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DESIGN OF THE EXPERIMENTAL EXPOSURE CONDITIONS TO SIMULATE IONIZING RADIATION EFFECTS ON CANDIDATE REPLACEMENT MATERIALS FOR THE HUBBLE SPACE TELESCOPE

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Introduction

Component stuctures consisting of 5- and 10-mil thickness Teflon (FEP) backed by plated layers of Aluminum or Silver and Inconel have been identified as candidate replacement materials for external components of the Hubble Space Telescope (HST). However, the effects of exposure to the space ionizing radiation environment (primarily trapped electrons and protons) is not known. Therefore, it was desired to ground-test these materials for degradation due to radiation exposure to trapped electrons and protons in the region of the HST orbit for the time period of Launch to SM2 (2490 days). This report describes the design of the ground-based experiment to simulate the space radiation effects using existing and available laboratory particle accelerators.

A major consideration in the experiment design was the limited energy ranges for the laboratory electron and proton accelerators (Edwards, 1997). Two electron accelerators were available with energy ranges from 1 keV to 50 keV and 220 keV to 2500 keV. A proton accelerator was available with an energy range of 70 keV to 700 keV. All accelerators operated at a flux of 1 nA/cm^2 (6.25×10^9 particles/cm^2· sec). The spectral distributions for the space environment electron and proton fluxes were known and are shown in Fig. 1 (Barth, 1997). As can be seen, the laboratory accelerators were not capable of duplicating these spectra exactly. Therefore, special effort was required to determine the appropriate exposure times to the available particle energies that would approximate in some sense of optimality the HST space radiation environment effects on these materials.

The approach taken was to determine computationally the dose to each material structure as a function of depth for both the full HST spectrum and for a limited number of discrete energies attainable by the available particle accelerators. Then, the optimum exposures for the monoenergetic particle fluxes were calculated by determining a least-squares approximation of their combined dose-versus-depth profiles in the material structures to the full spectrum profile. Dose-versus-depth for the electron fluence was calculated using the Integrated TIGER Series (ITS) Monte Carlo radiation transport code (Halbleib, et al, 1992), while the dose-versus-depth for the proton fluence was found by use of the Space Radiation prediction code (Letaw, 1990-1997). Special-purpose programs were written to perform the minimum-least-squares approximation.

Despite a "notch" in the available electron energies extending from 50 to 220 keV, exposure times for 50-keV, 220-keV and 500-keV monoenergetic fluxes were found that approximated the space electron fluence effects over 4-, 5- and 10-mil depths in Teflon. Ranging from 1000 to 3400 seconds, these times were realizable with the laboratory accelerators. The results for the proton exposures were severely limited by the 700 keV maximum machine energy with the HST full spectrum extending to over 500 MeV. The experimental dose profile could only approximate the full spectrum exposure profile for a small fraction of the material depth. Optimal exposure times for 200-keV, 500-keV and 700-keV monoenergetic fluxes on the order of milliseconds were determined, however, they were not realizable to any degree of accuracy with the available laboratory accelerators.

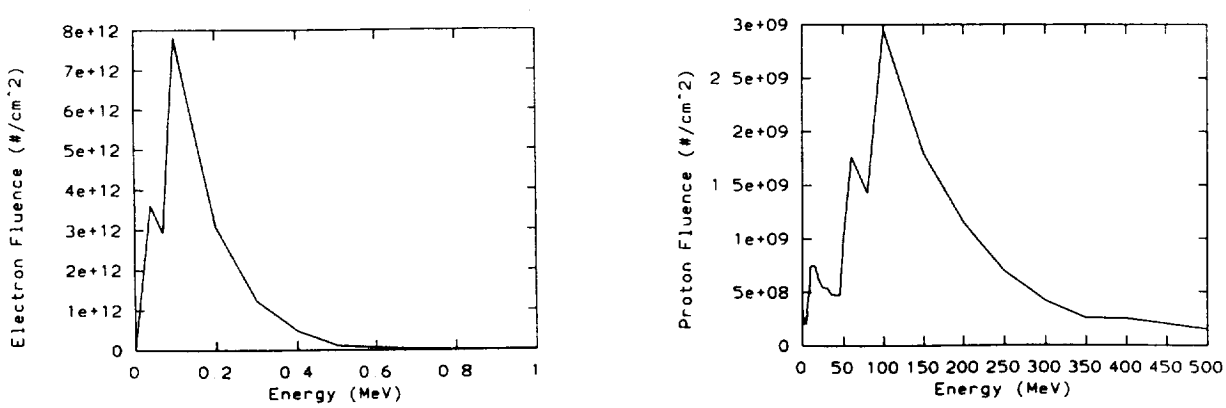

Fig. 1. Spectral distributions for the HST trapped electron and trapped proton fluences.

Calculation of the Dose-Versus-Depth Profiles

The first phase in the experiment design was to determine the dose as a function of depth in the candidate material structures. Six candidate material structures were initially considered, all of which consisted of a slab geometrical configuration:

1. 10-mil Teflon (FEP)/backed by 150-nm Silver (Ag)/backed by 27.5-nm Inconel
2. 5-mil FEP/150-nm Ag/27.5-nm Inconel/2-mil Kapton
3. 10-mil FEP/backed by 100-nm Aluminum (Al)
4. 5-mil FEP/100-nm Al/2-mil Kapton
5. 5-mil FEP/150-nm Ag/27.5-nm Inconel
6. 5-mil FEP/100-nm Al

The slab geometry simplified the analysis in terms of input files for the dose calculations and execution times for the Monte Carlo analysis. Although it was felt that the back surface platings would have negligible effects, they were initially included in the electron dose-versus-depth study for completeness.

The electron exposure calculations employed the TIGER 1-D slab geometry Monte Carlo radiation transport member code of the Integrated TIGER Series (Halbleib, et al, 1992). Files for the component materials were written for the XGEN scattering cross-section generation code, and input files for each structure were written for the TIGER code. Data for the HST trapped electron spectral fluence was used to model the spectral distribution of incident electrons on the front surface of each structure. The Teflon layer was divided into 25 subzones (for the 5-mil cases) or 50 subzones (for the 10-mil cases) so that the energy deposition in each subzone calculated by TIGER gave a direct measure of the dose as a function of depth.

The results are shown in Fig. 2, which shows the energy deposition in MeV (normalized to one particle per cm^2) as a function of depth into the Teflon layers for the six cases considered. As expected, the different back platings had negligible effect on the doses in the Teflon, and any discrepancies in the curves are felt to be the result of statistical uncertainties in the Monte Carlo process.

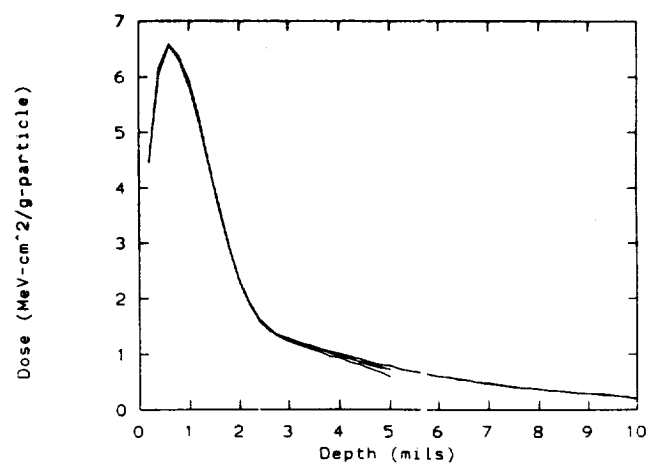

Fig. 2. Energy deposition as a function of depth in Teflon for the full HST electron spectrum.

Based upon experience with the dose-versus-depth calculations for electrons, the corresponding calculations for the proton flux were restricted to the simple case of a single layer of 10-mil thick Teflon. Although several computer codes were considered for usage, the Space Radiation prediction code (Letaw, 1990-1997) was chosen primarily because of availability and familiarity. Beause this code is limited in the materials that can be input, Lexan was chosen as the medium for the dose-versus depth code calculations, being that which is closest to Teflon in its material properties.

Calculation of the dose as a function of depth was something of a tedious process even with the spectral distribution of protons well-tabulated. Different thicknesses of the Lexan were treated as shielding material and the dose rate behind each thickness calculated for the full spectrum proton fluence. In this way, the dose-versus-depth profile was constructed for the input "shielding thicknesses."

The results are shown in Fig. 3, which shows the dose in rads (normalized to one particle per cm^2) as a function of depth into the Lexan layers over the 10 mil depth considered. Worth noting are the extremely low dose values and the penetration of the protons into the material. These effects result from the large amount of high-energy protons in the original incident spectrum.

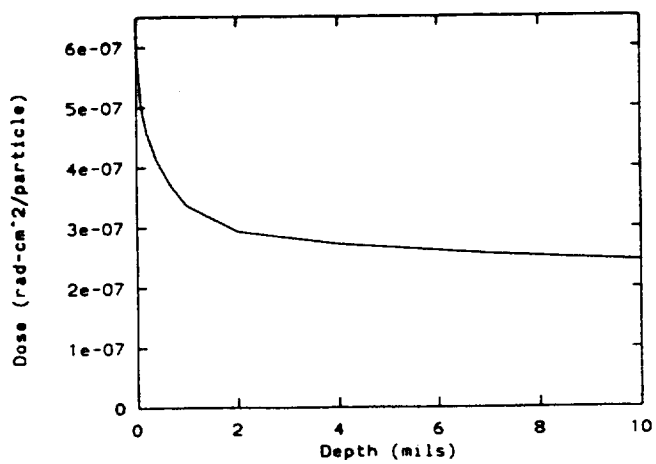

Fig. 3. Dose as a function of depth in Lexan for the full HST proton spectrum.

Determination of the Experimental Exposures

To determine the optimal exposure conditions, discrete particle energies were selected that were available with the laboratory accelerators, and dose-versus-depth profiles for the corresponding monoenergetic particle fluxes were computed. Using the data from these curves, optimal weightings and an overall scale factor were determined that minimized the mean-square-error between the linear combination of the monoenergetic profiles and the dose-versus-depth profile as calculated for the full HST spectrum. These optimal weightings allowed for a direct conversion to accelerator exposure times for the particle energies selected.

For the electron exposure conditions, four discrete energies were selected: 50 keV, 220 keV, 350 keV, and 500 keV. Energy deposition as a function of depth into a 10-mil slab of Teflon was calculated for each of these energies. A special-purpose C program was then written to take the data from these profiles and perform a five-parameter (four weightings and an overall scale factor) exhaustive search to minimize the mean square error between the composite curve and the full spectrum curve for the first case considered (10-mil Teflon thickness.) Optimization was performed for depths of 4, 5 and 10 mils, and weighting factors were calculated to within $\pm 0.5\%$ uncertainty.

Figure 4 shows the results for optimization of the discrete energy weightings over the full 10-mil depth. While the profiles appear quite dissimilar, it should be noted that energies in the range 50 keV to 220 keV encompass the peak in the space environment electron fluence spectrum and yet are exactly those unavailable in the laboratory accelerators. Without that range of energies, extremely accurate duplication is not to be expected.

Based upon the preceding analysis, the following experimental procedures were recommended for simulation of the space electron radiation environment on candidate components of the Hubble Space Telescope:

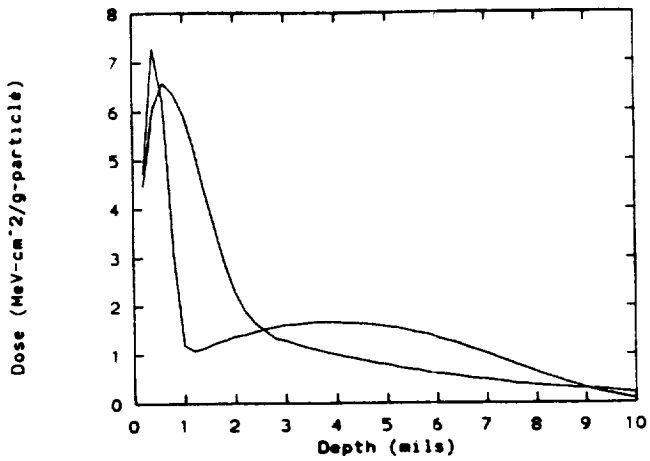

Fig. 4. Comparison of electron flux dose-versus-depth full spectrum profile with composite profile for discrete energies with weightings optimized over full 10-mil thickness of Teflon.

To simulate dose for 4-mil depth:

- Expose to 50-keV electron flux for 1005 ± 5 seconds
- Expose to 500-keV electron flux for 3363 ± 16 seconds

To simulate dose for 5-mil depth:

- Expose to 50-keV electron flux for 1104 ± 5 seconds
- Expose to 500-keV electron flux for 2703 ± 13 seconds

To simulate dose for 10-mil depth:

- Expose to 50-keV electron flux for 1289 ± 6 seconds
- Expose to 220-keV electron flux for 895 ± 4 seconds

These exposure times are within the normal operating parameters for the available laboratory accelerators. Thus, realizable experimental procedures were found that simulated the space radiation trapped electron environment to an acceptable degree of fidelity.

For the proton exposure conditions, three discrete energies were selected: 200 keV, 500 keV, and 700 keV. Dose as a function of depth into the first 0.5 mil of the 10-mil slab of Lexan was calculated for each of these energies. A special-purpose C program was then written to take the data from these profiles and perform a four-parameter (three weightings and an overall scale factor) exhaustive search to minimize the mean square error between the composite curve and the full spectrum curve. Optimization was performed only over this limited depth of 0.5 mils since protons at these low energies were found not to penetrate the Lexan any further.

Figure 5 shows the results for optimization of the discrete energy weightings over this 0.5-mil depth. The profiles agree reasonably well, but beyond this depth, doses from the monoenergetic protons are virtually zero. Without a much higher range of energies, accurate simulation of the space environment effects for any larger depth is not possible

From the optimal weightings and scale factor, the exposure times for the given laboratory electron accelerators were determined and are given by: 0.0085 sec exposure time for 200 keV protons, 0.0092 sec exposure time for 500 keV protons, and 0.016 sec exposure time for 700 keV protons. The available laboratory accelerators are not capable of being controlled to within the timing accuracy required to perform these exposures. Thus, while optimal values were determined to simulate at least the surface exposure effects of the space radiation trapped proton environment, the results were not realizable with the existing equipment.

Based upon the brevity of optimal exposure times and limited depth of effectiveness, it was recommended that no exposure to protons be performed. However, if proton exposure was essential to the simulation effort, it was recommended to use only the highest energy avaliable (700 keV) and expose components to that proton flux for the shortest time realizable with the existing laboratory accelerator.

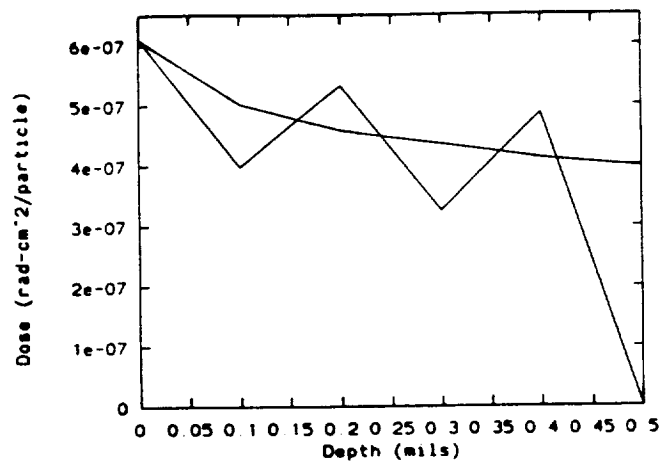

Fig. 5. Comparison of proton flux dose-versus-depth full spectrum profile with composite profile for discrete energies with weightings optimized over first 0.5-mil thickness of Lexan.

Summary and Conclusions

In this effort, experimental exposure times for monoenergetic electrons and protons were determined to simulate the space radiation environment effects on Teflon components of the Hubble Space Telescope. Although the energy range of the available laboratory particle accelerators was limited, optimal exposure times for 50 keV, 220 keV, 350 keV, and 500 KeV electrons were calculated that produced a dose-versus-depth profile that approximated the full spectrum profile, and were realizable with existing equipment. For the case of proton exposure, the limited energy range of the laboratory accelerator restricted simulation of the dose to a depth of 0.5 mil. Also, while optimal exposure times were found for 200 keV, 500 keV and 700 keV protons that simulated the full spectrum dose-versus-depth profile to this depth, they were of such short duration that existing laboratory could not be controlled to within the required accuracy.

In addition to the obvious experimental equipment issues, other areas exist in which the analytical work could be advanced. Improved computer codes for the dose prediction – along with improved methodology for data input and output – would accelerate and make more accurate the calculational aspects. This is particularly true in the case of proton fluxes where a paucity of available predictive software appears to exist. The dated nature of many of the existing Monte Carlo particle/radiation transport codes raises the issue as to whether existing codes are sufficient for this type of analysis. Other areas that would result in greater fidelity of laboratory exposure effects to the space environment is the use of a larger number of mononergetic particle fluxes and improved optimization algorithms to determine the weighting values.

References

Barth, J., Internal Memorandum: HST Radiation Environment/MLI Degradation, Marshall Space Flight Center, May 1997.

Edwards, D., Private communication, Marshall Space Flight Center, July 1997.

Halbleib, J. A., Kensek, R. P., Mehlhorn, T. A., and Valdez, G. D., *ITS Version 3.0: The Integrated TIGER Sries of Coupled Electron/Photon Monte Carlo Transport Codes*, SAND91-1634, March 1992.

Letaw, J. R., *Space Radiation SoftCopy Manual*, Space Radiation Associates, 1990-1997.