Methods and Approaches to Dosimetry

by

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Space radiation represents by far the most difficult and most challenging task for dosimetry. It comprises not only virtually all of the radiations observable on earth but also includes various components which will not be produced in the laboratory for many years to come. High Z particles having energies of the order of tens of Gev per nucleon and protons having even higher energies can initiate an enormous variety of processes and one cannot dismiss the possibility of unknown or unexpected particles or interactions. The fact that very energetic processes are likely to be quite rare aggravates rather than simplifies the problems. A number of lines of evidence indicate that at the low dose rates normally encountered in space the high LET of energetic nuclei of large Z, and the energy releases attendant to various cascades produced by very energetic nuclei in general will be of profound importance. Consequently dosimetry must totally encompass not only an extreme dynamic range but also great differences of fluence rate.

Missions in which this kind of equipment can be deployed are likely to be few and they may well entail the requirement that the equipment has to be completely automated and operate reliably for months or even years. The fact that the equipment must be both complex and reliable means of course that it will be expensive but this may be a comparatively minor problem since the costs should still be a small fraction of the funds required for the mission. However even in the absence of financial strictures it is difficult to conceive of systems that will yield the desired information.

For the purposes of current earthbound radiation protection practice irradiation conditions are completely specified by the absorbed dose and its distribution in linear energy transfer, at all points in a suitable phantom. Although, such a determination is already quite difficult it is by no means certain that it would be adequate for space. Radiation protection standards were developed with little or no regard given to some of the radiations encountered in space and they also envisage dose limits which one might not be able to accept for astronauts. For these reasons and also because the analysis of any unexpected biological effects would require optimum physical radiation data it is highly desirable that the dosimetry system yield what might be considered to be the most complete radiological physics information. This is best expressed in terms of R(y) the time rate at which lineal energy*, y, is deposited at all locations in a human phantom and at all diameters of interest.

*The lineal energy (1) y is defined as E/$\bar{d}$ where E is the energy deposited by a charged particle and its secondaries in a tissue region of mean diameter $\bar{d}$.

The diameters of interest can in principle range from nanometers (the dimensions of macromolecules) to perhaps tens of micrometers. This latter dimension which appears to be about the maximum effective track diameter for ions of any energy(2) corresponds to the volume occupied by from ten to perhaps a hundred cells. In this connection, it might be remarked that at least one theory of radiation carcinogenesis (3) postulates that malignances arise only if several contiguous cells are injured.

At present there appear to be no methods in existence to determine energy deposition in tissue regions that are smaller than a few 100 nanometers. Between this level and the upper limit given above individual energy depositions in tissue can be experimentally determined only by simulating tissue volumes by much larger volumes of tissue equivalent gas in which proportional counting is performed. (4) Gas detectors lack the comparative simplicity, permanance and energy resolution of various solid state devices. An additional short-coming is that under certain circumstances simulation of a unit density tissue equivalent mass by a cavity filled with tissue equivalent gas is imperfect and can lead to an overestimate of energy deposition. (4,5) Nevertheless, the superior sensitivity and spatial resolution of gas detection make it the method of choice.

It is thus evident that present day technology is incapable of producing the dosimetry system ideally required and that some compromises must be made. The remainder of this presentation will be a discussion of a system which may be near the optimum compromise possible today. This apparatus has not been built and the design is largely conceptual. While the discussion will be primarily concerned with basic principles a few technical points will be made to indicate how various functions could be accomplished.

This system is designed to meet six primary objectives:

1) Determination of the dose received at various locations in the body of an astronaut. This dose to be averaged over periods of the order of 5 minutes.
2) Determination of the frequency with which high LET particles (LET > 10 keV/μm) impinge on the human body.
3) The distribution in depth of the dose due to such individual particles.
4) The LET of these particles at various depths in the human body.
5) The direction of incidence of these particles.
6) A determination of the track structure of these particles, i.e. the distribution of delta rays and other secondaries within distances comparable to the dimensions of the mammalian cell (3μm).

In addition to these primary purposes the system could provide at least on a statistical basis information on the total energy and nuclear charge of heavy particles.

These objectives are to be met by evaluation of the data produced by two sub-systems, which in the following will be termed the macro-system and the micro-system.

The macro-system is designed to yield information on points 1 through 5, the micro-system is designed to provide information on points 4 and 6. Both systems are in essence multiple ionization chambers which are normally operated in a gated pulse mode. However, when objective 1 is pursued, the macro-system operates in a pre-set time mode (in the following termed the dose mode). Both of the multiple detectors and the early electronic stages are to be contained in a hermetically sealed stainless steel drum having approximate dimensions of 20" diameter and 20" height. The optimal location with respect to a space craft would be such that the axis of this detector system coincides with the outside surface of the vehicle so that half of the detecting system sees free space with a minimum of shielding, whilst the other half sees the interior of the space craft.

Associated equipment for gas replacement and any additional electronic equipment, such as power supplies, should occupy a space that is less than two cubic feet.

The macro-system is schematically shown in Figure 1. It consists of a series of concentric cylindrical shells of tissue equivalent plastic having a total diameter equivalent to that of the human body (about 12"). The thickness of shells decreases exponentially from the center outward. The annular gaps are occupied by tissue equivalent gas at such a pressure that the width of the gap is equivalent to about 3 μm of unit density tissue. Collecting regions are established in these gaps by suspension of grids of the type shown in the drawing. The grids are secured by two simple insulators across the top and bottom of the phantom. The individual collecting regions might on the average cover about 15° of a full circle in each gap. Quite possibly the width of these chambers may vary both with respect to polar angle and with respect to distance from the center. All of the cylindrical shells are connected to a positive high voltage supply.

When the macro-system operates in the dose mode the grids are ungrounded for some period (e.g., 5 minutes) and then sequentially grounded through a digitizing network in which the accumulated charge is quantified as a corresponding number of pulses. It should be possible to obtain and store all of the numbers in a matter of milliseconds. In this mode the macro-system merely yields absorbed dose as a function of location in a phantom of the human trunk.

When the phantom is operated in the pulse mode, the principle of operation is as follows:

All tissue equivalent rings are at a positive potential and connected to a fast triggering circuit and all the grids are normally grounded. Traversal of any one gap by a high LET (> 10 KeV/μm) particle results in the liberation of 10^3 to 10^4 electrons. These are collected very rapidly and provide a signal
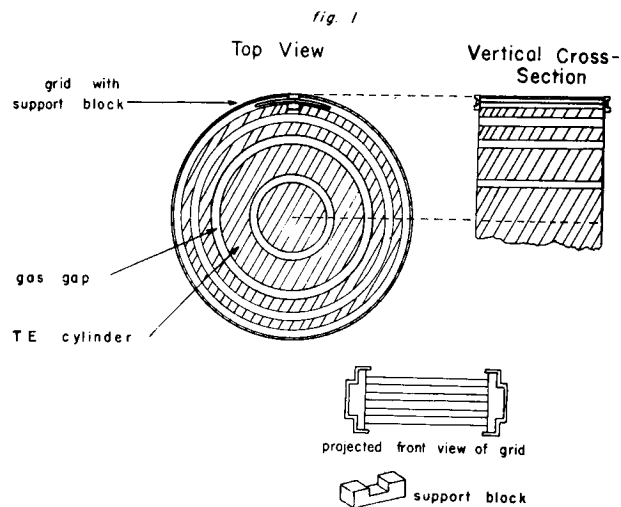
Figure 1. Schematic representation of the macro-system. Collection in various sectors of the annular gas filled regions is accomplished by grids. One of these is shown in position. Another grid together with one of its two supporting insulators is shown near the bottom.

which ungrounds all grids which then collect the much more slowly moving positive ions. After about a millisecond (to allow for ion collection) these grids are read in essentially the same manner as in the dose mode.

Large guarding scintillators above and below the ends of the cylindrical phantom can be operated in anticoincidence to assure that only particles entering nearly normal to the phantom axis can trigger the measuring cycle.

In the pulse mode only those sections in which the primary particle or any of its secondaries have passed register a signal.

In view of the very skewed distribution of particle energies it may be necessary to obtain continuous sensitivity for large but not for smaller events. This can be readily accomplished by utilization of a simple circuit which disables triggering by particles between 10 KeV/μm and, say, 100 KeV/μm for some period following each event registration.

The function of the micro-system is to provide detailed information on track structure. A pair of scintillators (or semiconductor detectors) operated in coincidence determines the direction of the incoming particle (see Fig. 2) which may traverse a number of vanes made of increasing thicknesses of tissue equivalent plastic. Strips consisting of multiple positive ion collectors are situated at some distance from these vanes. The collectors are mutually

insulated from each other and from a co-planar grounded conducting plane. The common electron collector serves again as the trigger for un-frounding of these collectors and the subsequent individual charge measurement.

This geometry permits a determination of lateral energy spread due to delta ray formation or other secondary particle production with a resolution of a few degrees. The prompt secondaries of a nuclear cascade are frequently emitted at angles of less than one degree but they are almost invariably of low LET, being protons or other light particles of very high energy. The products of nuclear evaporation having low energy (and consequently high LET) tend to be emitted isotropically.

Provided certain technical features such as an automatic gas replacement system and a variety of high speed electronic circuits are added to the elements which are shown schematically in Figs. 1 and 2 this system should be entirely feasible with present date technology and it should be well suited to automatic data transmission. It has been presented here as an example of the comprehensive and unorthodox approaches which will be needed in space radiation dosimetry.
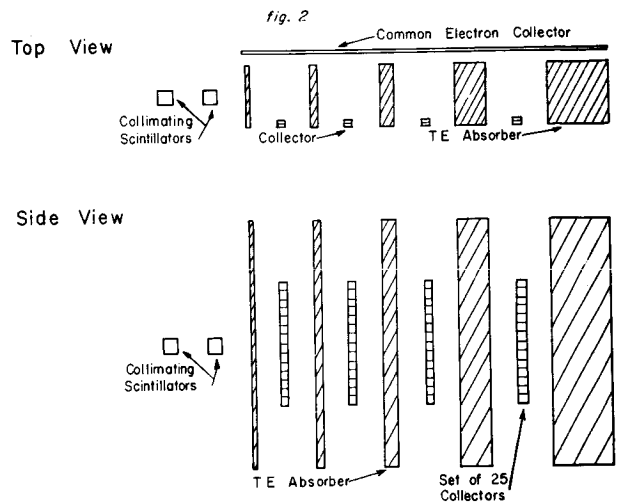
Figure 2. Schematic representation of the micro-system. High LET particles that have passed through both of the collimating scintillators traverse TE barriers of increasing thickness. The lateral energy spread is determined along strips of mutually insulated collectors.

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