CHAPTER 7

RADIATION DOSE

FROM REENTRANT ELECTRONS

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ABSTRACT

In estimating the crew exposures during an EVA, the contribution of reentrant electrons has always been neglected. Although the flux of these electrons is small compared to the flux of trapped electrons, their energy spectrum extends to several GeV compared to about 7 MeV for trapped electrons. This is also true of splash electrons. Using the measured reentrant electron energy spectra, it is shown that the dose contribution of these electrons to the blood forming organs (BFO) is more than 10 times greater than that from the trapped electrons. The calculations also show that the dose-depth response is a very slowly changing function of depth, and thus adding reasonable amounts of additional shielding would not significantly lower the dose to BFO.

INTRODUCTION

The astronaut exposures from trapped protons and electrons have traditionally been estimated using the AP8 and AE8 models (Sawyer and Vette, 1976, Heyndrickx, 1999). However, the contribution of reentrant and splash electrons has always been neglected. The reentrant electrons are the decay products of nuclear interactions in the upper atmosphere of GCR particles, which are trapped in the Earth's magnetic field, spiral along field lines, and reenter, in a downward direction in the opposite hemisphere, but at similar latitudes. The reentrant electrons are distinguished from *splash albedo* electrons, which are upward moving secondary electrons.

In this note, the dose to BFO from reentrant electrons has, for the first time, been calculated. It is compared to the dose from the trapped electrons for a typical ISS orbit of $51.65°$ x 400 km.

RESULTS

Figure 7-1 is plot of the AE8 estimated electron differential energy spectra and reentrant electron energy spectrum. The reentrant electron spectrum was obtained from measurements of Barwick et al. (1998) made during May 1994 (the value of deceleration potential that describe the level of solar modulation, ϕ, was estimated from the Climax neutron monitor rates, to be 640 MV) using the High-Energy Antimatter Telescope (HEAT). The reentrant flux is higher beyond ~ 8 MeV compared to that from the trapped component, assuming that the angular distribution of both components is isotropic. In thinly shielded locations, the dose contribution of trapped electrons would clearly be dominant. **Table 7-1** gives the estimated EVA exposures using the AE8-MIN model. The calculations were done using a Computerized Anatomical Model (Billings and Yucker, 1973) and electron transport program SheilDose2 (Seltzer 1988, Berger and Wang 1988). Data acquired by the Radiation Environment Monitor (REM) instrument mounted on the outside of the Mir core module (Buhler et al., 1996) shows that the AE8-MIN model over-predicts the electron dose by a factor of three and the AE8-MAX model over-predicts the dose by a factor of ~ 8. Data acquired onboard the CRESS satellite during solar maximum (Gussenhovan et al., 1991) also shows that the AE8-MAX model over- predicts the dose by nearly a factor of ~ 8. Thus, the actual BFO dose rate from trapped electrons is probably less than 0.23 mrad day^{-1}.

As is clear from **Table 7-1**, there is very large attenuation of the trapped electron dose due to their soft electron spectrum going inward from skin to BFO. The reentrant spectrum however is hard. An approximate idea of the dose contributed by these electrons can be obtained by integrating the reentrant flux with the stopping power (http://physics.nist.gov/PhysRefData/Star/Text/contents.html). This is the dose rate at zero depth and is 2.56 mrads/day. Because of the hardness of this spectrum, the dose rate would be a slowly decreasing function of depth and thus it is expected that the BFO dose contribution would be higher than that estimated from just trapped electrons. A number of electron transport codes have been developed to study the propagation of high-energy electrons (Nelson et al., 1985, GEANT 3, 1994) that take into account pair production. The dose was calculated by two methods. **Figure 7-2** gives the dose rate-depth dependence. The curves identified as rad dose (tissue) were calculated by using GEANT3 version 123-radiation transport code. The electrons, positrons, and photons were transported and their energy deposition in a thin tissue detector (assumed to be 0.001 cm thick) was tabulated. When the energy dropped below 100 keV, the kinetic energy of the particle was deposited and the particle terminated. The energy deposition was then converted to absorbed dose in rads. The results are given in **Figure 7-2** as a function of aluminum shielding thickness and show that the dose rate barely drops as the thickness increases from 0.5 to 20 g/cm^2. The curves in **Figure 7-3** marked as rem dose (in tissue) were also calculated using fluxes from GEANT3 and energy dependent flux to dose conversion factors for each particle type (Iwai et al., 1998), which yielded a dose in rems rather than rads. The factors used are for the maximum dose equivalent generated in a 30 cm slab of tissue, which should yield a moderate overestimate of dose. The factors were augmented at energies below 10 MeV for photons (Swanson et al., 1979). These results also show that the dose rate is a very shallow function of shielding depth and thus integrating them over the BFO shielding distribution has little effect. Using GEANT3 one gets a BFO dose equivalent rate of 4 mrem/day compared to 6 mrem/day using dose conversion factors. If the angular distribution were not isotropic, as is most certainly the case, these values would decrease somewhat. There is, however, the splash electron flux, which is nearly equal to that from reentrant electrons (Barwick et al., 1998). It is also worth noting that the measurements of Barwick et al. were not made near the solar minimum ($\phi = 640$ MV) and as such represent a lower limit to flux for a solar minimum time period ($\phi \approx 470$ MV). Thus the true combined solar minimum reentrant and splash electron fluxes is thus shown to be more than 10 times larger than the contributions from trapped electrons.

The nearly flat response of the dose rate with depth shows that augmenting the space suit by increasing the volume of the cooling garment or adding water through other means would not lower the BFO dose from electrons significantly.

CONCLUSIONS

Reentrant and splash electrons have never before been considered in estimating crew exposures during EVAs. It is shown that the contribution of reentrant electrons is more than 10 times greater than the contribution of trapped electron BFO dose. Including the splash electron contribution only increases the ratio. The dose decreases very slowly with increasing shielding and thus adding reasonable amounts of material to the space suit would not lead to a significant reduction to the BFO dose rate.
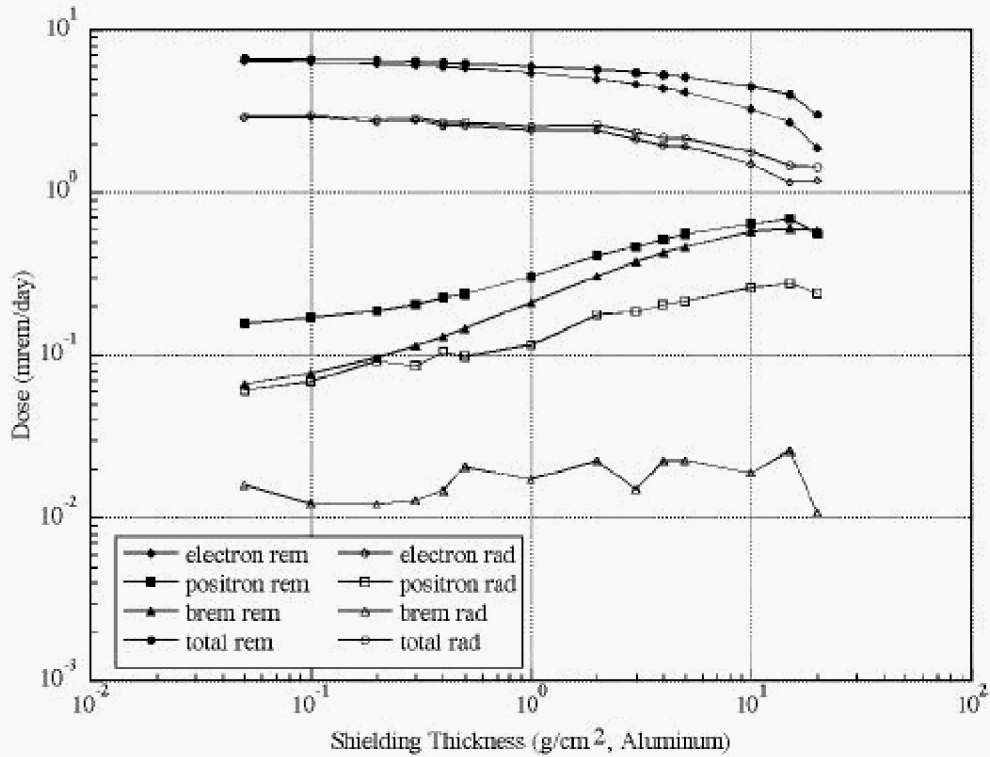
ACKNOWLEDGEMENT

Table 7-1. Trapped Belt Electron Absorbed Dose Rate

Organ	Skin (Arms & Legs)	BFO	EYE
Additional Space Suit Shielding (g cm^{-2})	0.154	0.490	0.490
Dose rate (mrad/day)	1493	0.70	75
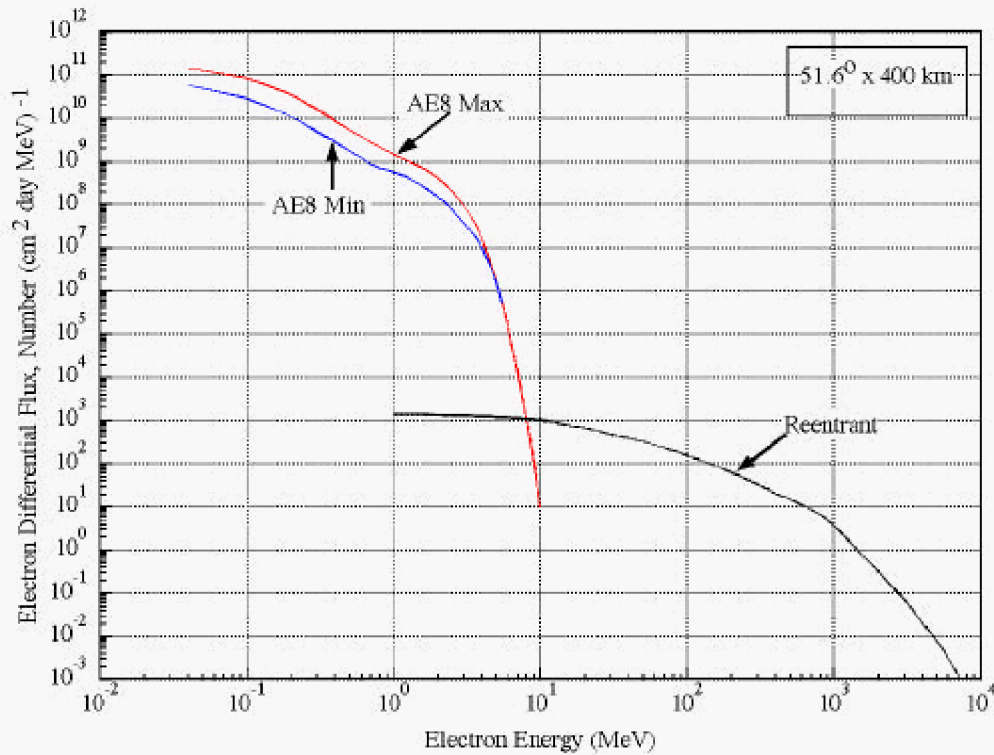
Figure 7-1: Plot of trapped and reentrant electron differential energy spectra.

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Figure 7-2: Plot of absorbed dose and dose equivalent rate from electrons, positrons, and photons using the fluxes from GEANT3 and the fluence to dose conversion factors.
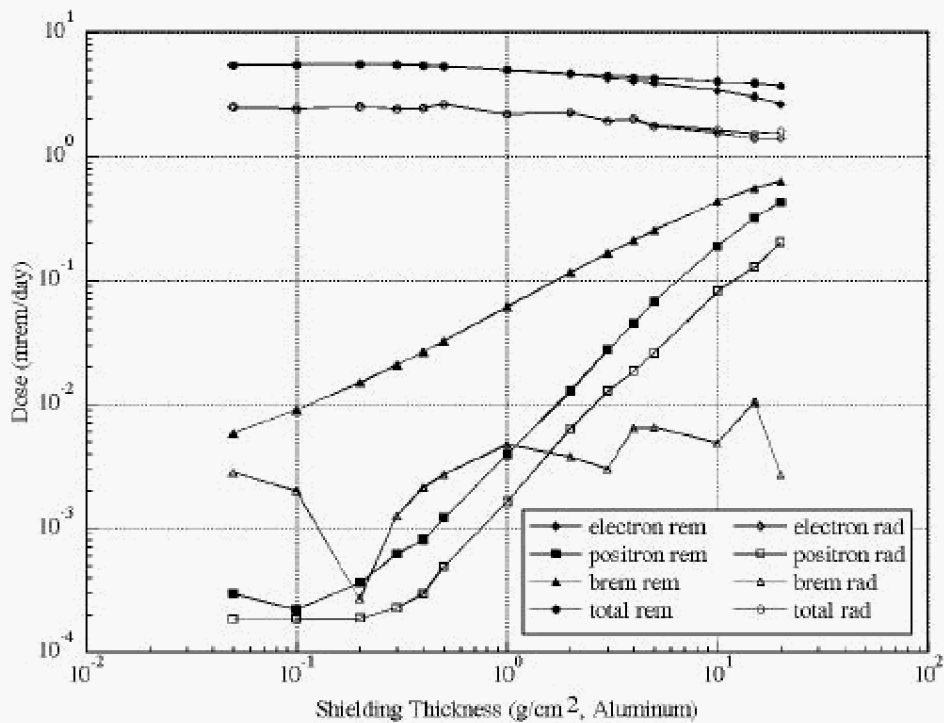
Figure 7-3: Plot of the absorbed dose from electrons, positrons, and bremsstrahlung using the GEANT3 transport code.

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