PREDICTION OF LDEF IONIZING RADIATION ENVIRONMENT

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SUMMARY

The LDEF spacecraft flew in a 28.5° inclination circular orbit with an altitude in the range from 172 to 258.5 nautical miles. For this orbital altitude and inclination two components contribute most of the penetrating charge particle radiation encountered—the galactic cosmic rays and the geomagnetically trapped Van Allen protons. Where shielding is less than 1.0 g/cm^2 geomagnetically trapped electrons make a significant contribution. The "Vette" models (ref. 1-3) together with the associated magnetic field models (ref. 4) were used to obtained the trapped electron and proton fluences. The mission proton doses were obtained from the fluence using the Burrell proton dose program (ref. 5). For the electron and bremsstrahlung dose we used the MSFC electron dose program (ref. 6,7) The predicted doses (ref. 8) were in general agreement with those measured with on-board thermoluminescent detector (TLD) dosimeters (ref. 9). The NRL package of programs, CREME, (ref. 10) was used to calculate the linear energy transfer (LET) spectrum due to galactic cosmic rays (GCR) and trapped protons (ref. 8) for comparison with LDEF measurements (ref. 11).

INTRODUCTION

The LDEF spacecraft flew in a 28.5° inclination circular orbit with an altitude in the range from 172 to 258.5 nautical miles. It was gravity-gradient stabilized and oriented so that one side always pointed along the velocity vector. For this orbital altitude and inclination two components contribute most of the penetrating charge particle radiation encountered—the galactic cosmic rays and the geomagnetically trapped Van Allen protons. Where shielding is less than 1.0 g/cm^2 geomagnetically trapped electrons make a significant contribution. All three sources are strongly modulated by the Earth's magnetic field. The trapped particles follow a helical path about a magnetic field line as shown in figure 1. As the field intensity increases, both the diameter and the pitch of the helix decrease until the pitch becomes zero. The point with zero pitch angle is called the mirror point and the center of the helical path is called the guiding center. From here the helix reverses direction and particles travel up the field line toward decreasing field intensity and away from the Earth. Almost all the trapped flux at LDEF altitudes will be encountered in the region called the South Atlantic Anomaly (SAA) shown in figure 2, which is produced because the Earth's magnetic field, though approximately dipolar, is not centered on the Earth. In the South Atlantic Anomaly almost all the particles observed are near their mirror points. Any trapped particle there which is not nearly mirroring will travel deep into the atmosphere and be scattered or stopped by atmospheric interactions. Thus the flux is anisotropic with most of the flux arriving from a narrow band perpendicular to the local geomagnetic field direction. Atmospheric interactions also affect the trapped proton angular distribution in another fashion as shown in figure 3. Trapped protons that are observed traveling eastward are following guiding centers above the observation point and protons traveling westward are following guiding centers below the observation point. The gyroradius (the radius of the helical path) for energetic protons in the SAA is on the same order as the atmospheric density scale height. Thus westward traveling protons encounter a significantly more dense atmosphere and are more likely to suffer atmospheric interactions and be lost. The resulting energy-dependent anisotropy is called the east-west effect. Galactic cosmic rays experience a similar effect. A model for predicting the trapped proton angular distribution has been developed (ref. 12) recently. A large part of the calculational effort (ref. 13) of the LDEF Ionizing Radiation Special Interest Group has been directed toward testing the prediction of this model against LDEF measurements (ref. 9, 14).

GEOMAGNETICALLY TRAPPED PROTON AND ELECTRON FLUXES

To predict the trapped fluxes the current environment model in use is the "Vette" model (ref. 1-3) together with the associated magnetic field models (ref. 4). To obtain the LDEF mission fluences we calculated long-term average fluxes for five circular orbits at 258.5, 255.0, 249.9, 230.0, and 172.0 nautical mile altitudes which occurred on mission days 0, 550, 1450, 1950, and 2105, respectively, and did a numerical integration over time assuming a straight line between time points. The solar F10.7 cm radio flux which characterizes solar activity exceeded 150 about mission day 1540 (June 27, 1988). Thus the last 565 days or 27 % of the mission was spent under solar maximum conditions. The environment models used for solar minimum (the first three times) were AP8MIN (ref. 2) for protons and AE8MIN (ref. 2,3) for electrons and the magnetic field model was the IGRF 1965.0 80-term model (ref. 4) projected to 1964, the epoch of the environmental model. The environment models used for solar maximum (the last two times) were

AP8MAX (ref. 2) for protons and AE8MAX (ref. 2,3) for electrons and the magnetic field model was the Hurwitz USCS 1970 168-term model (ref. 4) for 1970, the epoch of the environmental model. (The references provided for the electron environment document the previous models to AE8MIN and AE8MAX which remain undocumented.) Since LDEF was at a lower altitude during the last part of the mission about 15% of the proton fluence and 24% of the electron fluence was received under solar maximum conditions. In figure 4 the trapped proton fluence is compared to the galactic proton fluence and the atmospheric albedo fluences due to protons and neutrons produced by GCR interactions in the atmosphere. The galactic proton fluence was produced by the CREME code (ref. 10) which modified the free space spectrum external to the geomagnetosphere based on the vertical rigidity cutoff at points along the LDEF orbit. The albedo fluence was calculated from atmospheric transport of GCR (ref. 15). Figure 5 shows the predicted electron fluence.

TOTAL MISSION DOSE

The mission proton doses were obtained from the fluence using the Burrell proton dose program (ref. 5) which is based on the "straight-ahead" and "continuous-slowing-down" approximations for transporting the protons. Two simple geometries were used–a point tissue receiver material at the center of a spherical aluminum shell and a point tissue receiver material behind a plane aluminum slab with infinite shielding behind the receiver. For the electron and bremsstrahlung dose we used the MSFC electron dose program (ref. 6). The electron dose is based on fits to data from the ETRAN electron Monte Carlo program (ref. 7). Bremsstrahlung dose is based on exponential attenuation with buildup factors from an approximated source. It yields fair agreement with more complicated transports. It only performs the slab geometry calculation. As an estimate for the spherical shell geometry we doubled the slab results which underestimates the actual result. The dose due to trapped protons plus secondary particle, the dose due to electrons plus bremsstrahlung and the total of the two are shown in figures 6 and 7 for the two geometries. A comparison between the predicted total doses and doses measured with onboard TLD dosimeters (ref. 9) is shown in figure 8. Although there is general agreement between the measurement and the simple geometry calculation the planned three-dimensional geometry calculation (ref. 16) will better clarify the spatial variations about LDEF due to shielding configurations and proton angular distributions.

MISSION LINEAR ENERGY TRANSFER (LET) SPECTRUM

The LET of a charged particle specifies how much energy is deposited per unit length along its path in passing through material. Particles with higher LETs are more likely to produce single event upsets (SEUs) in electronic devices and their biological effects are larger compared to low LET particles. The NRL package of programs, CREME, (ref. 10) was used to calculate the LET spectrum due to GCR, the singly-charged anomalous cosmic ray component, and trapped protons for comparison with LDEF measurements. The CREME package calculates the LET spectra at LEO by attenuating the GCR and anomalous flux to the orbital position based on a magnetic rigidity cutoff model and material shielding transport, and then combining this result with the contribution due to trapped protons, also modified by material shielding transport.

Secondaries are not handled. The CREME results (ref. 8) for LDEF are shown in figure 9. Because of the long mission time, experimentally measured LET spectra from the LDEF data (ref. 11) will have greatly improved statistical accuracy at high LET compared to previous measurements.

CONCLUSIONS

Predictions of the LDEF mission's ionizing radiation exposure have been made using the currently accepted models. The LDEF experimental measurements are providing an opportunity to validate the model predictions. Preliminary results for the measured dose are in general agreement with predictions, suggesting that the Vette AP8 model, although more than 20 years old, is still valid, at least for predictions of long-term average dose. The observed variation in dose and activation about the spacecraft shows that the angular distribution of the trapped protons must be considered where more accurate predictions are needed. Because no dose measurements were at thinly shielded locations where the electron contribution to the dose is dominant, the LDEF results will provide little information about the trapped electron environment. The measured LET spectra from LDEF will provide a test of the CREME model with the best measurements at high LET to date.

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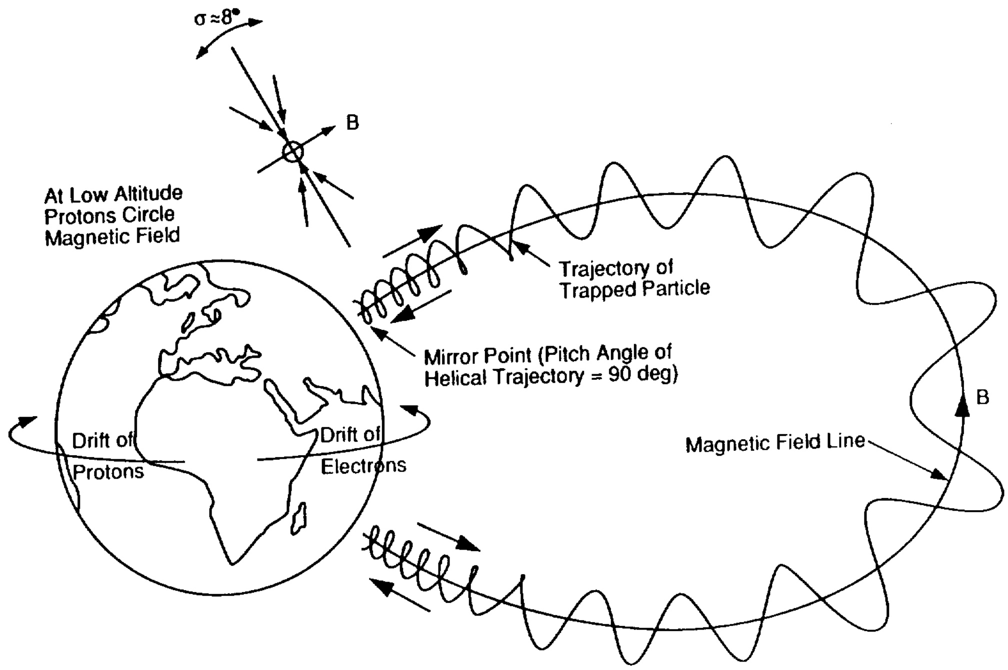

Figure 1. Path of trapped charged particles in the geomagnetic field.

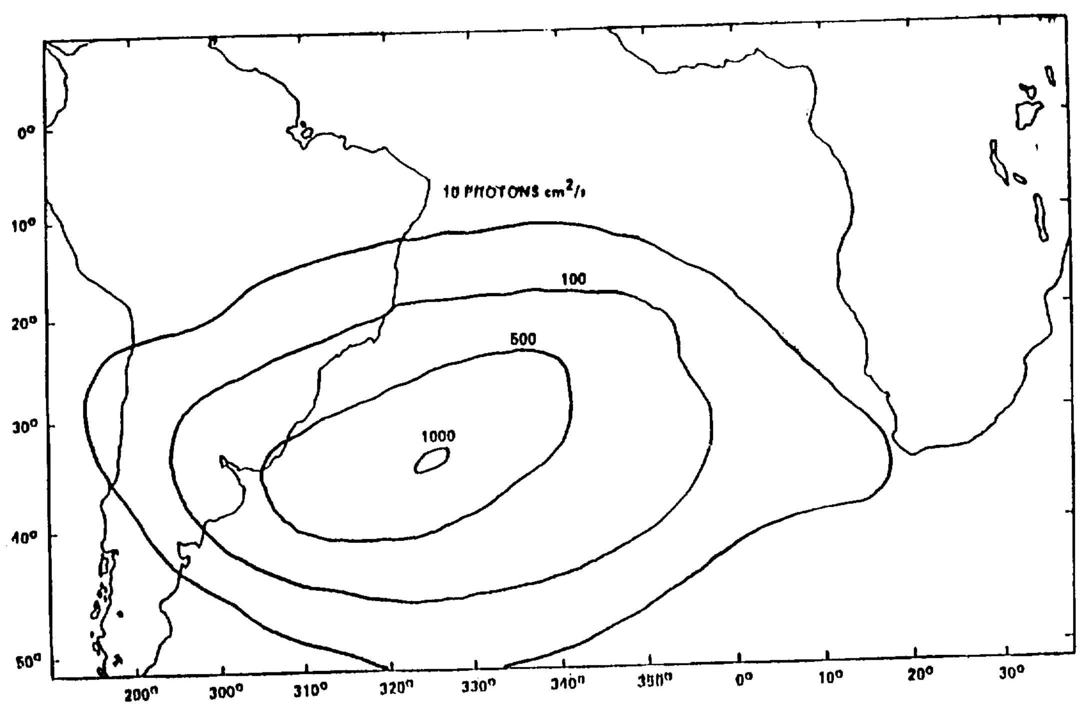

Figure 2. Proton isoflux contours for energies above 34 MeV in the South Atlantic Anomaly at 440 km (240 nautical mi.) altitude.

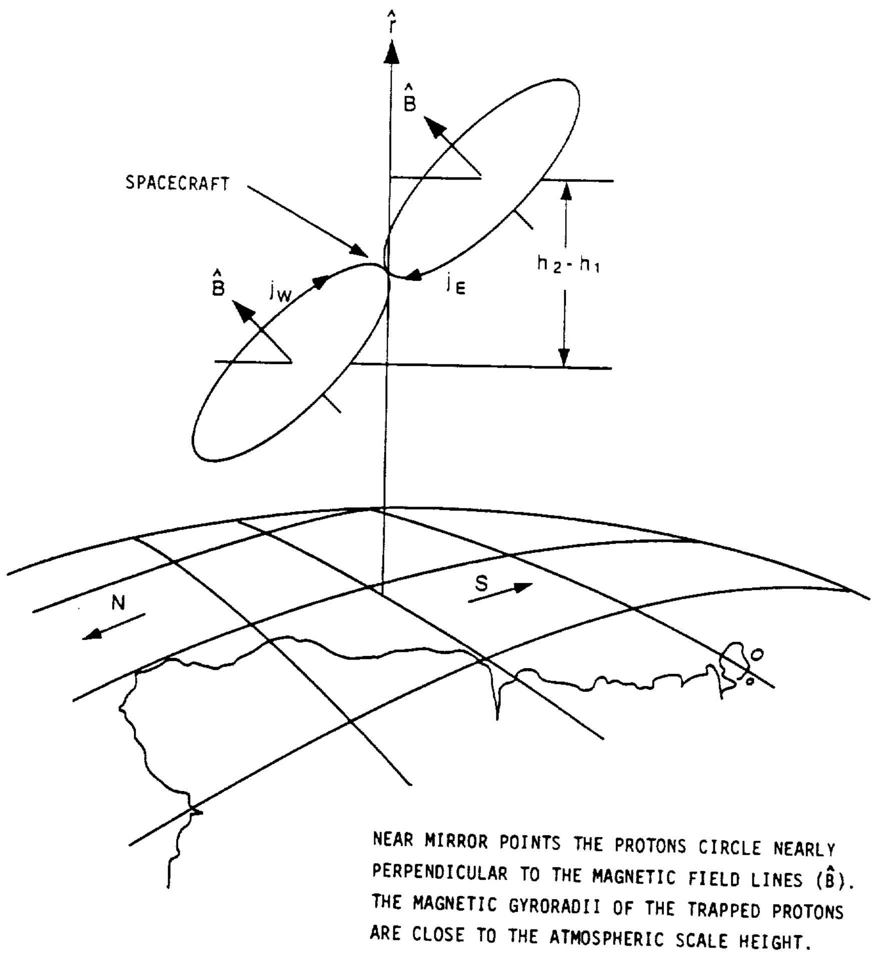

Figure 3. Charged particle path near the mirror point.

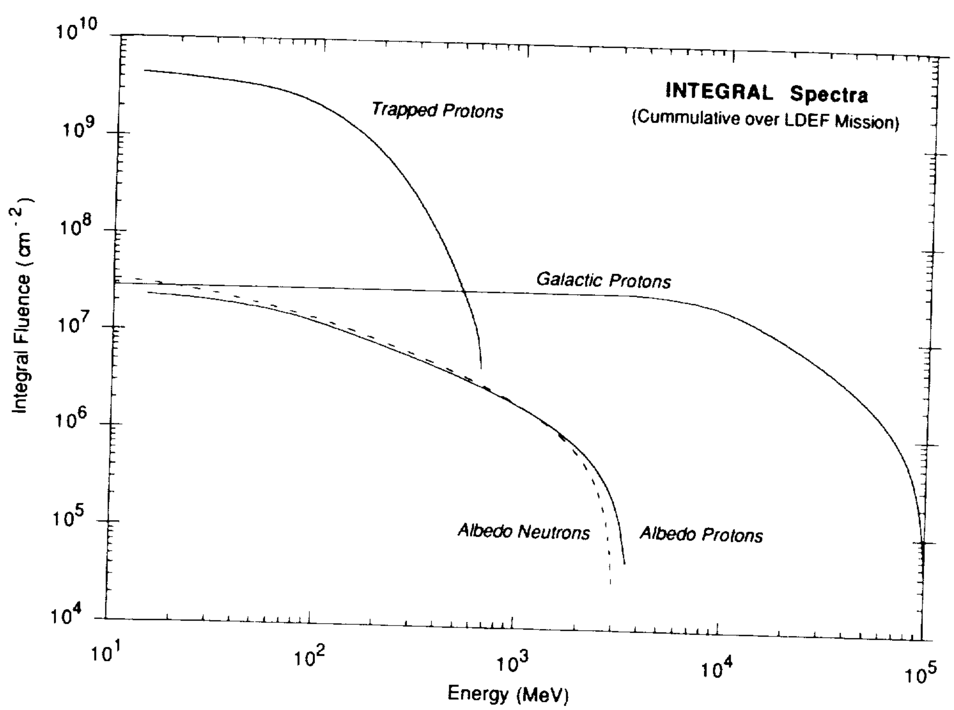

Figure 4. LDEF integral fluences from various sources (ref. 8).

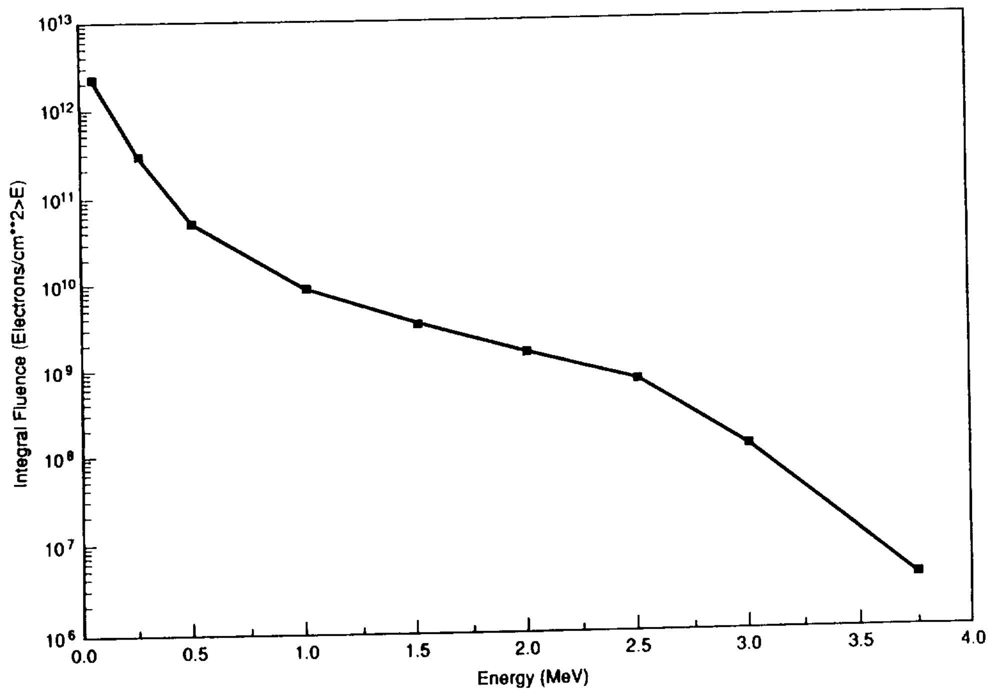

Figure 5. LDEF integral electron fluences (ref. 8).

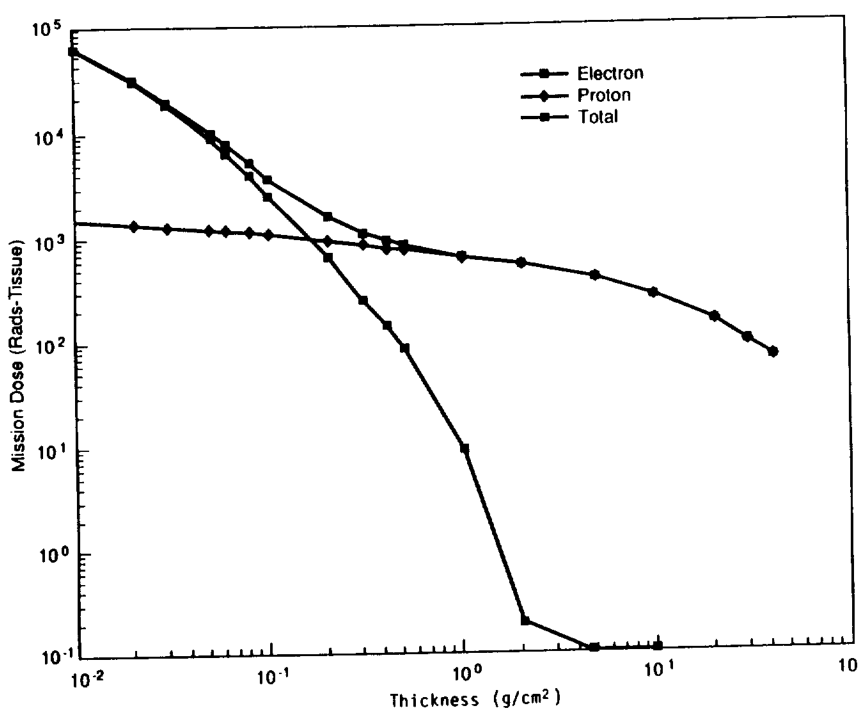

Figure 6. The calculated LDEF mission absorbed dose from trapped protons and electrons (ref. 8). The geometry consists of a point tissue receiver at the center of a spherical aluminum shell of the given thickness.

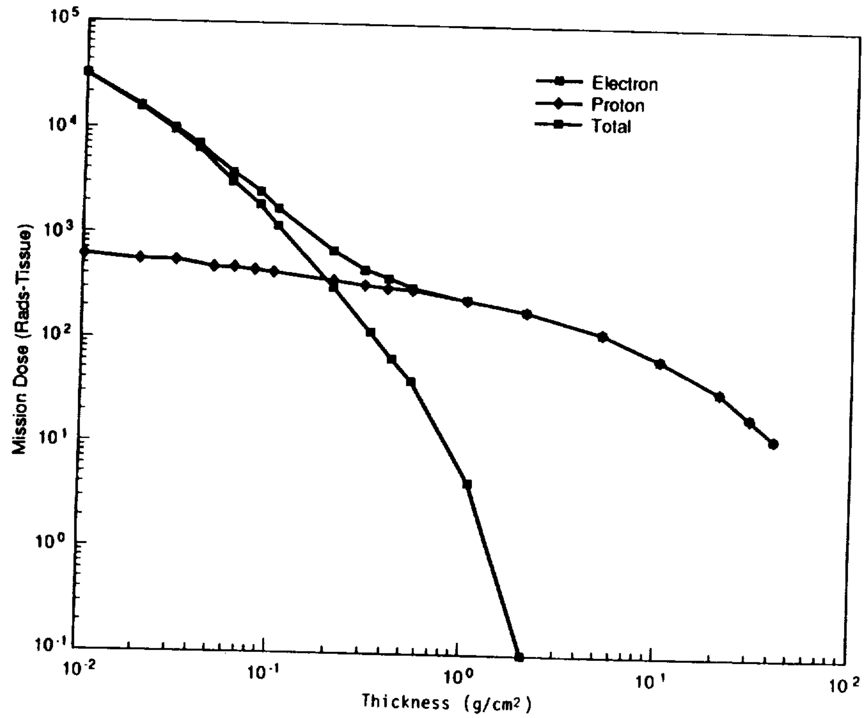

Figure 7. The calculated LDEF mission absorbed dose from trapped protons and electrons (ref. 8). The geometry consists of a tissue receiver behind a plane aluminum slab of given thickness with the receiver completely shielded from behind.

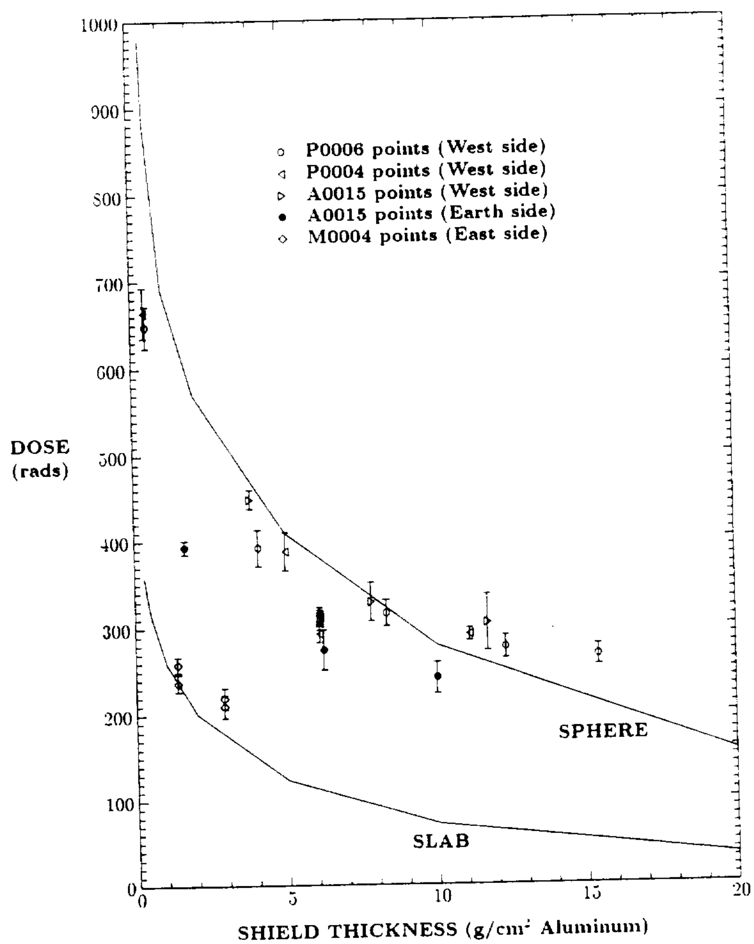

Figure 8. Comparison of the predicted LDEF total mission dose (ref. 8) with on-board TLD dosimeter measurements (ref. 9).

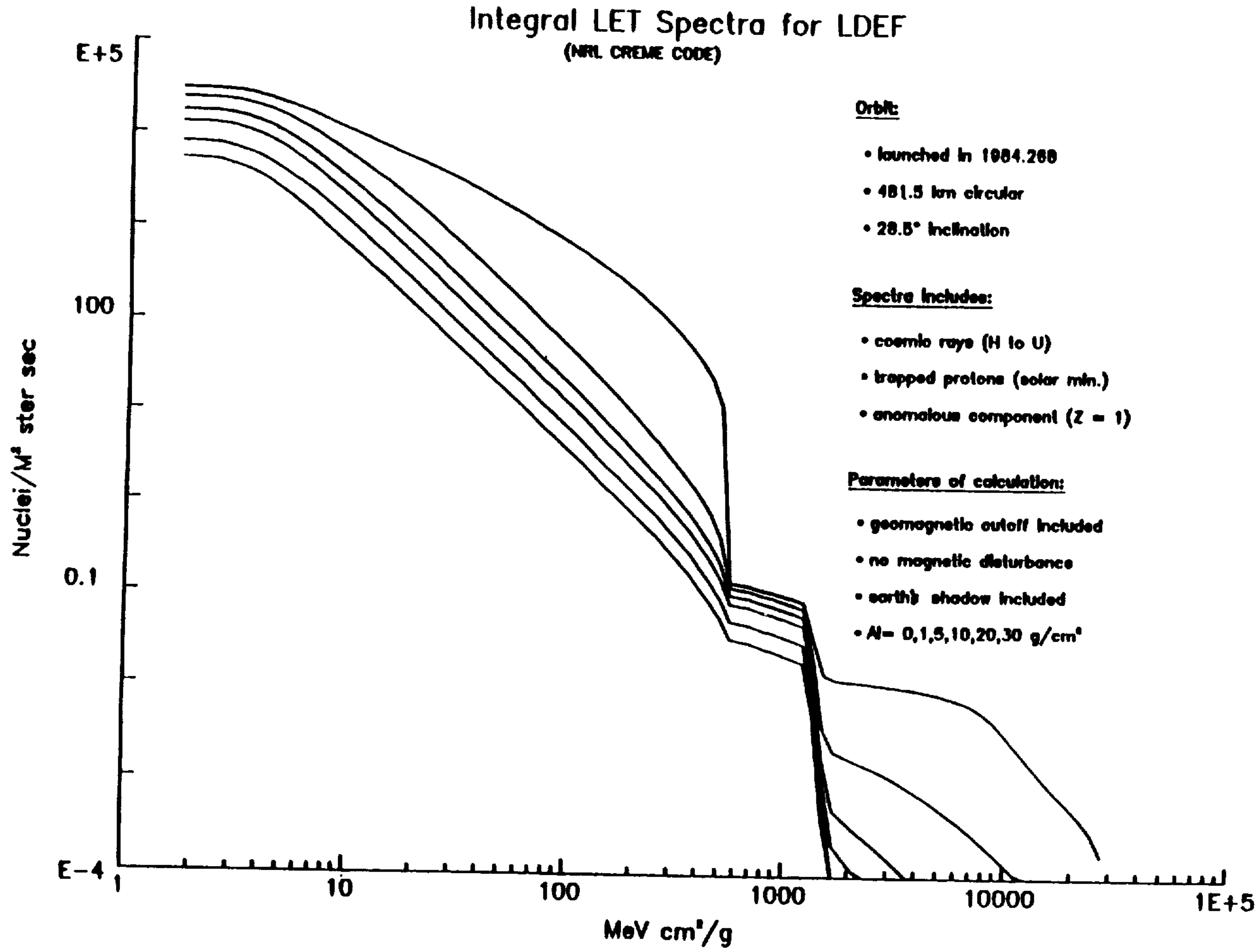

Figure 9. Predicted LET spectrum at the LDEF orbit (ref. 8) from the CREME code (ref. 10).