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PL-TR-92-2066

DEVELOPMENT AND USE OF DATA ANALYSIS PROCEDURES FOR THE CRRES PAYLOADS AFGL-701-2/DOSIMETER AND AFGL-701-4/FLUXMETER AND APPLICATION OF THE DATA ANALYSIS RESULTS TO IMPROVE THE STATIC AND DYNAMIC MODELS OF THE EARTH'S RADIATION BELTS

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4 March 1992

Scientific Report No. 4

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"This technical report has been reviewed and is approved for publication"

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE 4 March 1992

3. REPORT TYPE AND DATES COVERED Scientific #4

4. TITLE AND SUBTITLE Development & Use of Data Analysis Procedures for the CRRES Payloads AFGL-701-2/Dosimeter & AFGL-701-4/Fluxmeter & Application of the Data Analysis Results to Improve the Static & Dynamic Models of the Earth's Radiation Belts

5. FUNDING NUMBERS
PE 62101F
PR 7601
TA 20
WU CF

Contract:
F19628-87-C-0169

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Phillips Laboratory
Hanscom AFB, MA 01731-5000

Contract Manager: Lt Michael Violet/PHP

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
PL-TR-92-2066

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Response of the AFGL-701-4/Dosimeter instrument, flown on the CRRES spacecraft, to electrons with energies between 1 and 10 MeV is described in this report.

14. SUBJECT TERMS
Spacecraft Instrument, Electrons, Protons, Radiation Dose

15. NUMBER OF PAGES 16

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

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1. INTRODUCTION

This report contains the electron flux calibration of the CRRES 701-2 Dosimeter, the electron and proton dose calibration is described in Ref. 1. The primary purpose of this instrument is to measure the radiation doses, in the space radiation environment, that solid state devices will receive behind various thicknesses of shielding. The Dosimeter was designed, fabricated and calibrated by Panametrics Inc. for the Geophysics Laboratory, under contract F19628-82-C-0090. The CRRES Dosimeter is nearly identical to an instrument, designated SSJ*, built by Panametrics Inc. for the Geophysics Laboratory under contract F19628-78-C-0247 and flown on the Defense Meteorological Satellite Program (DMSP) F7 satellite.

This report is organized in the following way. Section 2 contains the instrument description. The electron accelerator facility and the experimental procedures followed during the calibration are described in Section 3. Calibration results and the extracted geometric factors are listed in Section 4. The report concludes with Section 5, the summary section.

2. INSTRUMENT DESCRIPTION

The isometric view of the 701-2 Dosimeter is shown in Figure 1, while a schematic diagram of a typical dome assembly is shown in Figure 2. Dome thicknesses, energy thresholds and sizes of the detectors are listed in Table 1. The detectors, p-i-n diodes with diameter d and thickness t, are mounted so that the face with the area A ($\pi d^2/4$) is parallel to the top of the box. A 1/2" thick tungsten plug shields the detectors from rear entry protons and electrons with energies below 130 MeV and 200 MeV respectively. A weak ^{241}Am α-particle source is placed behind each detector to aid in on orbit detector and electronics diagnostic procedures.

Particles which penetrate the shield, as well as bremsstrahlung produced in the shield, strike the p-i-n diode detector and produce a charge pulse proportional to the deposited

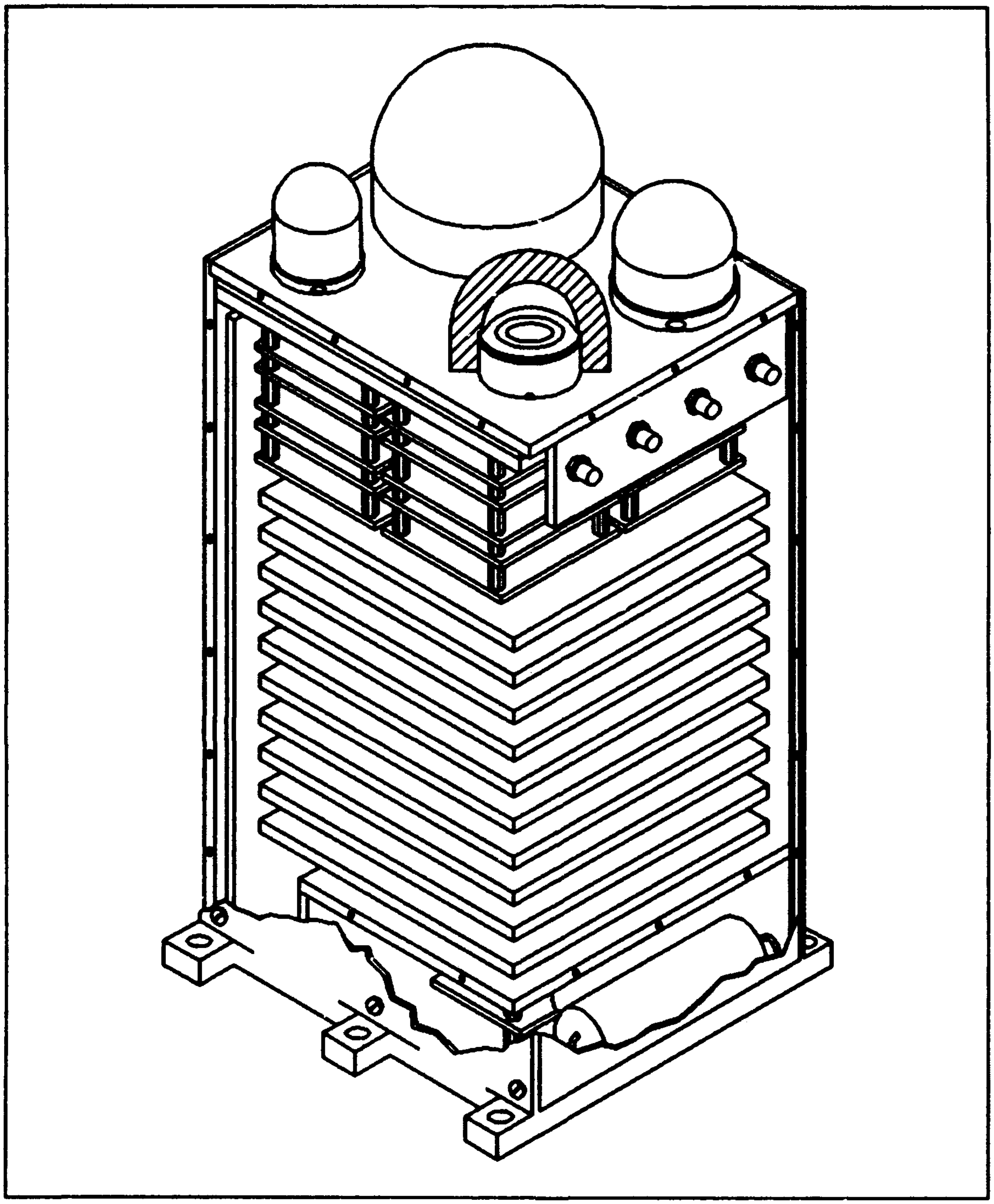

Figure 1. Isometric, cross-sectional view of the CRRES Space Radiation Dosimeter (AFGL-701-2).

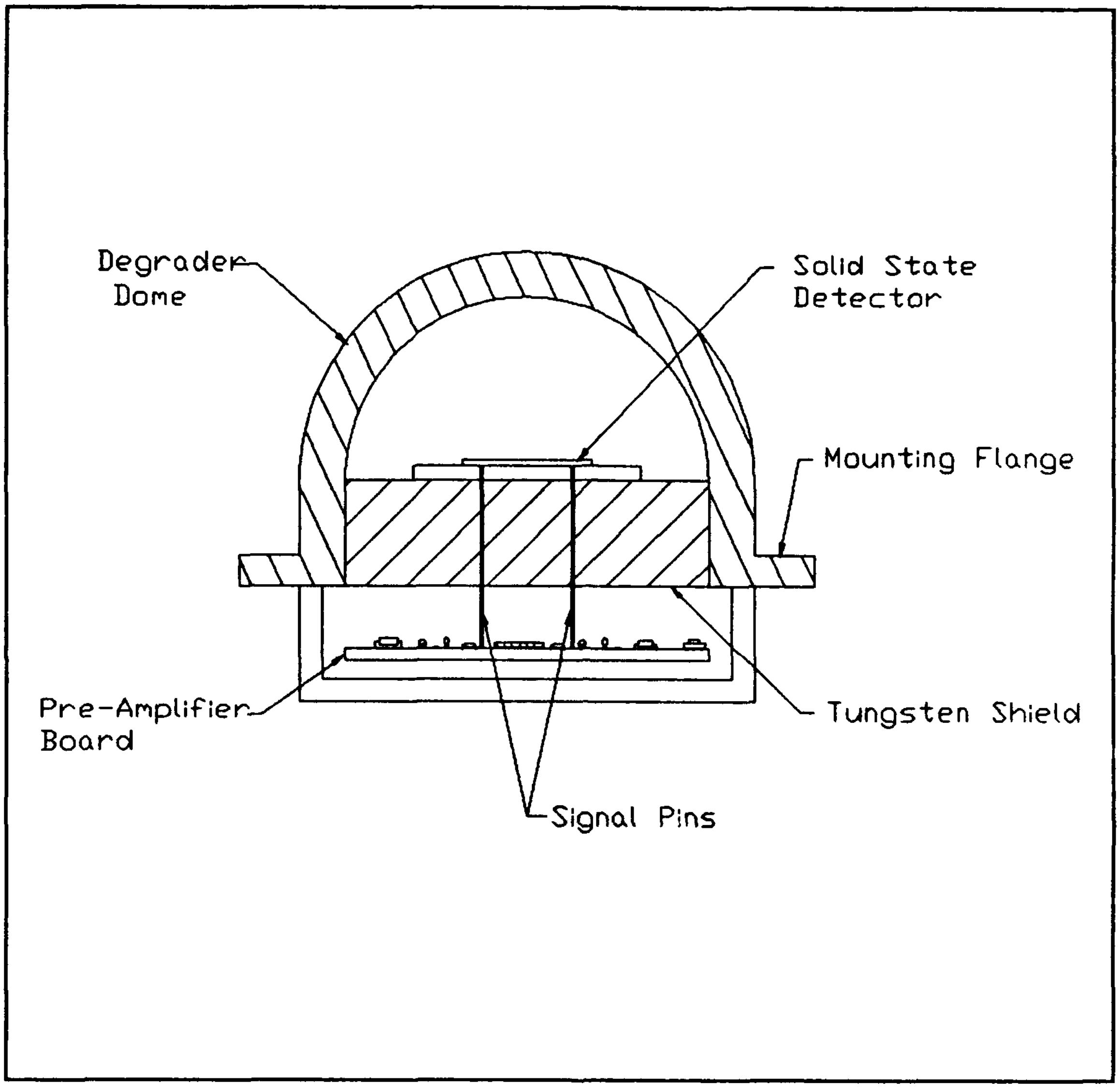

Figure 2. Cross-sectional view of a Space Radiation Dosimeter detector dome.

energy. Events with energy depositions between 50 keV and 1 MeV are treated as low linear energy transfer (LOLET) events while those with depositions between 1 and 10 MeV are treated as high linear energy transfer (HILET) events. Events with energy depositions above 40 MeV in dome 1,2 and 3 detectors and 75 MeV in the dome 4 detector are counted as nuclear star events. The LOLET events are primarily due to electrons, protons above 100 MeV and bremsstrahlung. HILET events are due to protons with energies between the threshold energy and approximately 100 MeV.

The Dosimeter measures the total radiation dose from both electrons and protons delivered to the detectors. This is accomplished by digitizing the pulse height from an event and adding it to all other pulse heights measured in the accumulation period (4 sec). There are separate LOLET and HILET event dose counters. In addition, the Dosimeter also provides information on the differential and integral fluxes of electrons and protons at energies above the thresholds determined by the dome shields. Finally the rate of nuclear star events is also measured.

TABLE 1

CRRES Dosimeter Dome Characteristics

Dome	Threshold Energy (T) (MeV)	Detector Area (L) (cm^2)	Detector Thickness (t) (μm)
1	1.0	0.0081	403
2	2.5	0.051	434
3	5.0	0.051	399
4	10.0	1.000	406

Note: Top face of detector has area A.
Total area exposed under the dome is A + πdt.

3. CALIBRATION PROCEDURE

Electron flux calibration of the Dosimeter was performed at the Rome Air Force Development Center (RADC) linac at the Hanscom AFB. This rf linac is designed to accelerate intense (mA) beams of electrons to energies of 2 to 20 MeV. During normal linac operation thousands of electrons are accelerated in each rf "bucket" and the resulting beam current is part of the feedback loop that controls the machine. The Dosimeter signal time resolution required that there be no more than one electron in each 2 μsec beam spill or "bucket" and the resulting, extremely small, beam current made control of the machine difficult. The most severe problems occurred for beam energies above 5 MeV. At these energies, the beam energy spread became large. For example, a beam with a nominal energy of 8.8 MeV was actually a broad distribution with particle energies between 5.8 and 10.2 MeV almost equally probable and nearly a third of the particles had an energy less than 5.8 MeV. The beam energy spread was a significant problem for dome 3, with its energy threshold of 5 MeV. No useful data could be collected for dome 4, which has an energy threshold of 10 MeV.

The Dosimeter was mounted on a rotating table at a distance of approximately 1.2 meters from the flange at the end of the 30° beam line. Beam electrons had to travel through a beam pipe end flange, consisting of aluminum and cooling water, and the 1.2 meter air gap before reaching the Dosimeter. The total amount of degrader areal density was equivalent to 0.61 gm/cm^2 of water, which implies an energy loss of 1.2 MeV for electrons with energies between 2.5 and 12 MeV (Ref. 2). A 1500 μm solid state detector, mounted next to the Dosimeter, was used to monitor the beam intensity. The beam monitor had a 1.27 cm thick Pb collimator with a 0.47 cm diameter hole and its center was approximately 10 cm from the Dosimeter dome under study. The Dosimeter itself was turned so that the dome under study was centered on the beam line axis. The monitor detector remained stationary as the Dosimeter was rotated with respect to the beam. Therefore, it was used to provide both the absolute and the relative angle-to-angle normalization as the Dosimeter response was mapped out as a function angle of incidence of the beam particles.

The following data taking procedure was used for each dome. First, with the beam turned off, the LOLET and HILET counts due to the α-particle source were measured for several 100 sec intervals. Next, the beam was turned on and, for each Dosimeter angle, the LOLET, HILET and beam monitor counts were recorded for 2 or 3 intervals of 100 sec each. The Dosimeter angles studied in the calibration measurements were 0, 30, 60 and 90°. At no point during the beam experiment did the proton response exceed the background response due to the α-particle calibration source.

4. CALIBRATION DATA AND ANALYSIS

The most direct quantity extracted from the data is the effective area of a dome detector for electrons, A_n, as a function of the beam energy, E, and angle of incidence, θ (θ = 0° is normal to the detector plane):

$$A_n(E,\theta) = A_{mon}\,\frac{N_n(E,\theta) - B_n}{N_{mon}(E,\theta)} \tag{1}$$

where n = 1,2,3 or 4 designates the dome, N_n are the LOLET counts for dome n, B_n are the counts due to the α-particle calibration source, N_{mon} are the beam monitor counts and A_{mon} is the effective monitor detector area, 0.173 cm^2.

Results of the DMSP Dosimeter calibration (Ref. 3) showed that the effective dome detector area for electrons, $A_n(E,\theta)$, could be described by the expression

$$A_n(E,\theta) = A_n(E,0°)\left[\frac{2 + 3Cos\theta}{5}\right] \; . \tag{2}$$

The energy dependent term in eq. (2), $A_n(E,0°)$, was successfully fitted, for the DMSP Dosimeter, by the expression

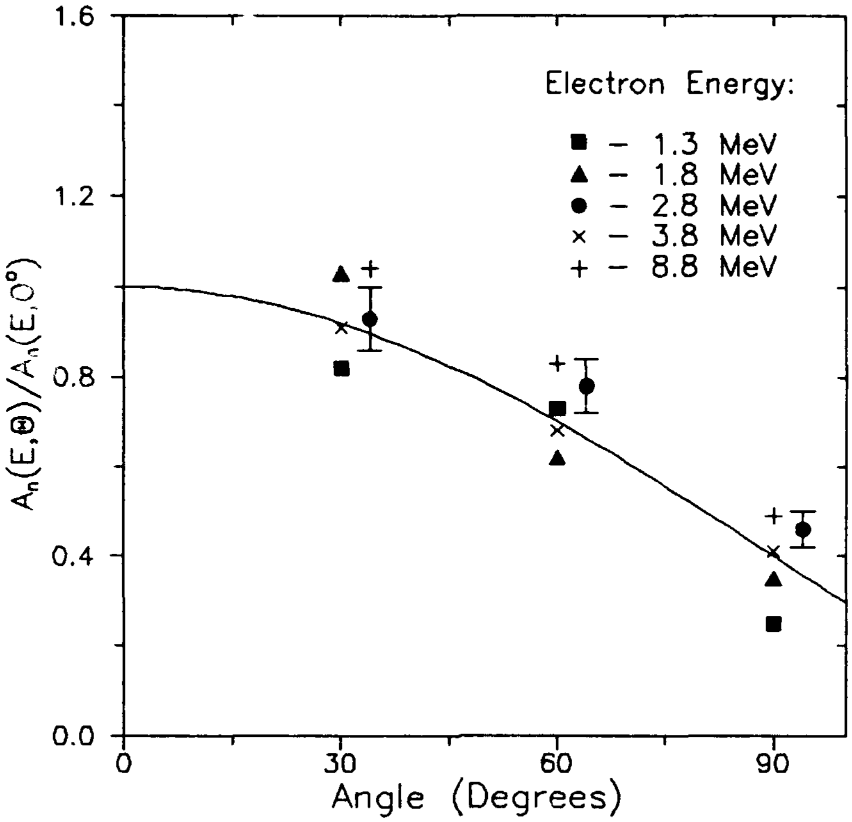

Figure 3. Measured angular distributions for dome 1. Solid line is fit given by eq. (2). Typical error bars are shown.

$$A_n(E,0^\circ) = \begin{cases} 0 & \text{if } E/T_n < 1 \\ 1.5 \cdot A_n^o(1 - T_n/E) & \text{if } 1 \le E/T_n \le 3 \\ 1.0 \cdot A_n^o & \text{if } E/T_n \ge 3 \end{cases} \qquad (3)$$

where T_n is the dome threshold and A_n^o is the detector area exposed to the incident particles.

The measured angular distributions for the CRRES 701-2 Dosimeter for domes 1,2 and 3 can also be reproduced by the function defined in eq. (2). The angular distributions measured

for dome 1 and the fit given by eq. (2) are shown in Figure 3. The agreement between data and calculated angular distributions for domes 2 and 3 is equally good.

Theoretically, A_n° is expected to be close to the purely geometric value of the exposed area, $A + \pi dt$. The reason for this is that the electrons are strongly scattered during the passage through the dome material and emerge inside the dome with all possible angles of incidence with respect to the detector. Therefore, the electrons will strike the top and side surfaces of the detector with a nearly equal probability per unit area. The bottom surface, is shielded by the tungsten plug and thus is inaccessible to the electrons.

The theoretical and experimental values of A_n°, and their ratios, for the four domes are listed in Table 2. The experimental values for domes 1 and 2 detectors have been obtained by using

TABLE 2

Measured and geometric values of A_n°.

Dome	A_n°, Geometric (cm^2)	A_n°, Measured (cm^2)	Ratio*
1	0.021	0.017	0.81
2	0.083	0.075	0.90
3	0.083	0.067**	0.81
4	1.142	0.888***	0.78

Notes:
* - Ratio = Measured value / Geometric value.
** - Value from Ref. 3 with area correction.
*** - Value from Ref. 3.

eq. (2) along with the measured values of $A_n(E,\theta)$ to evaluate A_n°. The values in Table 2 are an average over all angles for 2.8, 3.8 and 8.8 MeV beams for dome 1, and for 6.8 and 8.8 MeV beams for dome 2. At these energies, according to eq. (3), $A_n(E,0^\circ) = A_n^\circ$ to a good approximation. The Dome 4 assembly on the CRRES Dosimeter is identical to dome 4 on the DMSP Dosimeter and, since no useful data for that dome were collected at RADC, the DMSP calibration values from Ref. 3 have been adopted. The calibration of the dome 3 assembly on the CRRES Dosimeter was also obtained from the calibration of the corresponding dome on the DMSP Dosimeter. The two dome 3 assemblies differ by the size of the detector only. The CRRES detector has $A = 0.051\ cm^2$ and $t = 399\ \mu m$, while the DMSP detector has $A = 1.0\ cm^2$ and $t = 390\ \mu m$. The value listed in Table 2 is the DMSP dome 3 value corrected by the ratio of the areas of the two detectors.

Geometric factor of a dome detector, $GF_n(E)$, is defined by

$$GF_n(E) = 2\pi \int A_n(E,\theta)\, Sin\theta\, d\theta \quad . \tag{4}$$

The experimental geometric factors were obtained by using the measured $A_n(E,\theta)$ values at 0, 30, 60 and 90° in eq. (4) and integrating from 0 to 15°, 15 to 45°, 45 to 75° and 75 to 105°, respectively. The resulting geometric factors for domes 1 and 2 are listed in Table 3 and plotted in Figure 4. The solid line in Figure 4 is the analytic fit to $GF_n(E)$ obtained by integrating eq. (4) between $\theta = 0^\circ$ and $\theta = 105^\circ$:

$$GF_n(E) = \begin{cases} 0 & \text{if } E/T_n < 1 \\ 7.38 \cdot A_n^o (1 - T_n/E) & \text{if } 1 \le E/T_n \le 3 \\ 4.92 \cdot A_n^o & \text{if } E/T_n \ge 3 \end{cases} \tag{5}$$

where the A_n° values are taken from Table 2 and the T_n values from Table 3. The slight discrepancy in fitting the dome 2 data may be due to the large beam energy spread at the RADC linac.

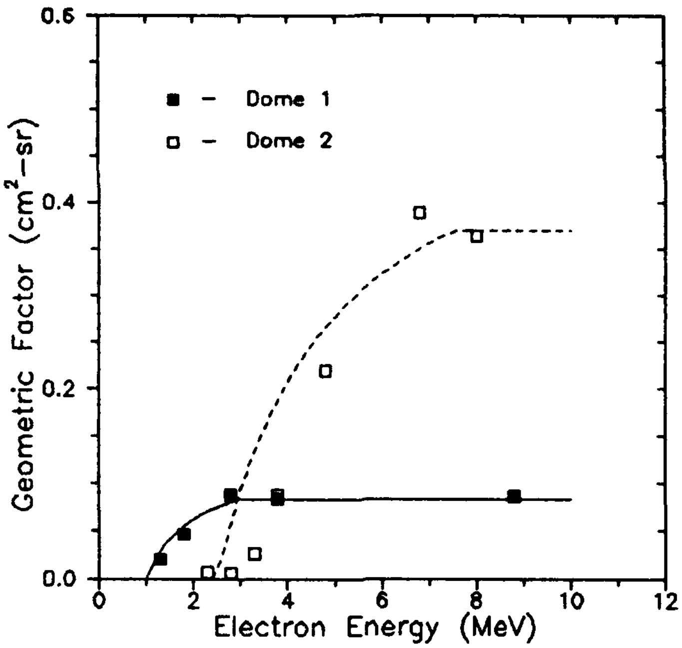

Figure 4. Geometric factors for domes 1 and 2. Curves are analytic fits using eqs. (2), (3) and (4).

TABLE 3

Measured geometric factors for domes 1 and 2.

Dome 1		Dome 2	
Energy (MeV)	GF (cm^2-sr)	Energy (MeV)	GF (cm^2-sr)
1.3	0.0205	2.3	0.0065
1.8	0.0467	2.8	0.0060
2.8	0.0876	3.3	0.0267
3.8	0.0841	3.8	0.0880
8.8	0.0862	4.8	0.2190
		6.8	0.3882
		8.8	0.3632

5. SUMMARY

The electron flux response of the CRRES 701-2 Dosimeter has been studied with 1.3 to 8.8 MeV electron beams from the RADC linac at Hanscom AFB. A full angular and energy calibration for domes 1 and 2 was obtained in addition to the angular response of dome 3. No useful data for dome 4 were collected. The measured response of the Dosimeter domes is in good agreement with the response reported in Ref. 3 for a nearly identical DMSP Dosimeter.

REFERENCES

1) P. R. Morel, F. Hanser, B. Sellers, J. Hunerwadel, R. Cohen, B. D. Kane and B. K. Dichter, "Fabricate, Calibrate and Test a Dosimeter for Integration into the CRRES Satellite," Report GL-TR-89-0152 (April 1989), Final Report for Contract F19628-82-C-0090, ADA213812.

2) M. J. Berger and S. M. Seltzer, "Tables of Energy Losses and Ranges of Electrons and Positrons," in Studies in Penetration of Charged Particles in Matter, Publication 1133, National Academy of Sciences - National Research Council, Washington D.C., 1964.

3) M. S. Gussenhoven, R. C. Filz, K. A. Lynch, E. G. Mullen, F. A. Hanser, and "Space Radiation Dosimeter SSJ* for the Block 5D/Flight 7 DMSP Satellite: Calibration and Data Presentation," Report AFGL-TR-86-0065 (March 1986), Report ERP, No. 949, ADA172178.