8th QUARTERLY PROGRESS REPORT

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on

THE DEVELOPMENT OF MEDICAL AND BIOLOGICAL SEMICONDUCTOR DETECTORS

by

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SECTION I - INTRODUCTION

During the previous quarter, a prototype proton dosimeter for manned space flight missions was developed. The dosimeter consisted of 1) an 8-cubic mm lithium-drifted silicon nuclear particle detector; 2) a low-noise, charge-sensitive preamplifier; 3) a pulse height integrator employing an electrochemical cell as an integrator. It was packaged complete with self-contained, rechargeable battery power supply in approximately 15 cubic inches. Readout was accomplished by means of a battery-powered readout register providing direct readout in terms of proton dose in rads. During the beginning of the present quarter, a performance of the unit was verified, using 30 MeV protons from the University of Southern California accelerator, which qualitatively verified the previously calculated dose calibration. This represents the completion of the breadboard feasibility demonstration phase of the total effort of developing a self-contained, miniaturized dosimeter for space environment. As a result of the difficulty in allocation of funds for proceeding to the next phase of the program, no work was performed during the second month of this quarter. Following the availability of funding, the program was again activated, and work proceeded on the design and fabrication of the space dosimeter.

SECTION II - CALIBRATION OF THE BREADBOARD MODEL

Calibration of the breadboard system was accomplished with the cooperation of the accelerator personnel of the University of Southern California, who made available their 30 MeV proton accelerator for this work. In order to provide a large area and solid angle flux of protons, the primary beam from the accelerator was scattered from a thin gold target and the scattered protons observed at an angle of approximately 30 degrees to the beam direction. Such an intermediate scattering process was required to transform the extremely small-area intense beam of protons from the machine into a diffuse, large diameter flux of protons of sufficiently low intensity to permit simulating space radiation effects. As adequate proton dose standards were not available, the instrument itself was used as a means of measuring the proton flux. The pulse output of the prototype dosimeter was counted with the aid of a discriminator and high-speed scaler. Since all events above minimum ionizing in the detector were counted, this provided a precise measurement of the flux of protons passing through the detector. The energy of the protons was calculated from the knowledge of a scattering angle and the kinematics of the scattering process. Quite low counting rates were used to avoid the possibility of pulse pile-up effects which could have introduced errors. This is particularly aggravated because of the relatively low duty cycle of the machine. In a series of measurements, the integrated dose observed was within experimental error of the predicted dose on the basis of a measurement of the flux. It was concluded from this measurement that the calculated curves included in the seventh quarterly progress report should be valid for proton dose measurement. The energy proton employed represents the most critical energy for a dosimeter. The largest pulse heights result from protons in this energy range, protons of higher energy resulting in lower ionization, and protons of lower energy either being stopped in the shielding material surrounding the detector, or producing reduced pulse heights. The calibration points obtained was entered into the data reported in the previous report, since they were available at the time of that report's writing.

SECTION III - DESIGN OF THE MINIATURIZED DOSIMETER FOR SPACE APPLICATION

In order to make the prototype dosimeter, developed during the previous quarter of the contract, suitable for application as a space dosimeter for the Apollo Program, three major modifications are required:

1) Reduction in size, weight and power consumption through miniaturization techniques.

2) Extension of the lower energy threshold to include minimum ionizing particles and Compton processes from gamma rays.

3) Modification of the readout to permit completely self-contained operation.

The reduction of size, weight and power consumption is to be accomplished by adopting a micro-modular configuration for all electronic circuitry. In this type of construction all resistors, inter-connections and small capacitors are deposited on a ceramic substrate, semiconductors and large capacitors being attached later as discrete components. A conservative estimate indicates that the entire electronic circuitry can be reduced to a volume of considerably less than 1 cubic inch. The problem of power consumption is being attacked through systematic examination of the circuits involved. Every effort is made to operate transistors in their cut-off or nearly cut-off mode, except in the presence of a pulse. In order to maintain reasonable transistor characteristics, standing currents of from 20-30 microamperes are required for each stage. For even the most elaborate instrument, no more than 20 such stages should be required. This, then, sets a minimum power requirement of approximately 0.5 milliamperes for the entire system. The voltage requirement is based on the necessity for a reasonable, dynamic range of outputs from the amplifier. Since thresholds of approximately 0.5 volts are involved in the pulse analysis process, a pulse amplitude output of at least 5 volts is desirable. This would establish a requirement for approximately 6 volts on the power supply. Thus, the minimum of power required would be in the neighborhood of 6 volts x 0.5 milliamperes, or approximately 3 milliwatts. This power requirement then determines the physical size and weight of the battery required to produce a given number of hours of operation. For example, if a rechargeable nickel cadmium type battery were used, 500 hours operation without recharging, would be provided by approximately 2 cubic inches of battery weighing .145 lbs.; 1000 hours of operation without recharging, would be provided by approximately 3 cubic inches of battery weighing .375 lbs. Mercury cells, while possibly unsuited to use in spacecraft, could provide 5,000 hours of operation with a volume of 2.5 cubic inches and a weight of .3 lbs. Conventional dry cells provide a service life of approximately 500 hours in approximately 3 cubic inches and .14 lbs. Considerably better factors can be expected from improved cell types now available. Investigation is being carried on to determine the feasibility of the use of some of these advanced cell types. The dynamic range of the prototype dosimeter was intentionally limited to include only those contributions which originated from fast protons. This energy threshold was established by considering the minimum size pulse which could be obtained from the highest energy proton under consideration. Since it is the high energy protons that produce the reduced pulse heights, the pulse height from such high energy protons is about 1-1/2 times minimum ionizing. For this reason, a threshold set slightly greater than minimum ionizing would eliminate contributions from minimum ionizing particles and from Compton and photoelectric processes from all but the most energetic gamma rays. In a 2mm detector this threshold is approximately 1 MeV. In discussing the dosimeter problem with the technical personnel of the Manned Spacecraft Center, it was deemed desirable to integrate dose from as wide a range of radiation types as possible. In principle, it would be desirable, then, to integrate pulse heights all the way down to 0. This, as a matter of practice, cannot be done due to the finite noise output of the detector. This noise, in the most quiet detector preamplifier combination which can be considered, is of the order of 15 keV (FWHM). Thus, to avoid integrating noise pulses, it would be important to set a threshold at least twice or three times this value, in order that occasional, large-noise pulses will not contribute. This would indicate a threshold of the order of 50 keV. While the introduction of such a threshold does introduce some errors in integrating dose from gamma rays, the error is primarily introduced for extremely soft X-rays, and for this reason is probably of less radiobiological significance than might be at first assumed. If the threshold, then, is to be set at 50 keV and pulses are to be accepted from the most heavily ionized proton to be encountered, i.e. one which is completely stopped in the detector, the integrator system must be linear to greater than 20 MeV. This requires a dynamic range of almost 4 orders of magnitude in pulse height acceptance. If the lower threshold is of the order of 0.5 volts as set by the energy gap of a silicon diode, then a linear response would be required in excess of 1000 volts. This is clearly neither practical nor interesting in a battery-powered, compact device. In its place a technique of using separate channels for various energy events will be employed. While this introduces some complication into the integrator, it relaxes considerably the dynamic range response required on any individual component, and for this reason leads itself much more readily to the microminiaturized design undertaken. Essentially, three channels are provided, each having a dynamic range of approximately 10:1: the most sensitive channel having a threshold at 50 keV, and the saturation level of 500 keV; the second - a threshold of 500 keV, and a saturation level of 5 MeV; and the third - a threshold of 5 MeV, and a saturation level of 50 MeV. These three channels are summed into the integrator through capacitors whose magnitude of capacitance is proportioned to take into account the varying sensitivity, i.e. the low energy channel is summed through a small capacitor and the high energy channel through a larger capacitor. Thus, linearity is preserved in the final integrated output, even though the greatest dynamic ranges which must be accommodated by any given channel, is only 10:1.

Self-contained Readout

In order to make the instrument useful without the necessity for connection to external equipment, it was deemed desirable by personnel of the Manned Spacecraft Center to use a readout means which could be incorporated in the dosimeter package itself. Since the readout of the electrochemical cell is essentially a time required for backplating, various timing devices have been considered. One of the most interesting for this purpose is the Accutron Wrist Watch movement, which is essentially a tuning-fork-actuated watch movement normally powered by a small cell contained in the watch case. This provides a means of non-destructively integrating time by the simple process of advancing the hands of the watch in response to the electrical readout signal. As the space required by such a watch movement is under 1/10 cubic inch, and the reliability and suitability for space environment for these movements has been demonstrated previously, this would seem to constitute a very practical readout system. There are essentially two modes in which the readout process can be used. In the first, the electrochemical cell is manually read out at the time when the information is desired, by depressing a button and observing the advance of the watch movement. If a more automatic procedure is required, it would be necessary to include a timer which would switch the system to readout, say every five minutes or so, and accumulate the dose automatically. The disadvantage of this latter method is the lack of flexibility for the astronaut observing very rapid changes in accumulated dose. On the other hand, should he neglect to initiate readout, the stored information would not be available. A better alternative would consist of using an E cell with very limited amount of platable material when the total amount of platable material, which would correspond, for example, to 1/10 of a rad, were plated onto the receiving electrode. The end point would be detected and used to either initiate readout or simply reverse the cell. The dose in units of 1/10 rads would then simply be the number of cell reversals which could be recorded either on the Accutron, or on another type of register. This has the disadvantage of requiring a relay-type of reversing device, which may prove cumbersome for introduction into the package. In order to provide MSC with the alternatives of these three methods, each will be carried to the breadboard point in order that the advantages and disadvantages can be adequately evaluated.

SECTION IV - PROGRAM FOR THE NEXT QUARTER

It is expected that the next quarter will permit the microminiaturization to be virtually complete. Some delays may be introduced from component suppliers. In addition, the E cell readout techniques will be breadboarded and presented for consideration by MSC.