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SPACE VEHICLE SHIELDING STUDIES
(PART II): THE ATTENUATION OF
SOLAR FLARES BY ALUMINUM SHIELDS

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J. E. Murphy

OAK RIDGE NATIONAL LABORATORY

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SPACE VEHICLE SHIELDING STUDIES (PART II): THE ATTENUATION
OF SOLAR FLARES BY ALUMINUM SHIELDS*

R. G. Alsmiller, Jr.
J. E. Murphy**

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JAN 24 1964

*Work supported by the National Aeronautics and Space Administration.

**Central Data Processing Facility of the Oak Ridge Gaseous Diffusion Plant.

OAK RIDGE NATIONAL LABORATORY
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Abstract

Using the straight-ahead approximation, nucleon-meson cascade calculations have been carried out for several solar-flare proton spectra incident on a shield. The shield material has approximately the properties of aluminum. Both spherical-shell and slab geometries are considered.

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I. Introduction

In a previous report¹ (hereinafter referred to as 1) nucleon-meson cascade calculations were carried out and results were given for a variety of cases of interest in the shielding of manned space vehicles. In this report similar calculations showing the attenuation of several solar flares by aluminum shields are presented.

The method of calculation, the data used to describe the shielding medium, and the notations are, except for minor changes, the same as those used in 1. These slight changes are discussed in Section II.

In Section III the time-integrated differential and integral energy spectra for the solar flares considered are given. In Section IV the results of the calculations are presented and discussed.

II. Details of the Calculation

The data used to describe the shielding medium is the same as that discussed in 1 except that the charged-pion nonelastic cross section has been changed to conform to the calculations of H. W. Bertini.^{2,3} Since the pions play only a minor role in the calculations, this change is of no practical importance.

In 1 it was pointed out that the approximations involved in the calculation become invalid at low particle energies and therefore the particle fluxes were calculated only for energies greater than 32 Mev. Since the lower energy particles contribute to the dose, it was necessary to estimate their contribution and this was done by a crude extrapolation procedure. In this report we continue to use this extrapolation procedure*

*In the terminology of 1, all curves in this report are for $\Gamma = 0$.

1. R. G. Alsmiller, Jr. and J. E. Murphy, Space Vehicle Shielding Studies: Calculations of the Attenuation of a Model Solar Flare and Monoenergetic Proton Beams by Aluminum Shields, ORNL-3317 (1963).
2. H. W. Bertini, Monte Carlo Calculations on Intranuclear Cascades, ORNL-3383 (1963).
3. For a plot of this cross section, see R. G. Alsmiller, Jr., F. S. Alsmiller, and J. E. Murphy, Nucleon-Meson Cascade Calculations: Transverse Shielding for a 45-Gev Electron Accelerator (Part II), ORNL-3365 (1963).

except in the case of the primary proton dose at small shield thicknesses ($\leq 10 \text{ g/cm}^2$).

Since the primary protons move in straight lines, to a high degree of approximation, it is quite possible to calculate the proton flux at all significant energies and therefore it is possible to calculate the primary proton dose directly, i.e., without extrapolation. This procedure⁴ has been used in this report to obtain the primary proton dose at shield thicknesses of less than or equal to 10 g/cm^2 where the extrapolation was felt to be inaccurate. In truth, the primary proton dose obtained by extrapolation and that obtained by direct calculation are never very different (less than a factor of 2) and become essentially the same at a thickness of 10 g/cm^2 , so this slight change in the method of calculation is of very little importance.

III. Solar Flare Spectra

In this report proton spectra corresponding to three very different solar events will be considered. The time-integrated integral energy spectra for these events are taken from the work of W. Gill⁵ and are shown by the solid curves in Fig. 1. For purposes of numerical calculation it is necessary to have the time-integrated differential energy spectra. The differential spectra were obtained by using an analytic fit to the curves in Fig. 1 and are shown in Fig. 2. In Fig. 2 and in all calculations it is arbitrarily assumed that the flare spectra contain no protons with energy less than 32 Mev or greater than 2 Gev.

For purposes of comparison the time-integrated integral energy spectra obtained by integrating the differential spectra of Fig. 2 are shown as plotted points in Fig. 1.

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4. F. S. Alsmiller, R. G. Alsmiller, Jr. and D. K. Trubey, "Comparison of Primary Proton Dose with the Dose from Gamma Rays Produced by Inelastic Scattering of Solar-Flare Protons," Proceedings of the Symposium on the Protection Against Radiation Hazards in Space, Book 2, p. 718, TID-7652 (1962).
  5. Private communication. (At the higher energies, $> 500 \text{ Mev}$, these curves were obtained by power law extrapolation; and thus the high-energy behavior, particularly in the case of the Sept. 28, 1961 event, may be unrealistic.

Fig. 1. Time-Integrated Integral Energy Spectra for Solar Proton Events.

Fig. 2. Time-Integrated Differential Energy Spectra for Solar Proton Events.

IV. Results and Conclusions

Before giving the results it is perhaps worthwhile to again emphasize that the calculations are only approximate and are meant to give only preliminary answers until the more rigorous results of H. W. Bertini⁶ and W. E. Kinney⁷ become available. A comparison between the results in 1 and the calculations of Kinney for one specific case has been published.⁸

In Figs. 3, 5, and 7 the particle doses at the center of a spherical-shell shield, when each of the three flares in Fig. 2 is incident isotropically on the shell, are plotted as a function of shell thickness, r . In these figures, and in all subsequent figures, the smallest shield thickness considered is 1.6 g/cm^2 for the primary dose and 2.3 g/cm^2 for the secondary doses. A thickness of 1.6 g/cm^2 is slightly greater than the range of a 32-Mev proton. At shield thicknesses smaller than this, those incident protons with energy less than 32 Mev which have been neglected will contribute to the dose.

In all three figures the dose due to the secondary particles does not become comparable to the primary dose until rather large shield thicknesses are considered. In Fig. 7 the secondary dose becomes appreciable at somewhat smaller thicknesses than in Figs. 3 and 5 because of the relative number of high-energy particles in the Sept. 28, 1961 event. As one goes to thick shields ($> 200 \text{ g/cm}^2$), the primary dose rapidly becomes negligible and the dose is due almost entirely to secondary neutrons. Note that for very thick shields the total dose is decaying nearly exponentially and at all shield thicknesses the pions and muons are negligible.

In Figs. 4, 6, and 8 the particle doses behind a slab shield, when each of the three flares is incident isotropically on the slab, are plotted

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6. H. W. Bertini op. cit.

7. W. E. Kinney, R. R. Coveyou, and C. D. Zerby, "A Series of Monte Carlo Codes to Transport Nucleons Through Matter," TID-7652 op. cit., p. 608 (1962).

8. R. G. Alsmiller, Jr., F. S. Alsmiller, and J. E. Murphy, "Nucleon-Meson Cascade Calculations in the Straight-Ahead Approximation," TID-7652 op. cit., p. 698 (1962).

Fig. 3. Dose vs. Shell Thickness.

Fig. 4. Dose vs. Slab Thickness.

Fig. 5. Dose vs. Shell Thickness.

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Fig. 6. Dose vs. Slab Thickness.

Fig. 7. Dose vs. Shell Thickness.

Fig. 8. Dose vs. Slab Thickness.

as a function of slab thickness, x . As in the spherical-shell geometry, the secondaries contribute appreciably to the total dose only for rather thick shields.

In Fig. 9 the total doses from Figs. 3 to 8 are replotted for purposes of comparison. As is to be expected, the dose attenuates much more rapidly in a slab geometry than in a spherical-shell geometry.

Since the calculations of Bertini⁶ and Kinney⁷ are now available for energies less than 400 Mev, the question arises as to whether valid information for shielding against solar flares can be obtained by considering only those protons in the flare spectrum with energy less than 400 Mev.

In Figs. 10 through 15 the particle doses from the spectra in Fig. 2 are compared with the particle doses obtained when these flares are assumed to contain no particles with energy greater than 400 Mev. Figures 10, 12, and 14 show the results for spherical shells while Figs. 11, 13, and 15 show the results for slabs. As indicated in the figures, the validity of cutting off the incident spectrum above 400 Mev depends to a large extent on the shape of the spectrum being considered.

Acknowledgment

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Fig. 9. Total Dose vs. Shield Thickness.

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Fig. 10. Dose vs. Shell Thickness.

Fig. 11. Dose vs. Slab Thickness.

Fig. 12. Dose vs. Shell Thickness.

Fig. 13. Dose vs. Slab Thickness.

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Fig. 14. Dose vs. Shell Thickness.

Fig. 15. Dose vs. Slab Thickness.

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