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RADIATION DEGRADATION OF

SOLAR CELL ARRAYS

Prepared by:

C. W. Hill

Prepared for:

George C. Marshall Space Flight Center
Marshall Space Flight Center, Huntsville, Alabama 35812

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Final Report

SCIENCE APPLICATIONS, INCORPORATED
2109 W. Clinton Avenue, Suite 800
Huntsville, Alabama 35805
205/533-5900

FOREWORD

This report is submitted to the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama, in accordance with the requirements of NAS8-30608.

ABSTRACT

A method of incorporating a detailed solar cell radiation degradation model into a convenient computational scheme suitable for the Solar Electric Propulsion System is outlined. The study shows that several existing codes may be applied in sequence to solve the problem.

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1. INTRODUCTION

Solar cells used to supply power for space missions are subject to degradation by energetic radiations encountered in space. The dominant radiation sources are electrons and protons in the trapped radiation belts, or protons and heavier nuclei due to solar flares. Degradation due to galactic cosmic radiation is usually negligible. The effects of nuclear weapon radiation will not be discussed in this report. Damage to adhesives and darkening of cover glass materials due to electromagnetic radiation are also excluded. The latter effects are often slow and linear with exposure.

Radiation damage to solar cells depends upon many factors. This complexity forces most analyses and predictive methods to use simplifying assumptions. The inaccuracies thus introduced force the designer to use conservative safety margins for mission planning. Degradation of existing solor cell array power supplies in space provide checkpoints, but the rapid evaluation of solar cell types and the uncertainties of extrapolating these data to other trajectories pose severe problems.

Parameters used to assess cell performance include the open circuit voltage, Voc; the short circuit current, Isc; and the maximum power available, Pmax. These parameters are easier to deal with than the voltage - current performance curve. However, these parameters are functions of light spectrum in the undamaged state. Following radiation exposure, the parameters are functions of particle type, particle energy, particle fluence, light spectrum, time, and temperature-vs time profile. Certain other effects such as the angular distribution of the radiation and non-uniform damage across the cell due to low energy protons complicate the problem.

The George C. Marshall Space Flight Center recognized the need for more accurate degradation predictive methods for the Solar Electric Propulion Stage (SEPS). Accordingly, MSFC commissioned Horne and Wilkinson to survey the state-of-the-art and recommend an approach to improve damage prediction[1]. Horne and Wilkinson conclude that a reasonably detailed transport calculation be performed within the cell. A microscopic defect damage coefficient may be calculated at various points across the cell. The resulting damage profiles should then be analyzed with the PN code developed by GGA under Air Force contract[2, 3].

The present effort attempts to integrate the above recommendations into a computational scheme. Implementation of the scheme has not been possible due to limited funds and a delay in delivery of the PN code to MSFC.

2. COMPUTATIONAL MODEL

The computational model devised for solar cell radiation degradation models requires several steps. Each stage in the calculation is outlined below.

2.1 RADIATION ENVIRONMENT

Trapped radiation levels comprizing protons and electrons are described by the models of Vette and his co-workers[4]. A trajectory code presently operational at MSFC may be used to estimate radiation fluences over specified orbits.

The estimation of solar radiation fluxes is more difficult. It is suggested that the work of Burrell[5] be used to determine the number of solar events during a mission at various probability levels. It will be necessary to assume a spectral shape and normalize it to event magnitude. For missions within the magnetosphere, a code developed by Wright[6] may be used to estimate flux reduction due to magnetic shielding.

2.2 PROTON AND ELECTRON TRANSPORT

It is necessary to find the differential proton and electron spectra at the two faces of the solar cell and at a number of mesh planes between the faces. A total of three to five calculations should be sufficient; the spectra at other postions may be obtained by semi-logarithmic interpolation for such thin components.

For some satellities, the solar cell arrays are attached to a reasonably massive body structure. In such cases the radiation component entering the back face may usually be ignored. The SEPS solar cell array will probably be unfurled on a thin backing material which may be comparable in thickness to the cell itself. Here it will be necessary to compute radiation levels entering the back side through the attachment sheet as well as that entering the front side through the cover material. The front and back radiation components will be summed.

Horne and Wilkinson suggest the SPARES code system[7] for performing the proton and electron transport calculation. These programs are suitable for such use and should give accurate results. Alternatively, the burden of converting those programs from an IBM installation to the Univac computers at MSFC may be avoided by using codes developed by Burrell[8] and Watts or by Hill et al [10]. which are operational at MSFC. Should the latter approach be chosen, two code modifications will be desirable. First, the treatment of low energy protons should be improved by limited parameter fits to range date in the low energy regime. Second, the monodirectional proton beam technique should be generalized to isotropic incidence.

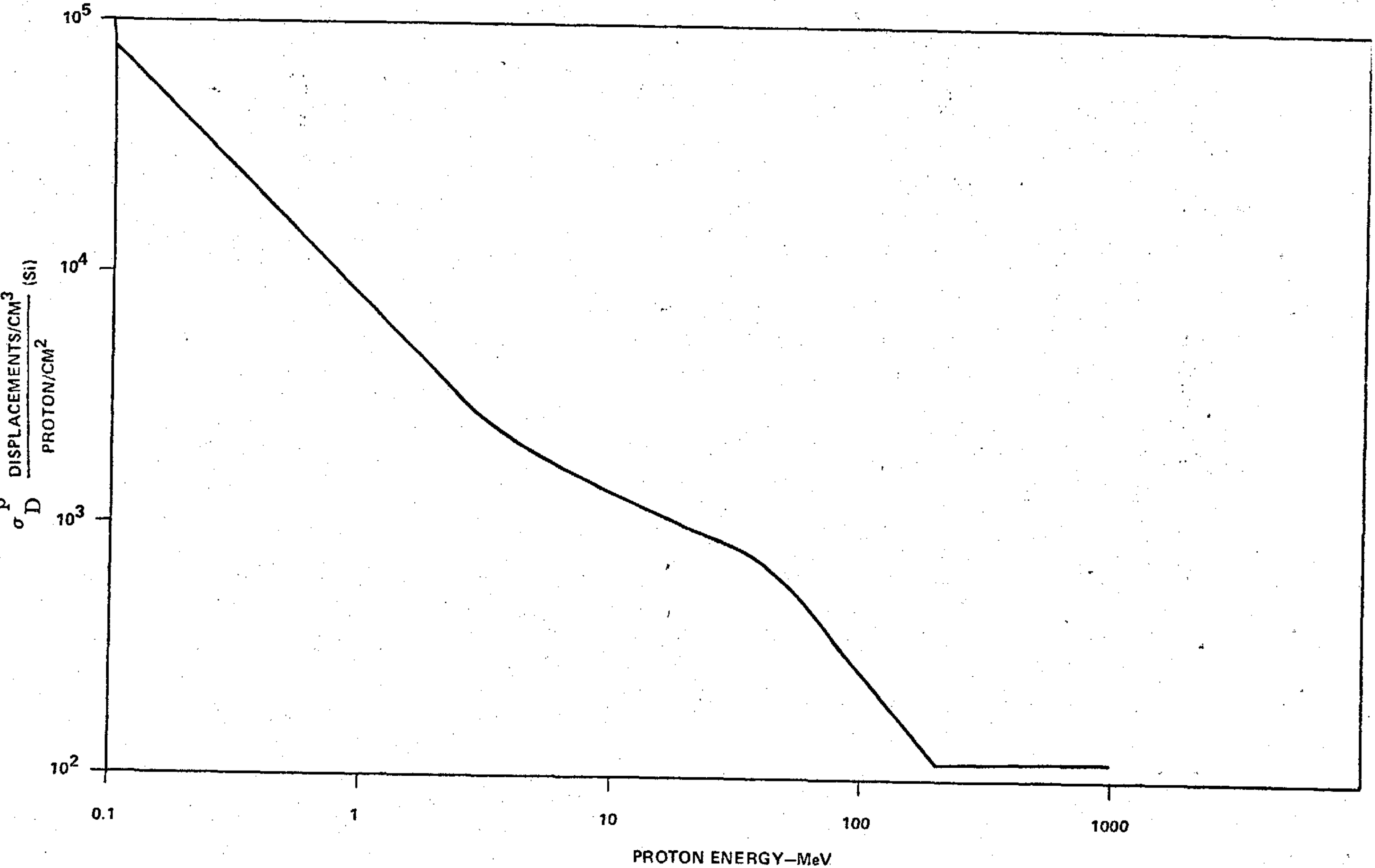

Figure 1. Proton Displacement Cross Section in Silicon

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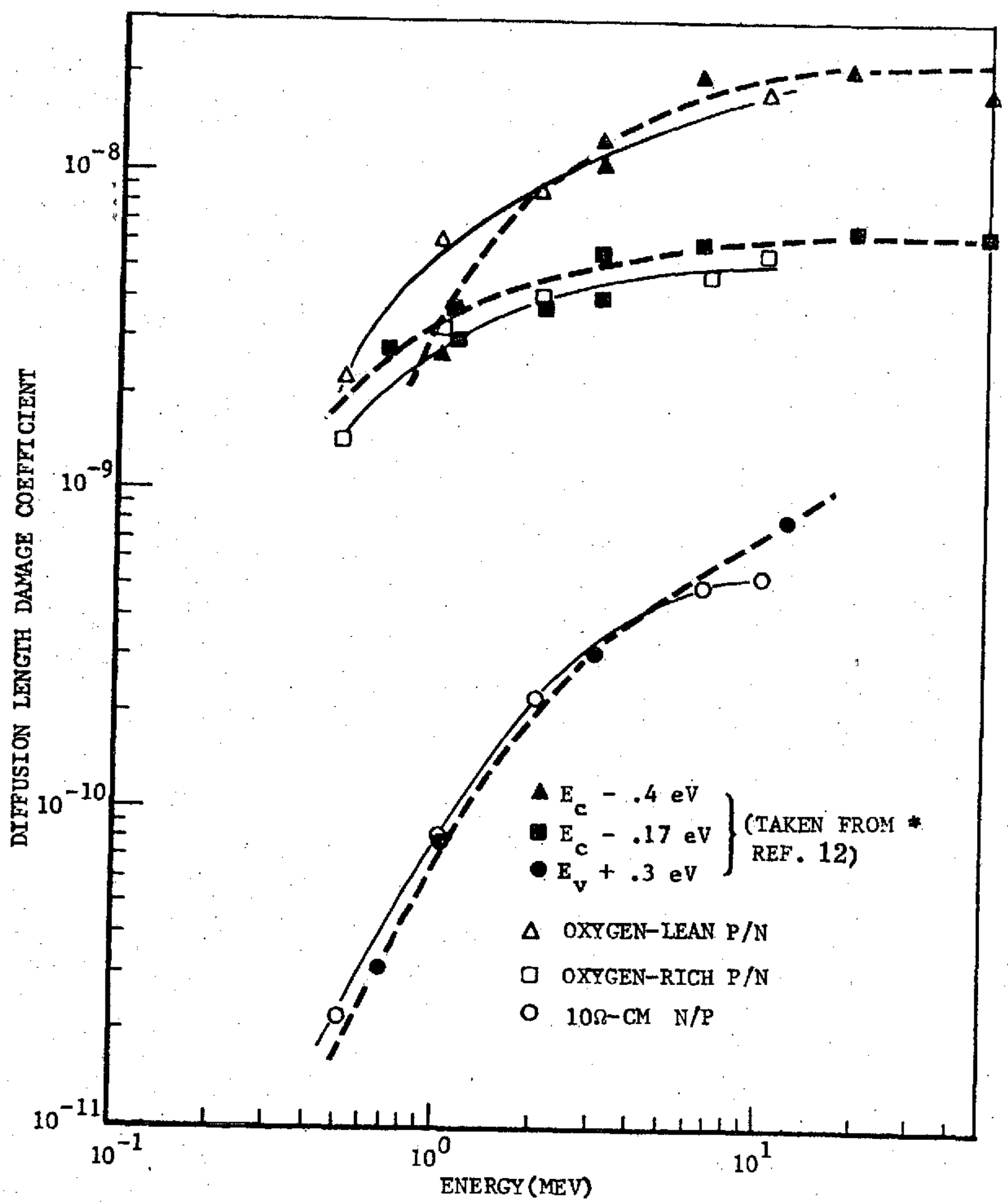

* (Note: Recombination Center Curves have been normalized to respective damage coefficient curves.)

Figure 2: Comparison of Energy Dependence of Damage Coefficients for Different Types of Solar Cells with the Energy Dependence of Recombination Center Introduction Rates

to the low electron mass. The solid data points in Figure 2 are derived from the assumption that all the recombination centers can be characterized by a single energy level for a specific material. This assumption greatly simplifies the analysis but may lead to some inaccuracies in predicting annealing rates.

2.4 SOLAR CELL DEGRADATION CALCULATIONS

The defect density profiles derived from the method outlined in Section 2.3 identify the radiation-associated variables. Other variables such as light transmittance, impurity profiles, diffusion length, etc., must be derived from experimental data and supplied to the PN code. This code may then be used to predict gross behavior of the solar cell based upon microscopic treatment of the interactions within the cell.

At the end of the present contract period, the PN code has not been delivered to MSFC. This delay has precluded the development of efficient approaches to SEPS mission analysis based on parametric runs. At this point it is not known whether the superposition principle will be valid for extrapolating damage calculations to long time intervals, particularly for steep damage profiles within the cell. The question of annealing during a fluctuating temperature profile is also unresolved. A study of these factors must be made in order to devise a rapid analysis tool suitable to the SEPS requirements.

3. RECOMMENDATIONS

In order to advance the development of a radiation degradation analysis tool suitable for SEPS missions, the following steps are recommended.

1. Increase the accuracy of the proton range function parameters down to 0.2 MeV for the MSFC transport code. The code should be modified so that it can sum isotropic proton and electron fluxes incident from both sides of the array, fold in the defect cross sections, and output the displacement defect profiles.

2. Conduct a parametric damage study using the PN code in order to determine degradation sensitivity to critical parameters. Knowledge of these sensitivities will permit a choice of suitable approximations to be made in the analysis method.

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