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ABSTRACT

A compact, modular, tissue equivalent proportional counter system has been developed for use in space. The data acquisition system consists of a microcomputer, multi channel analyzer, memory, and power converter on individual circuit cards which can be used in various combinations for specific measurement requirements. The system uses separate, interchangeable detectors, each with its preamplifier and shaping amplifier connected directly to the detector. The microprocessor provides the computing power of a personal computer, and utilizes an operating system which is compatible with a subset of MSDOS. Experiment procedures can be programmed in high level languages and down loaded to the microprocessor. A typical application, used to characterize the dose rates due to trapped radiations in space, monitors the dose rate and records energy deposition spectra frequently when the dose rate is high. The microprocessor also measures and records system operation characteristics such as MCA linearity, proportional counter gain, and power supply voltages on a periodic basis.

Running Head: Systems for Measuring Dose and Radiation Quality

Introduction

The advantages, and limitations, of tissue equivalent proportional counters (TEPC) for measuring dose and evaluating dose equivalent in complex radiation fields have been known for many years[1,2]. Many portable radiation area monitors[3,4,5,6] and even personnel monitors have been built using TEPCs[7] (Baum, Booz, Menzel, Braby etc). However, these instruments have not yet found widespread application in radiation protection. There are undoubtably many reasons for this lack of acceptance, and different reasons may dominate in different situations, but design of improved TEPC based instruments should take into account the factors which have prevented widespread use of previous instruments.

Several properties of a radiation detection system are generally considered when evaluating it for a specific application. These include:

- Accuracy
- Precision
- Cost
- Size and Weight
- Versatility
- Convenience
- Reliability
- Response time
- Risk of underestimation

The weight given to these properties will differ with the application, making the advantages of a TEPC more significant in some cases than others, but the factors which limit them can be considered in a general way.

The accuracy of most dosimetry measurements is limited by the relationship between the quantity being measured and that being reported, and by the extent to which the measuring instrument distorts the quantity being measured. Thus, measurements of dose can be relatively accurate for a wide range of radiations because there is a nearly constant relationship between ionization and energy deposited. However, there are no simple measurable quantities which relate directly to quality factor (Q) or linear energy transfer, and those quantities which are measured to evaluate dose equivalent are applicable over only limited ranges of energy. Thus the evaluation of dose equivalent in complex radiation fields has always involved relatively large errors.

All instruments disturb the quantity being measured, and the larger the detector the more severe the distortion is likely to be. With cavity detectors, such as ion chambers and proportional counters, the wall thickness needed for charged particle equilibrium for one particle will attenuate another. This problem is not unique to TEPCs and is generally solved by utilizing detectors with different wall thicknesses.

The limiting factor at low doses is often the precision of the measurement. Since it is important to not underestimate dose equivalent, limited precision necessitates special ways of processing the data to assure that Q is not underestimated. Precision may depend on the sensitivity of the electronic system used with a detector, but is more often limited by the stochastics of energy deposition in the detector. The number of energy deposition events sampled limits the minimum size detector required in order to meet a specified precision for each type of detector. Detector size, and the resulting count rate, is also the limiting factor determining the response time of most systems.

The size and weight of a dosimetry system depend on the size of the detector and on the data acquisition system required to convert the detector output to a usable reading. With the improvements in electronic components, including microprocessors, in the last few years, the basic signal conditioning requirements for most detectors can be met with a very compact system. Thus the size and weight of the electronics is often dependent on features added to gain versatility and operation convenience. Since the minimum detector size is often greater than that of the electronics package, it may be unwise to sacrifice versatility and convenience for a marginal reduction in total system size.

Convenience is a difficult property to incorporate in a design since it means different things to different users. However, TEPC instruments intended for radiation protection applications will be replacing much less versatile instruments which typically are controlled by only an off/on switch and possibly a range switch. In most applications an instrument which requires any additional control actions during routine operation will be considered too complex and cumbersome to operate. The added versatility which can be achieved using a proportional counter and microprocessor based data acquisition system should not interfere with this simple mode of operation. The additional information should be obtained automatically, without distracting the operator, and should be easily available when one is ready to utilize it.

TEPC Spectrometer for the Space Shuttle

One application where all of the properties of a good instrument are important, but where the versatility of the TEPC based dosimeter is particularly valuable is the collection of radiation protection data for people working in low earth orbit. The radiation field experienced in this environment includes almost all types of directly and indirectly ionizing radiation. The majority of the dose is due to high energy protons trapped by the earth's magnetic field. Due to the geometry of this magnetic field, the trapped radiation flux varies dramatically with geographical location as well as altitude. Because the magnetic field varies slowly and is also subject to sudden changes initiated by solar storms, the radiation exposure in a specific orbit and altitude varies with time. In order to track these changes and predict future radiation exposures, as well as to obtain an accurate evaluation of current exposures, an instrument which can evaluate the dose and dose equivalent as a function of time, and therefore geographical location, is required. In areas where the dose rate is high or changing rapidly, such as the South Atlantic Anomaly, measurements every few seconds would be desirable. However during most of each orbit the dose rate is low and changing very slowly if at all. During these times there is no reason to collect spectra frequently, and data storage memory can be conserved if spectra are accumulated for several minutes. A new TEPC spectrometer system has been built to meet the requirements for radiation protection measurements in low earth orbit.

Two specific design features, modular construction and high level language programming, were incorporated to maximize the versatility of this system. Physically the instrument consists of a data acquisition system which measures 6.3 x 11.4 x 21.6 cm and a separate detector assembly, Figure 1. The linear electronics, that is the preamplifier and two shaping amplifiers, are mounted directly on the detector. One of the advantages of the external detector is that different sizes can be used depending on the application. The one shown is a 5 x 5 cm cylindrical detector which measures 7.7 cm in diameter and 9.5 cm long outside. The linear electronics are the same for any proportional counter and measure 2.1 x 6.0 x 10 cm.

The data acquisition system is built with interchangeable circuit boards which connect through a backplane which includes a 16 character by 2 line liquid crystal display, Figure 2. The circuit boards use a small format, 5.7 x 18.4 cm, but by using surface mount components on both sides of the board, can perform all of the functions which previously required a full size personal computer board. Five different types of boards are currently used to assemble systems for different applications. These include the microprocessor card, CPU, the multi channel analyzer, MCA, power supply, static random access memory, SRAM, and flash electrically erasable programmable read only memory, EEPROM. The minimum configuration is one each of the CPU, MCA, and power supply cards. Various combinations of memory cards are used to store data depending on the volume of data expected between opportunities to archive it.

The CPU card utilizes an 80C186 microprocessor with 896k of static RAM, two serial (RS 232) communications ports, and a precision clock on the card. This microprocessor provides control and data analysis capacity equivalent to an AT class personal computer. The instructions required to start the system are stored in read only memory, immune to soft upset errors, and a watch dog timer monitors system operation and restarts the operation if the software becomes damaged. The operating system is compatible with a subset of MSDOS and will run applications programs which have been written in high level languages such as Pascal.

The MCA card includes two 256 channel analog to digital converters, sample and hold circuits, peak detector, logic circuits to construct the multi channel spectra, detector bias supply, and two independent computer controlled test pulsers. The test pulser outputs, controlled by digital to analog converters, are to the preamplifier input and are used in a variety of diagnostic tests to confirm that the instrument is operating properly. By using the two analog to digital converters and shaping amplifiers with a gain ratio of 50, a pulse height range of 10,000:1 can be obtained, Figure 3. Depending on the detector and preamplifier noise, a lower level discriminator may be set to block noise in the first few channels. The detector bias supply output voltage is controlled by the CPU card through a digital to analog converter, and is adjusted to place an alpha particle calibration peak in a predetermined MCA channel. The bias supply output voltage and current are monitored by analog to digital converters to provide information on the condition of the detector.

The 3 Mbyte battery backed static RAM card is used for data buffer storage when the data will be transferred to an external device through the RS 232 port on a regular schedule. When the data will be retained in the instrument until the experiment is completed the 8 Mbyte flash EEPROM is preferred because it does not require battery backup. For this large memory capacity, the size of a backup battery becomes significant, and can be more important than the increased cost of the EEPROM components. The data storage capacity required for a specific experiment depends on the spectral and temporal resolution required. Since the energy deposition spectra are relatively slowly varying curves, the data from the two 256 channel spectra is typically condensed into 32 sudologarithmic bins before storing. For space shuttle experiments, data on the dose rate as a function of time is needed with 1 second resolution where the dose rate is changing, but most of the time much less temporal resolution is preferred. Energy deposition spectra may also change where the dose rate is changing rapidly, but it requires a minimum of 10 s to obtain any sort of spectrum with most detectors. As a result, the current application software for space shuttle experiments monitors the dose rate on one second intervals. If the dose rate exceeds a threshold value for any second during a 10 second period, the dose rate is recorded for each second, along with the spectrum recorded during that 10 seconds. If the dose rate remains low the average dose rate for the 10 s interval is recorded and the spectrum is recorded at one minute intervals. The power supply voltages, test pulse data, and other diagnostic information is recorded at longer intervals. With this data storage procedure an 8 Mbyte memory is sufficient for several weeks in low earth orbit.

The power supply card converts the external power source, typically 28 VDC, to the + and - 12 VDC and + 5 VDC required by the other boards. Since electromagnetic interference and line noise can cause major problems with low noise preamplifiers, this power converter provides isolation between the power source and the sensitive circuits. It is also carefully shielded to prevent it from emitting frequencies which might interfere with the rest of the system. The power supply card also monitors the input and output voltages and currents and the board temperature as additional checks of the condition of the system.

The detectors intended for use with this data acquisition system have been designed to minimize electronic noise and microphonics. They are directly coupled to the preamplifier in order to minimize capacitance to ground, a source of electronic noise, and eliminate the high voltage blocking capacitor, which may be a major source of microphonic noise. The cylindrical design is used because it provides good resolution without requiring a field shaping helix, and these detectors are relatively compact for a given detector diameter. The tissue equivalent plastic detector wall is insulated from the vacuum chamber so that the latter can be operated at ground potential. An internal ^{244}Cm calibration source with an electromagneticly operated shutter is provided so that detector gain can be calibrated automatically. These detectors have been built in two diameters, 1.78 and 5.0 cm, for different applications. Since the detectors can all be calibrated to a specified gas gain, they are interchangeable. The data analysis routines are written so that a single constant incorporating the diameter of the detector is changed when different detectors are installed.

These instruments are expected to provide a major improvement in the resolution of the position of trapped radiation belts and the dose rates encountered by people working in low earth orbit. Although they are extremely simple to operate, having only to be connected to a power source to start collecting data, the full versatility of the TEPC can be realized since operating procedures and data analysis algorithms can be developed in high level languages and transferred to the instrument by an RS 232 link.

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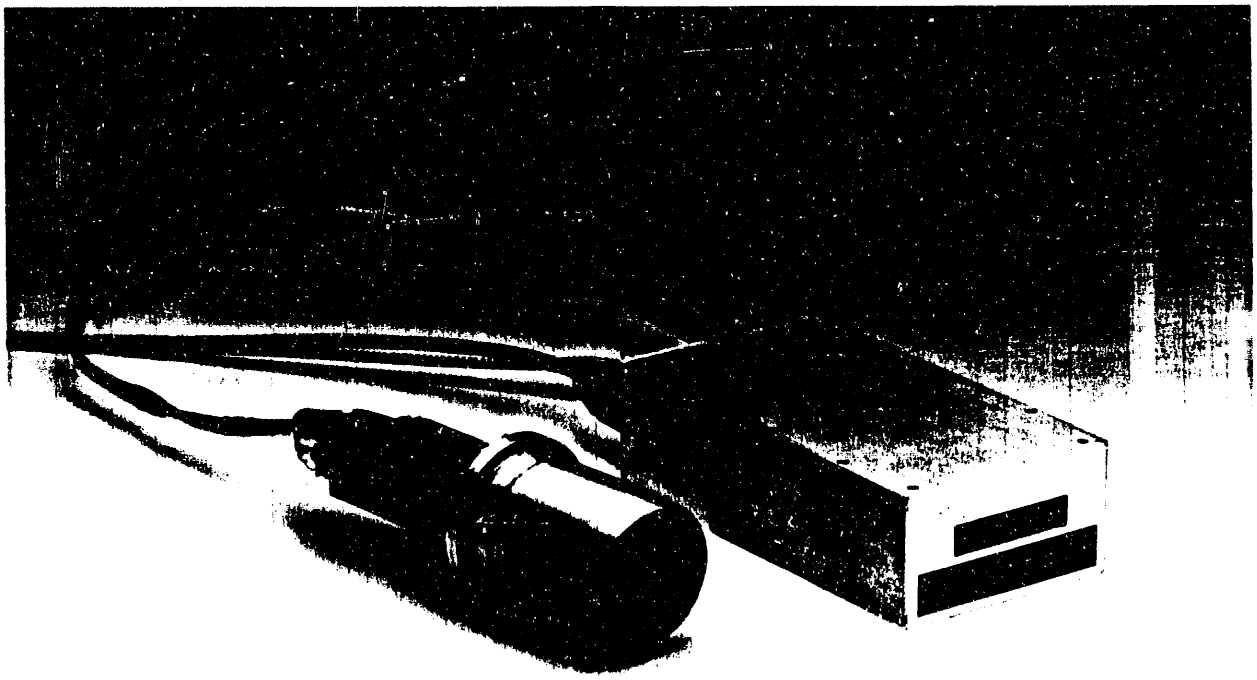
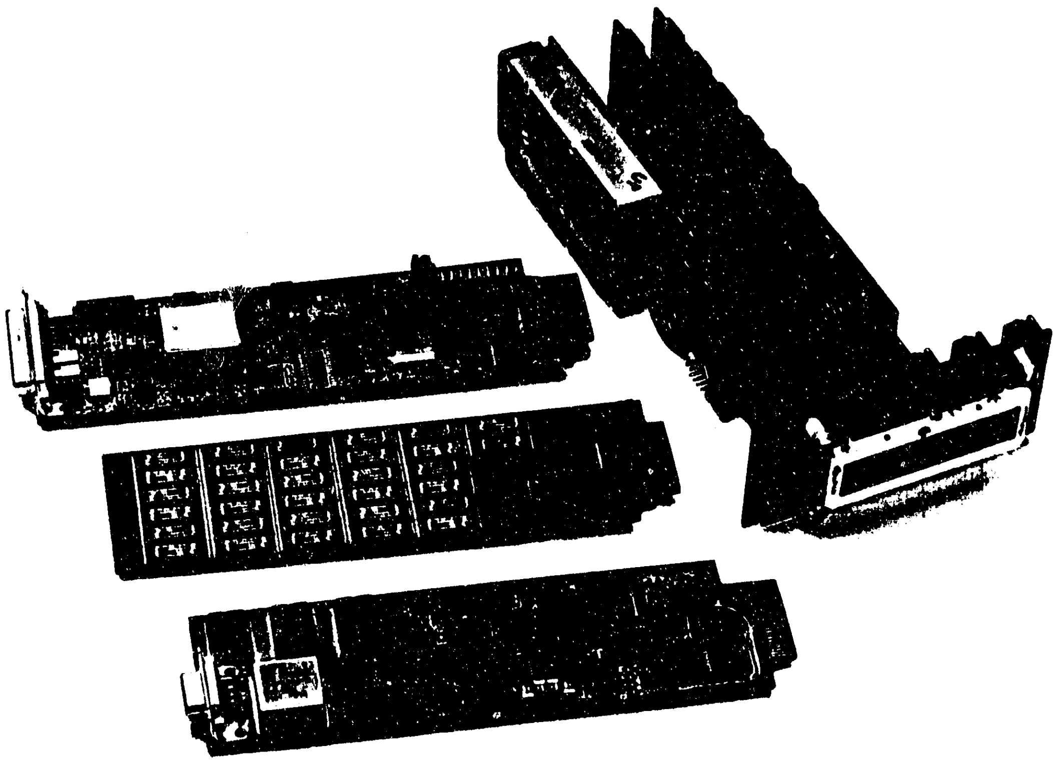
Figure Captions

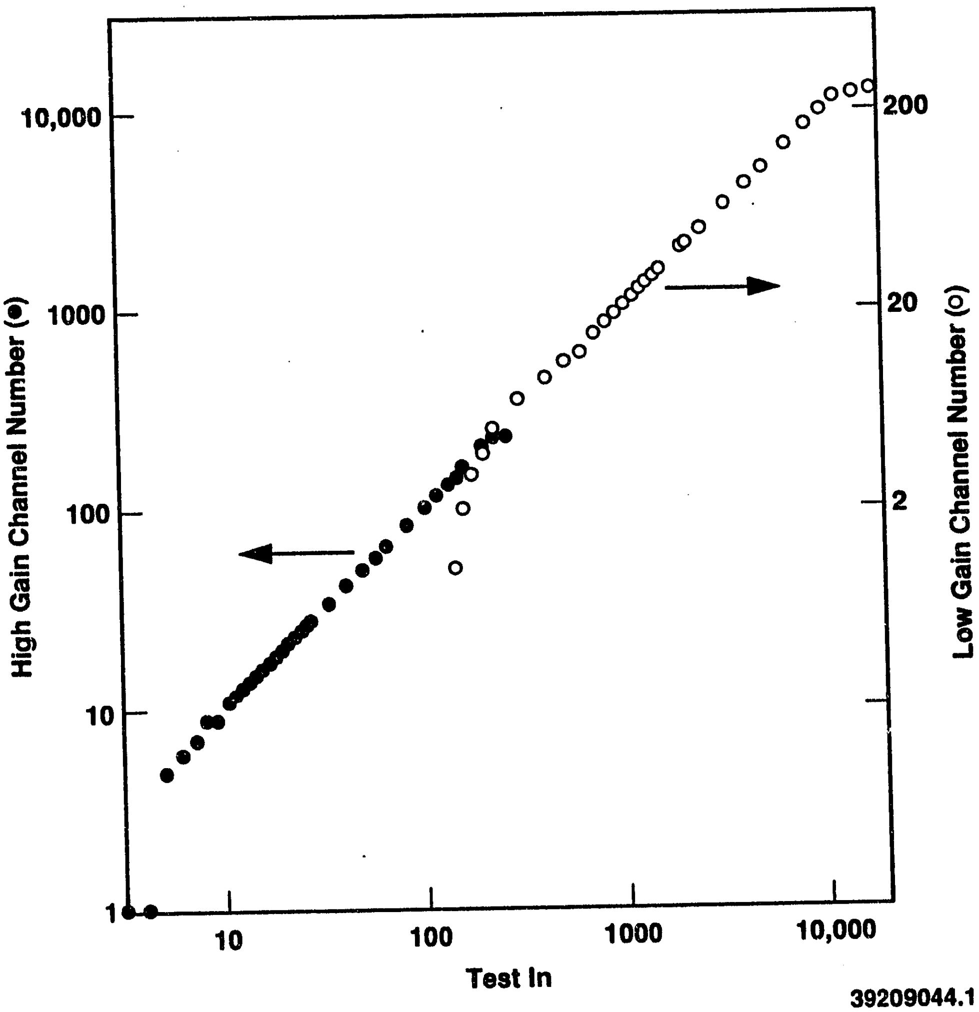
Figure 1 The TEPC spectrometer for use on the space shuttle.

Figure 2 The data acquisition system is composed of a minimum of one each of the microprocessor, multichannel analyzer, and power supply circuit cards and a backplane. The 8 Mbyte flash EEPROM, center, can be used to store detailed spectra and dose rate information without requiring a battery backup.

Figure 3 The analog to digital converter test shows that there is a smooth transition between events processed by the high and low gain amplifiers and their respective analog to digital converters.







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