Conf-920431--24

PNL-SA--19981

DE92 012347

USE OF TISSUE EQUIVALENT PROPORTIONAL COUNTERS TO CHARACTERIZE RADIATION QUALITY ON THE SPACE SHUTTLE

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April 1992

Presented at the
American Nuclear Society New Horizons in
Radiation Protection and Shielding
April 26 - May 1, 1992
Pasco, Washington

Work supported by
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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ABSTRACT

Tissue equivalent proportional counters (TEPC) are essentially cavity ionization chambers operating at low pressure and with gas gain. A small, battery powered, TEPC spectrometer, which records lineal energy spectra at one minute intervals, has been used on several space shuttle missions. The data it has collected clearly show the South Atlantic anomaly and indicate a mean quality factor somewhat higher than expected. An improved type of instrument has been developed with sufficient memory to record spectra at 10 second intervals, and with increased resolution for low LET events. This type of instrument will be used on most future space shuttle flights and in some international experiments.

INTRODUCTION

Because the radiation encountered in space is primarily high energy charged particles and their secondaries, the evaluation of the quality factor (Q) is as important as the measurement of the dose. Furthermore, since numerical values and even the definition of quality factor have been under scrutiny for several years[1,2] it is important to obtain as much information as possible about the radiations producing the dose so that the effect of alternative definitions of Q can be evaluated. Quality factor, which is currently based on linear energy transfer (LET), has been evaluated many different ways. If the LET spectrum is known or can be measured, Q can be obtained from the definition for each LET value, and dose equivalent can be calculated directly. In most terrestrial radiation protection situations, instruments with response functions which simulate dose equivalent are used. In some situations measurements of lineal energy density, f(y), have been used both to determine the LET spectrum and to estimate Q or dose equivalent directly.

The ideal instrument for dosimetry in space would be a radiation spectrometer which responds to all directly and indirectly ionizing radiations, indicating the type and energy. Because the incident radiation fields are not isotropic, the detector would have to be omnidirectional, or sensitive enough that it could sample all directions in a reasonable time. Because the fluence of particles with the highest LET values is quite low, the detector would have to have a large sensitive area. In fact, charged particle spectrometers have been used extensively for characterizing the space radiation environment,[3] and will probably continue to play an important part in the radiation protection program, but no single spectrometer which meets all the requirements has been devised. Charged particle spectrometers do not respond to indirectly ionizing radiations which may constitute a significant portion of the dose in well shielded locations. They typically have a relatively small sensitive area and acceptance angle and require a long time (many days) to obtain statistically significant data at all angles. They generally have a limited range of response, often excluding significant portions of the incident radiation and its secondary particles. Furthermore, in order to take advantage of the available data, a great deal of information has to be processed and stored, at a minimum a three dimensional histogram of the number of particles as function of mass and of velocity. As the miniaturization of electronic components progresses and microprocessors become more powerful, it will be possible to develop more compact and versatile spectrometers, but they will remain sensitive to only specific types of radiation.

Cavity ionization chambers, on the other hand, are sensitive to all types of radiation, are fundamentally omnidirectional, and can be sensitive to very low doses, even to individual energy deposition events. The accuracy of dose measurements made with a cavity chamber is limited only by the fidelity with which a chamber can simulate the subject for which the dose is desired. The depth in tissue where the dose is to be measured and the wall thickness of the chamber influence the attenuation of low energy radiation and buildup of dose due to secondary particles. For practical reasons these are not generally identical in the subject and the detector. Furthermore, truly tissue equivalent materials suitable for building detectors are not available, generally the detector materials contain too much carbon and too little oxygen to be truly tissue equivalent, but the simulation in terms of energy deposition is quite good. The primary limitation of a cavity ionization chamber operating at atmospheric pressure is that it provides no information about the radiation quality.

The tissue equivalent proportional counter, a cavity ionization chamber simulating a very small tissue volume, provides additional information in the form of the stochastic quantity lineal energy (y) and related microdosimetric properties of the radiation.[4] The lineal energy is defined by

$y = \epsilon/l$ where ϵ is the energy imparted to the small volume and l is the mean chord length of that volume. The energy imparted is the sum of the energy transferred in each interaction between the incident particle and the atoms in the volume minus any energy that is transported outside the volume by secondary particles. This is essentially the stopping power times the chord length with corrections for energy loss straggling, delta ray transport and short tracks.[5] For the radiations of concern in the space environment these corrections are generally quite small and the LET distribution can be determined by deconvolution of f(y) and the cord length distribution. Relatively simple approximations can also be used to calculate the dose equivalent, and in most situations these give statistiely significant results at much lower doses than are needed for an accurate deconvolution of the LET.[6]

The definitions of microdosimetric quantities are independent of the size and shape of the volume and are relevant whenever the volume is small enough that the stochastic properties of the radiation are important. However, the measured distribution does depend on the size of the volume if straggling, delta ray range, or primary particle range are important, so the geometry of the detector must be specified. Frequently a spherical detector is used, primarily because of its unique chord length distribution, Figure 1, and possibly because it simulates the typical biological target, a cell nucleus. Cylindrical detectors may be a better choice for dosimetry instruments since they can be made more rugged and resistant to microphonic noise. Their chord length distribution is more complicated in that it depends on the ratio of diameter to length, but some of the approximate methods for evaluating dose equivalent may be more accurate with a cylindrical detector than when used with a spherical detector.

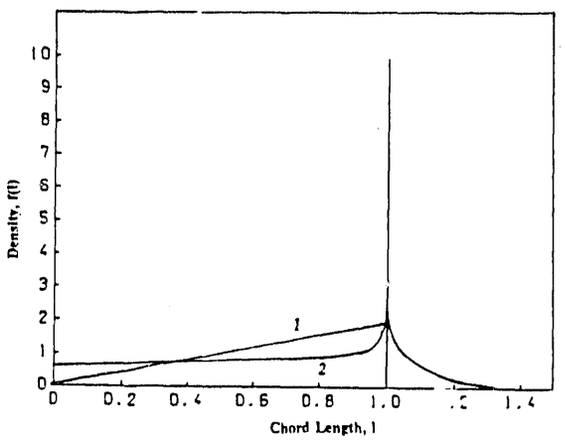


Figure 1 Calculated chord length distributions for a sphere (1) and a cylinder with length equal to its diameter (2).

Site diameters from a few tenths of a micrometer to a few hundred micrometers can be simulated by a proportional counters a few cm in diameter. Typically a simulated diameter of one or two micrometers is used because it minimizes the effects of straggling and delta ray escape without exceeding the track lengths of most radiation. The physical size of the detector can also be varied over a wide range, from about 1 mm to more than 25 cm in diameter, depending on the requirements of the application. For a given dose rate the detected count rate increases with the cross sectional area of the detector. Increased count rate reduces the dose required to get a statistically significant value of the dose equivalent, but the maximum count rate is generally limited by the processing time of the electronics. Thus detector diameter is chosen as a compromise between minimum resolved dose equivalent, maximum dose rate and overall instrument size.

A tissue equivalent proportional counter utilizes a gas avalanche to amplify the ionization produced in the gas filled cavity. The gain is determined by the gas properties, the anode wire diameter, and the voltage between the anode and cathode. Gains of over 1000 can be obtained, but saturation may occur for very large energy deposition events. A gas gain in the vicinity of 300 is more reliable. At this gain, a single ionization in the detector, corresponding to an average energy deposition of about 30 eV (depending on the W value of the gas), will result in 300 electrons, 4.8×10^{-17} coulombs, at the preamplifier input. At this detector gain a high energy heavy ion with a stopping power of 1000 keV/μm crossing center of a 1 μm site will produce a 1.6×10^{-12} coulombs at the preamplifier input. Analysis of these signals requires an extremely low noise electronics system with an unusually wide dynamic range.

A block diagram of the electronics usually used to analyze the signals from a TEPC is shown in figure 2. A charge sensitive preamplifier with a gain of 10^{12} volts per coulomb and the lowest possible noise, typically 100 electrons RMS without added input capacitance, is required. Shaping amplifiers with a time constant of about a microsecond are required to achieve this low preamplifier noise level. Two shaping amplifiers, with different gains and independent analog to digital converters, are used to analyze the wide range of pulse sizes. One amplifier gain is set at about 3 (shaped pulse peak height over preamp pulse height) in order to avoid saturation for the maximum energy deposition expected. The second one is set with gain approximately 100 times larger in order to resolve the low LET events. The high voltage required is in the range of 500 to 1000 volts, depending on the individual detector. Since gas gain is a strong function of voltage, approximately doubling for each 50 volt increase, the voltage must be stable. Noise and ripple on the high voltage will be capacitively coupled into the preamplifier, so they must be minimized. However, the detector current is extremely small, generally much less than a nanoamp, so the high voltage is easily filtered. Conventional multi channel analyzers and data storage devices are used in laboratory applications of tissue equivalent proportional counters, but a variety of specialized instrumentation packages have been developed for stand alone dosimetry applications.

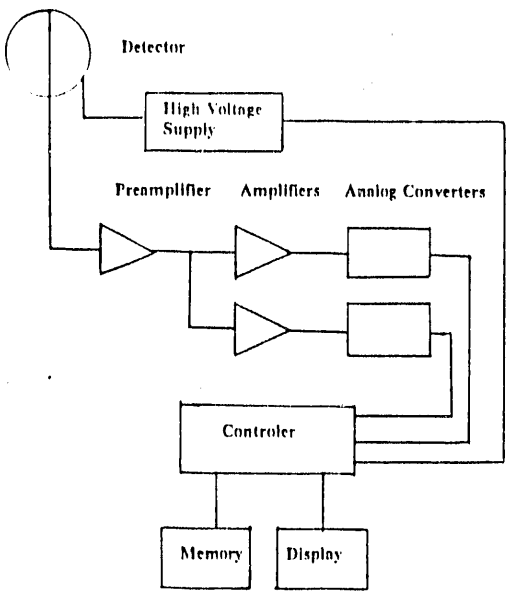


Figure 2 Block diagram of a typical TEPC based dosimeter.

INSTRUMENT FOR SPACE SHUTTLE EXPERIMENTS

A compact, battery powered electronics system for use on the space shuttle, designated Model B, was designed a few years ago. This instrument was intended primarily to monitor the total dose, and the component of the dose due to high LET secondary particles, as a function of time. In order to accomplish this function with minimum size and power consumption, the spectral data from the low gain analog to digital converter is compressed into a 14 channel, approximately logarithmic, histogram by the system's microprocessor. The low LET, high gain amplifier, data occurs at much higher count rates and could not be histogrammed by the low power circuitry available at the time this system was designed. Instead, each event is analyzed and the sum of the pulse heights as well as the number of events in a time interval is recorded in two additional channels. In this way the total dose due to low LET events and the average y value of events below the high LET threshold can be calculated and the spectrum of high LET events can be seen in some detail. The boundary between high and low LET events is adjustable, and has been set at 5 keV/μm for recent experiments. The dose can be determined by summing the energy deposited in the detector, that is the number of events in each bin times the mean energy for that bin, and dividing by a constant which includes the detector size and mass.

In order to characterize the radiation field as a function of geographic location, the instrument is designed to accumulate data for a specified period and then transfer it to static random access memory. The accumulation period is adjustable, but the total memory is limited to 256 kbytes, or about 7500 spectra plus time stamps and other overhead. In most space shuttle experiments the accumulation period has been set at one minute, resulting in about 5 days of data.

The configuration of this instrument was chosen for minimum physical size so it uses a cylindrical detector 1.24 cm in diameter and 6.3 cm long. The detector is located inside the electronics enclosure, figure 3, and is partially shielded by the circuit boards as well as the aluminum housing in addition to its own electrostatic shield and vacuum housing. The entire

Figure 3 The model B spectrometer with battery box.

detector and electronics package measures 5.4 x 8.25 x 17.8 cm and weighs 0.725 kg. It consumes slightly less than one watt of power which is provided by zinc air cells in a separate battery box measuring 4.1 x 7.6 x 17.8 cm and weighing 1 kg. This battery is sufficient to operate the system continuously for more than 7 days.

The model B spectrometer has been utilized on several space shuttle missions including STS 31 (Hubbel telescope) and STS 40 (Spacelab). Figure 4 shows the dose rate as a

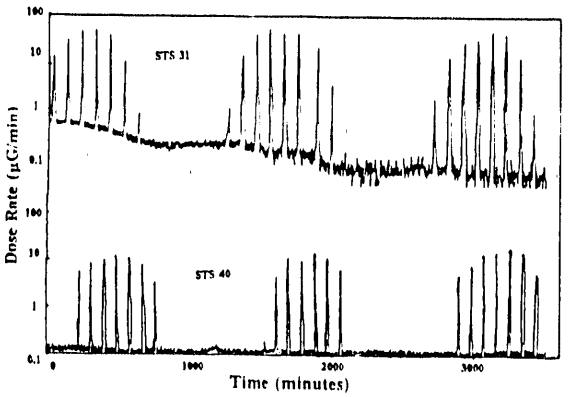


Figure 4 Dose rate as a function of time (measured at one minute intervals) for segments of the STS 31 and STS 40 space shuttle flights.

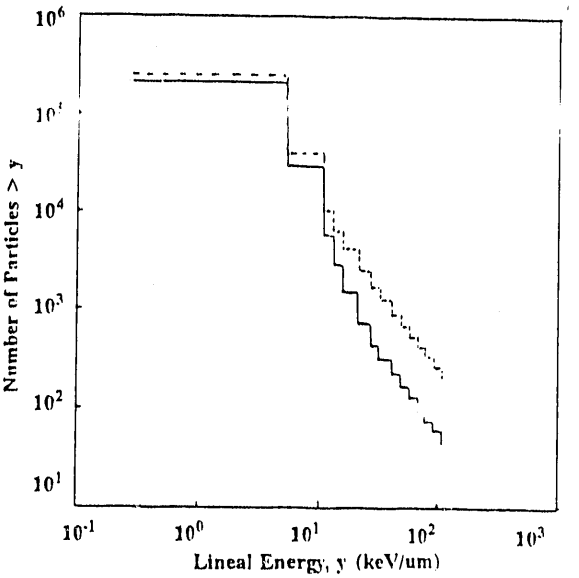


Figure 5 The number events due to trapped particles (solid) measured in SAA and non-trapped particles (dashed) measured on STS 40.

function of time for a portion of each of these flights. The peaks in these records result from the passage of the instrument through the South Atlantic anomaly, SAA, a region where asymmetry in the earth's magnetic field results in the trapped radiation belts dipping to altitudes which are used by the space shuttle. This region extends from roughly 0 to -60 degrees longitude. Approximately 7 successive orbits of the shuttle each day will pass through the anomaly, and a passage through the center of the anomaly lasts for about 10 minutes of the 90 minute orbit. The dramatic difference is the dose rate through the SAA is due to the difference in the altitude of these two flights; 390 x 278 km for STS 40 and 620 km for STS 31. This difference is reflected in the average dose rates of 0.0095 and 0.24 rad/day respectively. On STS 40 slightly less than half of the total, 0.0042 rad/day is due to these passes through the SAA, while the remainder of the dose is due primarily to galactic cosmic rays which penetrate the earth's magnetic field. On STS 31, the vast majority of the dose is accumulated in the SAA.

Because of the strongly peaked path length distribution in the long cylindrical detector, it is reasonable to assume that the LET of each event is equal to the lineal energy. Figure 5 shows the lineal energy density, f(y), for STS 31. The dose equivalent can be calculated by summing, over all channels, the product of the number of counts in each channel, the mean energy of that channel, and the quality factor for the corresponding LET. The average quality factor is obtained by dividing the dose equivalent by the dose. For the STS 40 data, which should be representative of the exposures in the planned space station Freedom, the quality factors were 1.55 in the SAA and 2.36 for the remainder of each orbit.

FUTURE INSTRUMENTS

Although the model B TEPC spectrometer is satisfactory for its originally intended application, the investigation of high LET secondary particle dose, it lacks sufficient resolution at low LET values to provide a good test of dose prediction models or an accurate evaluation of quality factor. Use on long term missions such as the space station and Mars exploration is not possible since the unit must be recalibrated at approximately 6 month intervals to compensate for gradual contamination of the counting gas. Furthermore, more precise location of the South Atlantic anomaly is desired, and this requires recording spectra on shorter intervals when high dose rates are encountered. Increased memory for data storage, and a more powerful microprocessor, capable of modifying the data acquisition procedure in response to dose rate are needed. A more powerful microprocessor would also make a variety of self-test and calibration functions possible, and would result in substantially reduced calibration and maintenance costs. Finally, many measurements would benefit if the detector were independent of the electronics enclosure, significantly reducing the shielding around the detector, and also making it possible to install it at selected locations.

A new system, incorporating all of these features has been developed for future space shuttle experiments. New detectors, cylindrical, but with length equal to diameter and specifically designed for grounded anode operation to reduce electronic noise have been designed. These detectors can be equipped with an internal alpha particle source and a computer controlled shutter for automated detector gain

checks. If the gas gain is low, the microprocessor increases the high voltage to return the gain to its nominal value. The preamplifier and shaping amplifiers are housed in a small enclosure mounted directly to the detector, again to minimize electronic noise and electromagnetic interference from the digital components of the rest of the system. The spectrometer employs two fast 8 bit successive approximation type analog to digital converters and a programmable gate array, rather than a microprocessor, to histogram the data. As a result, the processing time for each event is approximately equal to the shaping amplifier pulse length, and low LET events can be analyzed in detail. The compression of the two eight bit spectra into histogram bins for data storage is under microprocessor control, but 32 logarithmic bins will generally be used. A microprocessor controlled duel test pulser is provided for automated testing of the electronic system and time or temperature induced changes in the amplifier or analog to digital converter offset or linearity can be corrected in the dose and dose equivalent calculations. A variety of calculations and data compression routines can be performed. For example, the instrument can calculate and record the dose rate at one second intervals, record spectra at ten minute intervals, and also record spectra at shorter intervals if a significant increase in dose rate is detected.

The system is modular in design, allowing easy custimization for specific experimental requirements. The basic system would consist of a detector with linear electronics and a spectrometer box with multichannel analyzer card, a microprocessor card, a power supply, and one or more memory cards. One of the 80x86 family of microprocessors is used, ant a limited subset of MSDos services is provided. This allows application development to be carried out in high level languages. Both 3 Mbyte battery backed static random access memory and 8 Mbyte electronically erasable and programmable read only memory cards have been built. The EEPROM has the advantage that it does not require battery backup for long term data storage, and thus can be considerable lighter than the static RAM. The increased capacity and versatility of this system has resulted in some increase in size, the box for up to six cards is 5.97 x 11.4 x 20.3 cm, but power consumption has remained at about one watt.

ACKNOWLEDGEMENT

This work supported by the US National Aeronautics and Space Administration under related services agreement with the US Department of Energy under contract DE-AC06-76RLO 1830.

REFERENCES

1. NCRP, Recommendations on Limits for Exposure to Ionizing Radiation, National Council on Radiation Protection and Measurements, Bethesda (1987).

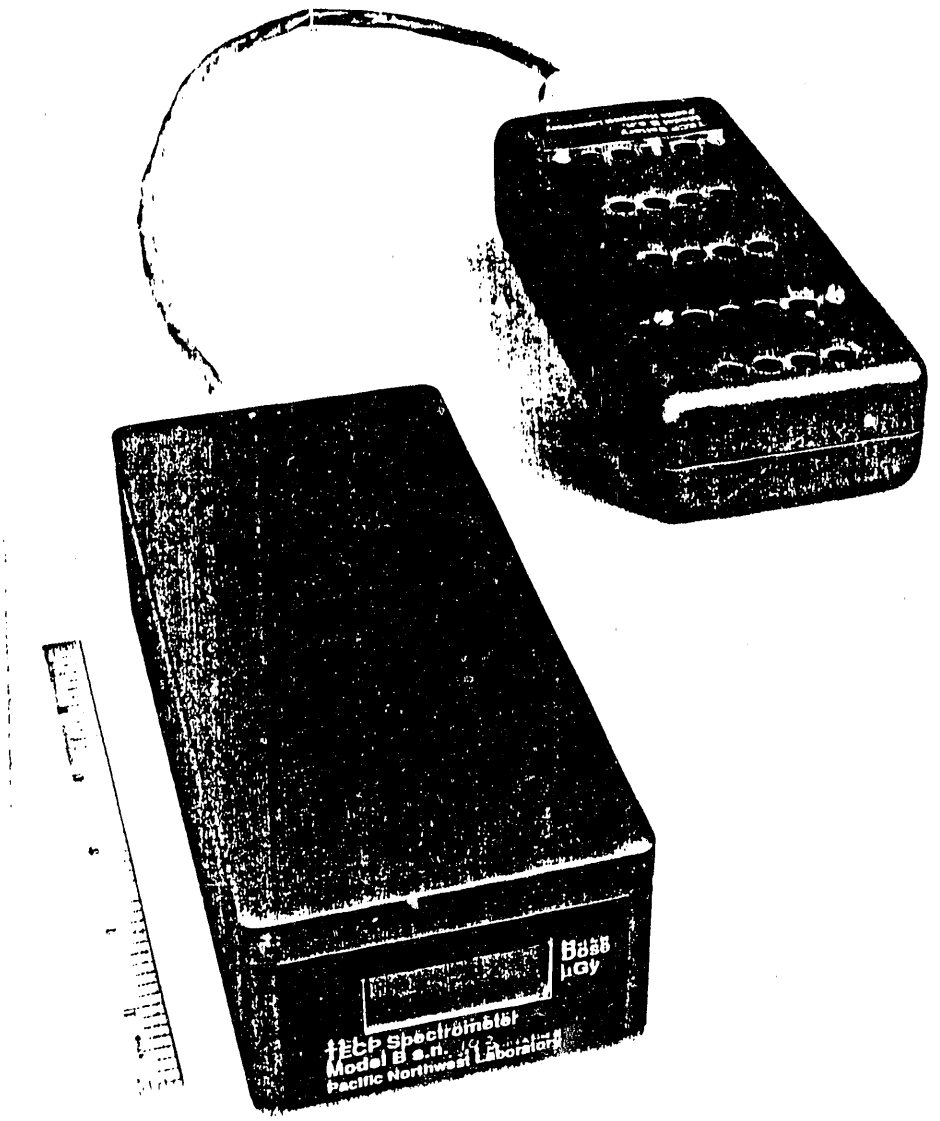
2. ICRP, 1990 Recommendations of the International Commission on Radiological Protection, Pergamon Press, New York (1990).

3. E. G. Stassinopoulos, "Charged Particle Radiation Exposure of Geocentric Satellites," High-energy Radiation Background in Space, ed. A. C. Rester, jr. and J. I. Trombka, American Institute of Physics, New York, pp 3-63 (1989).

4. ICRU, Microdosimetry, International Commission on Radiation Units and Measurements, Bethesda (1983).

5. A. M. Kellerer and D. Chmelevsky, "Criteria for the Applicability of LET," Radiation Research, 63, 226-234 (1975).

6. L. A. Braby, C. A. Ratcliffe, and N. F. Metting, "A Portable Dose Equivalent Monitor Based on Microdosimetry," Radiation Protection, ed. J. Booz and H. G. Ebert, Commission of the European Communities, Luxembourg (1983)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