons. After irradiation, the Faraday cage is grounded and the charge acquired by the high-Z layer is read out by an electrometer connected to it.

Laboratory devices were constructed in exactly this simple way. Initial tests of their operating characteristics revealed a number of problems which had to be solved, including leakage due to air ionization during irradiation, and low sensitivity. The modifications made to solve them were only one possible method; others will be developed for future models.

Avoidance of Air Ionization

Discharge by air ionization, principally in the electrometer and its connections, competes with charge accumulation on the high-Z layer, giving false readings. One way to avoid this is to isolate the readout electrometer from the charge accumulation plate during irradiation; a momentary connection is made later only for readout by pressing a needle switch through the insulator to the high-Z layer. If a silicone rubber insulator is used, the puncture remaining in it after the needle is removed has a negligible influence on the subsequent performance of the system. By using a high-Z plate whose capacitance is much larger than the capacitance of the electrometer, many readings (with subsequent discharges of the electrometer) can be taken without significantly reducing the potential on the center plate.

Variation of Sensitivity

When the thickness of the center plate and insulator are chosen to optimize the radiation-induced charging of the center plate, the capacitance of the assembly is large. Because of this large capacitance, the induced voltage on the center plate (while ample to be read with electronic instruments in the laboratory) is too low to be read directly by a simple quartz fiber electroscope such as would be used in a field dosimeter. This problem was solved by connecting a variable capacitor in parallel with the electroscope. With this capacitance maximized, the collecting plate is connected to the electroscope, charging it to the plate potential. The connection is broken and the capacitance then reduced, raising the voltage on the electroscope. The dose is determined by the reduction in capacitance necessary to raise the electrometer to a fixed voltage. Using this system, a wide range of doses can be read with the same instrument.

Laboratory models measured doses between 10 rad and 40000 rad (tissue) with less than 15% error.

Variation of Energy Dependence and Neutron to Gamma Response Ratio

The neutron energy response of the dosimeter depends on the composition of the radiator. Within the constraints of significant hydrogen content and low-Z, its composition can be adjusted over a range of materials to give a desired spectral response. The sensitivity can be varied also by adjusting the radiator thickness. Figure 2 shows the calculated sensitivity to D-T neutrons vs radiator thickness. The calculated sensitivity to fission neutrons has a saturation value of 0.012 $\mathrm{pC \cdot cm^{-2} \cdot rad^{-1}}$. Polyethylene was chosen for the laboratory model to approach tissue equivalence.

The quantum energy response to gamma rays is a function of both the thickness and the atomic number of the high-Z collector. There are severe constraints on its thickness: if it is thin enough to significantly affect the gamma ray response (less than 5% of the electron range) (2), its fast neutron sensitivity is drastically reduced. So it is best to control the gamma ray response through control of the layer's differential electron density, i.e., through proper choice of composition. Typical gamma ray sensitivities are 1.5 $\mathrm{pC \cdot cm^{-2} \cdot rad^{-1}}$ for a lead collector in a Mylar medium and 0.5 $\mathrm{pC \cdot cm^{-2} \cdot rad^{-1}}$ for an aluminum collector in Mylar.

Freedom from Dose Rate Saturation

No effect which could make the instrument dose rate dependent exists for even the highest obtainable dose rates. Recombination effects are negligible in the solid dielectrics. Space charge saturation does not occur because of the high energies and low currents of the protons and electrons.

LABORATORY TESTING

To investigate the effects of varying the composition and dimensions of the collecting and emitting portions of the dosimeter, test models were constructed. Each of these devices was a planar disk whose cross section was similar to that shown in Figure 1. The high-Z collecting layer was a 9.8 cm diameter lead disk; the Mylar insulating layers were each 0.0012 cm thick; the polyethylene radiators were each 0.2 cm thick; the inner conductive shells were of Aquadag-coated paper; and the outer shells were of 0.48-cm thick aluminum. The

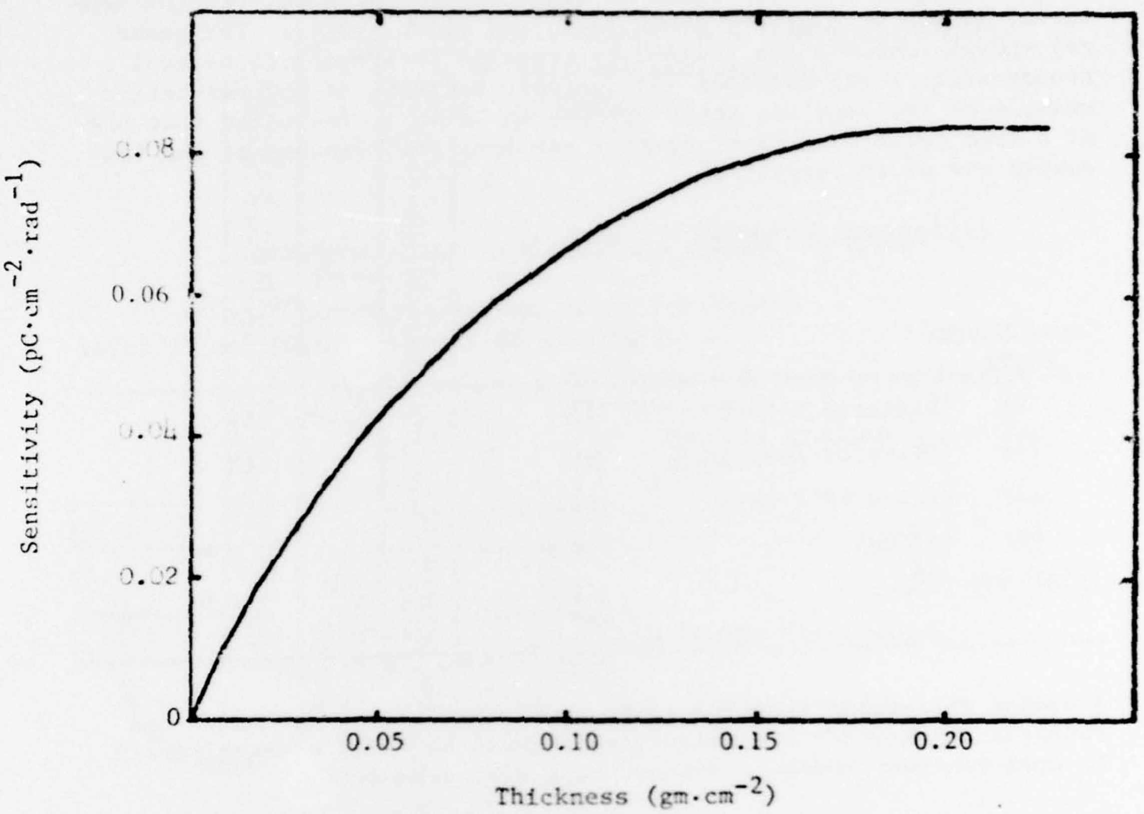

Figure 2. D-T Neutron Sensitivity of Charge Transport Dosimeter vs Radiator Thickness.

collecting electrode was connected by a shielded cable to an external Keithley 610B electrometer. Care was taken to assure that no accidental ion chamber was created in any part of the device exposed to radiation.

The expected dose rate independence and freedom from high dose rate saturation were confirmed at tests using fast burst reactor neutrons, linear accelerator gamma rays, and flash x-rays. The gamma ray energy response was studied by exposing the device to several steady-state x-ray machines and isotopic sources. A representative example of the results, which appears in Table 1, indicates that use of a lead collecting layer greatly enhances the response at the low-energy end of the spectrum.

TABLE 1. ENERGY DEPENDENCE OF GAMMA RESPONSE

Gamma Energy (KeV)		Response ($pC \cdot rad^{-1} \cdot cm^{-2}$) 0.0025 cm Pb layer	0.039 cm Pb layer
85	(Filtered X-ray)	12	13
178	(Filtered X-ray)	11	12
222	(Filtered X-ray)	12	11
661	(^{137}Cs)	2.6	2.9
1170-1330	(^{60}Co)	1.4	1.6

A number of further response tests involving various collector and radiator thicknesses and materials, as well as tests of sensitivity to both fission and D-T neutrons, were also conducted.

In the course of further development, a systematic series of such experiments is necessary to optimize the operational parameters to match desired performance characteristics of specific dosimetry systems.

DESCRIPTION OF WORKING MODELS

Bench models of the charge transport dosimeter (Figure 3) have been constructed which incorporate some necessary features of the field dosimeter, although at this time in a form suitable only for laboratory use. To provide a more isotropic response, they were

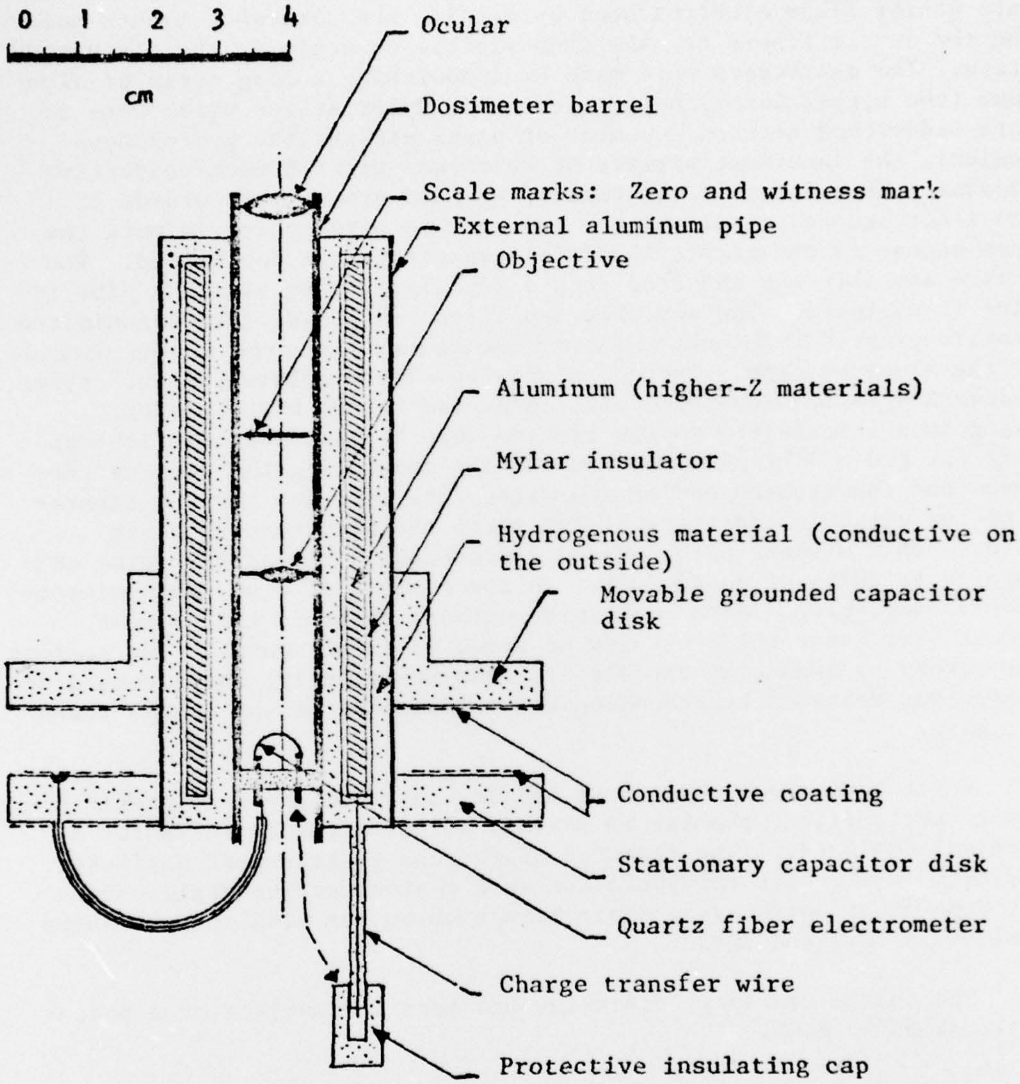

Figure 3. Working Bench Model of the Charge Transport Tactical Dosimeter

made cylindrical. Obsolete civil defense dosimeters were converted into quartz fiber electroscopes by bending the horseshoe mounts holding the quartz fibers to make them visible on scale in the discharged state. The dosimeters were made by sandwiching a long strip of aluminum (the high-Z layer) between two thin Mylar strips which were in turn sandwiched between a number of paper strips (the hydrogenous medium), the innermost surface of which was painted with conductive Aquadag. This assembly was tightly wrapped around the outside of the electroscope barrel and the ends potted with epoxy, in much the same manner as ordinary cylindrical capacitors are fabricated. The entire assembly was inserted into a tightly fitting aluminum pipe to give it rigidity. The variable capacitor consisted of two aluminized acrylic plastic disks, one fixed and one movable, mounted on the outside of the aluminum pipe. Instead of having a "zero volume switch," these models had Teflon-insulated wire connected to the high-Z layer. Charge was transferred to the electroscope by removing a Teflon cap from the end of the wire and momentarily connecting the exposed terminal and the exposed end of the wire. The dose was read by separating the variable capacitor plates until the electroscope fiber pointed to a witness mark, the distance between the plates being calibrated in units of dose (similar to the readout of a standard micrometer). Replacing a dose scale with witness marks in the readout viewer eliminates the necessity of using an electrometer. The readout was zeroed by grounding the electroscope momentarily; the accumulated charge was released by grounding the exposed end of the charge transfer wire.

Tests have shown that these models, and more advanced models now under construction, promise to satisfy all Army requirements for a tactical dosimeter. The features of the charge transport dosimeter may also lead to its consideration as a cost-effective replacement for some other nontactical dosimeters such as the civil preparedness dosimeters IM92 and IM95.

The charge transport dosimeter has been the subject of a patent application by ECOM.

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