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REVISED PREDICTION OF LDEF EXPOSURE TO TRAPPED PROTONS

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SUMMARY

The LDEF spacecraft flew in a 28.5° inclination circular orbit with an altitude in the range from 319.4 to 478.7 km. 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 (refs. 1-3) together with the associated magnetic field models (ref. 4) and the solar conditions were used to obtain the trapped electron and proton omnidirectional fluences reported previously (ref. 5). Results for directional proton spectra using the MSFC anisotropy model for solar minimum and 463 km altitude (representative for the LDEF mission) were also reported (ref. 6). Here the directional trapped proton flux as a function of mission time is presented considering altitude and solar activity variation during the mission. These additional results represent an extension of previous calculations to provide a more definitive description of the LDEF trapped proton exposure.

INTRODUCTION

The LDEF spacecraft flew in a 28.5° inclination circular orbit with an altitude in the range from 319.4 to 478.7 km. 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 with the trapped flux being anisotropic with most of the flux arriving from a narrow band perpendicular to the local geomagnetic field direction. A model for predicting the trapped proton angular distribution has been developed (ref. 7) including both the pitch angle and east-west effects. Since trapped protons produce most of the spacecraft activation except at heavily shielded locations and almost all of the dose at most LDEF measurement locations, a large part of calculational effort (refs. 6 and 8) of the LDEF Ionizing Radiation Special Interest Group has been directed toward testing the predictions of this model and the Vette omnidirectional flux model (ref. 1) against LDEF measurements (refs. 9-12). Here is presented further refinement of the trapped proton exposure over the LDEF mission. Improvements include detailed consideration of solar cycle modulation of the flux, improved time resolution near the mission end where the altitude was changing rapidly, directional flux calculations over the whole mission, and modification to the B and L calculations.

DISCUSSION

Previous predictions of the LDEF mission fluences (refs. 5 and 6) were obtained by calculating long-term average fluxes for five circular orbits at 478.7, 472.3, 462.8, 426.0, and 319.4 km altitudes which occurred on mission days 0, 550, 1450, 1950, and 2105, respectively, and performing a numerical integration over time assuming a straight line between time points. The solar $F_{10.7}$ cm radio flux which characterizes solar activity exceeded 150 about mission day 1540 (June 27, 1988). The environment models used for solar minimum (the first three times) were AP8MIN (ref. 1) 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. 1) and the magnetic field model was the Hurwitz USGS 1970 168-534M model (ref. 4) for 1970, the epoch of the environmental model. Both magnetic field calculations used a fixed constant magnetic moment of 0.311653 which was built into the ALLMAG package for calculating B and L magnetic parameters.

For low altitude orbits such as that of LDEF the flux retrieved from the Vette model is very sensitive to the input calculated B and L values. For the current calculation the constant magnetic moment in the ALLMAG package was replaced by a moment calculated from the magnetic model expansion coefficients at the epoch of the model. At the highest altitudes this change reduced the fluxes by about 5%. At the lowest altitudes near the mission end fluxes were reduced by a factor of 2.

The goals for improving the flux model were better representation of the solar cycle modulation and better time resolution near mission end. In Figure 1 solar activity as defined by the solar $F_{10.7}$ cm flux (ref. 13) and orbital altitude over the LDEF mission period are shown versus mission day. The LDEF mission began near the end of the last cycle and ended near the maximum of the current one with the orbital altitude changing slowly over the first 1500 days but rapidly during the last 500 days of the mission. From the data represented in Figure 1 the mean $F_{10.7}$ value at the last solar minimum F_{min} was 67 and the mean value at solar maximum F_{max} was 183. Rather than an abrupt switch from AP8MIN to AP8MAX a parameter

$$Alpha(t) = (F(t) - F_{min})/(F_{max} - F_{min})$$

was defined where $F(t)$ is the $F_{10.7}$ flux at time t. Then the proton flux, $\phi(t)$ at time t, was given as a mixture

$$\phi(t) = \phi_{AP8MIN}(1 - Alpha(t)) + \phi_{AP8MAX} Alpha(t)$$

where ϕ_{AP8MIN} and ϕ_{AP8MAX} are the Vette model proton fluxes for solar minimum and solar maximum, respectively. Table 1 shows the mission times for the current model, the orbital altitude, the $F_{10.7}$ value, *Alpha* and the scale height parameter for solar minimum (min) and solar maximum (max) (used in the directional flux calculation).

Table 1. Model Inputs

Mission Day	Altitude (km)	$F_{10.7}$ Flux	*Alpha*	Scale Height (km)	
				min	max
0	478.7	95	0.24	116.6	127.2
300	475.8	67	0	115.7	---
1000	469.1	67	0	113.7	---
1300	466.2	87	0.17	112.8	123.4
1500	461.5	118	0.44	111.4	122.0
1700	449.5	158	0.78	108.0	118.5
1800	433.6	171	0.90	103.6	114.0
1900	412.8	183	1.00	---	108.4
2000	388.8	183	1.00	---	102.3
2050	368.0	183	1.00	---	97.2
2105	319.4	183	1.00	---	86.4

Note that about half the points are distributed during the last 500 days of the mission. In Figures 2 and 3 the current model flux is compared to the pure AP8MAX and AP8MIN model fluxes and the previous model fluxes, respectively, over the mission period. Note the transition near 1500 days in the previous model curve due to switching from AP8MIN to AP8MAX. In Figure 4 the predicted mission fluences from the current and previous model are compared. The current fluences are about 20% lower.

For the previously directional flux calculation the AP8MIN model and a fixed orbital altitude of 463 km were used. The current model has now been used to calculate directional fluxes at each of the time points in Table 1 as input for dose and activation calculations using a complex geometrical model of LDEF (ref. 14). In Figure 5 the cumulative mission fluence and the ratio of eastward to westward traveling flux are shown as a function of mission time. Note that the proton flux is much more directional near the mission end. Short half-life isotopes produced by activation might be expected to reflect this greater directionality by greater ratios in abundance on the west side versus the east side of LDEF.

CONCLUSIONS

Predictions of the LDEF mission's trapped proton exposure have been made using the currently accepted models with improved resolution near mission end and better modeling of solar cycle effects. Mission fluences are reduced by 20% from previously reported results. The LDEF experimental measurements are providing an opportunity to validate the model predictions.

REFERENCES

1. Sawyer, Donald M. and Vette, James I.: AP-8 Trapped Proton Environment for Solar Maximum and Solar Minimum. National Science Data Center, Goddard Space Flight Center, NSSDC/WDC-A-R&S 76-06, 1976.

2. Teague, Michael J. and Vette, James I: A Model of the Trapped Electron Population for Solar Minimum. National Science Data Center, Goddard Space Flight Center, NSSDC 74-03, 1974.

3. Vette, James I.: The AE8 Trapped Electron Model Environment. National Space Science Data Center, Goddard Space Flight Center, NSSDC/WDC-A-R&S 91-24, 1991.

4. Stassinopoulos, E. G. and Mead, Gilbert D.: ALLMAG, GDALMG, LINTRA: Computer Programs for Geomagnetic Field and Field-Line Calculations, National Space Science Data Center, Goddard Space Flight Center, NSSDC 72-12, 1972.

5. Watts, J. W.; Parnell, T. A.; Derrickson, J. H.; Armstrong, T. W.,: and Benton, E. V.: Prediction of LDEF Ionizing Radiation Environment. First LDEF Post-Retrieval Symposium, NASA CP-3134, 1991, pp. 213-224.

6. Armstrong, T. W.,; Colborn, B. L. and Watts, J. W.: Radiation Calculations and Comparisons with LDEF Data. First LDEF Post-Retrieval Symposium, NASA CP-3134, 1991, PP. 347-360.

7. Watts, J. W.; Parnell, T. A.; and Heckman, H. H.: Approximate Angular Distribution and Spectra for Geomagnetically Trapped Protons in Low-Earth Orbit. High Energy Radiation Background Space, Proceedings of AIP Conference, Sanibel Island, Florida, Vol. 186, 1989, pp. 75-85.

8. Armstrong, T. W. and Colborn, B. L.: Radiation Model Predictions and Validation Using LDEF Satellite Data. Second LDEF Post-Retrieval Symposium, NASA CP-3194, 1993.

9. Benton, E. V.; Frank, A. L.; Benton, E. R.; Csige, I.; Parnell, T. A. and Watts, J. W.: Radiation Exposure of LDEF: Initial Results. First LDEF Post-Retrieval Symposium, NASA CP-3134, 1991, pp. 325-338.

10. Frank, A. L.; Benton, E. V.; Armstrong, T., W. and Colborn, B. L.: Absorbed Dose and Predictions on LDEF. Second LDEF Post-Retrieval Symposium, NASA CP-3194, 1993.

11. Harmon, B. A.; Fishman, G. J.; Parnell, T. A.; and Laird, C. E.: Induced Radiaoactivity in LDEF Components. First LDEF Post-Retrieval Symposium, NASA CP-3134, 1991, pp. 301-312.

12. Harmon, B. A.; Fishman, G. J.; Parnell, T. A.; and Laird, C. E.: Induced Activation Study of LDEF. Second LDEF Post-Retrieval Symposium, NASA CP-3194, 1993.

13. Adjusted Ottawa 2800 MHz Solar Flux. Herzberg Astrophysics Institute, Ottawa, Ontario, Canada National Geophysical Data Center, Boulder, CO, 1991.

14. Colborn, B. L. and Armstrong, T. W.; Development and Application of a 3-D Geometry/Mass Model for LDEF Satellite Ionizing Radiation Assessments, Second LDEF Post-Retrieval Symposium, NASA CP-3194, 1993.

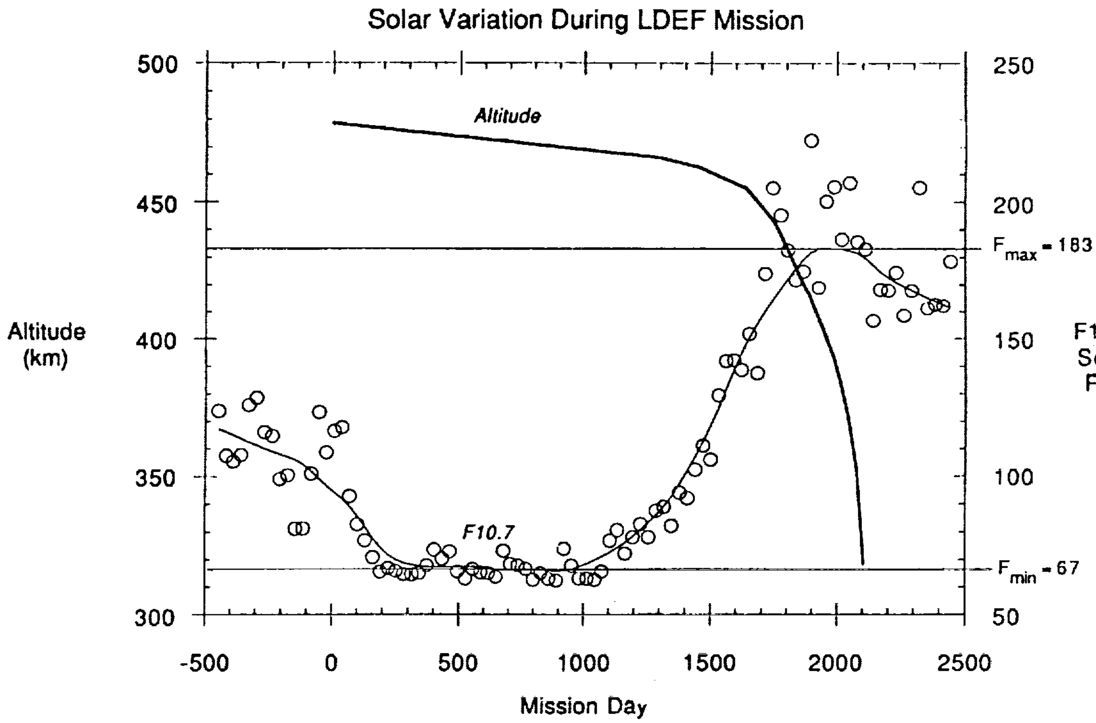

Figure 1. Variation of the solar $F_{10.7}$ cm flux (ref. 13) in units of 10^{-22}J/(s-m^2-Hz) and LDEF orbital altitude during the period of the LDEF mission.

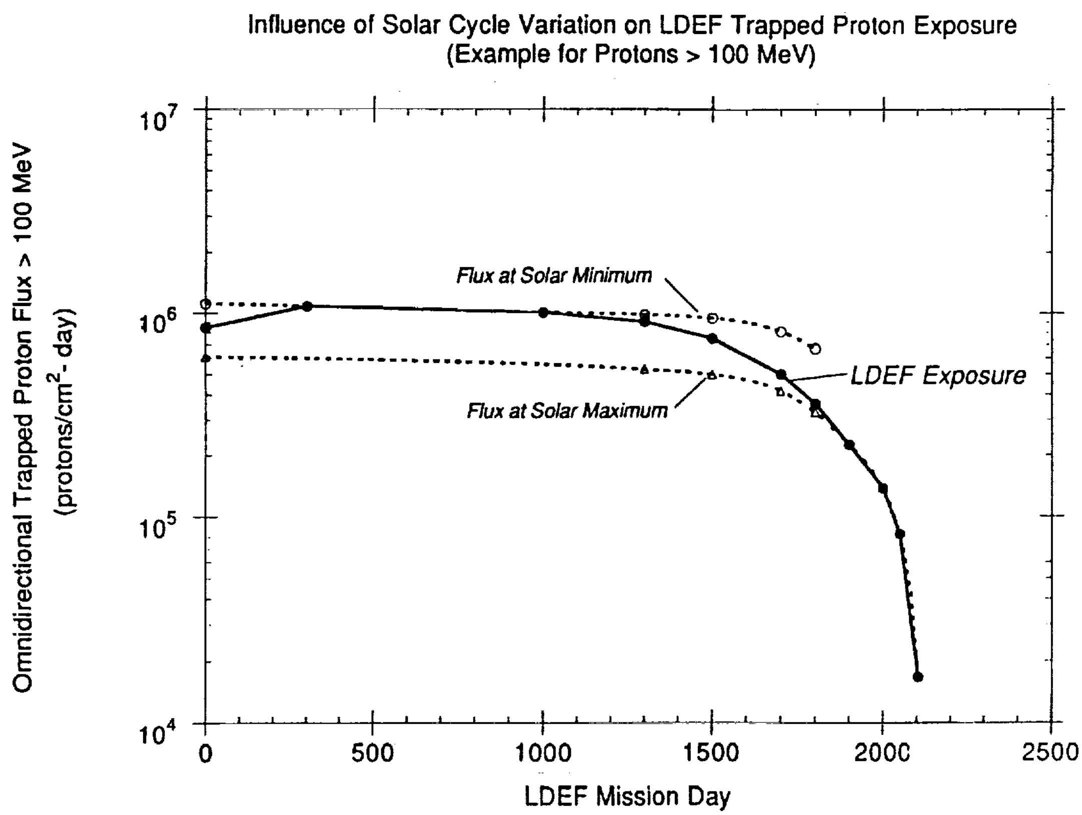

Figure 2. Current model proton flux > 100 MeV compared to APSMIN and APSMAX model predictions.

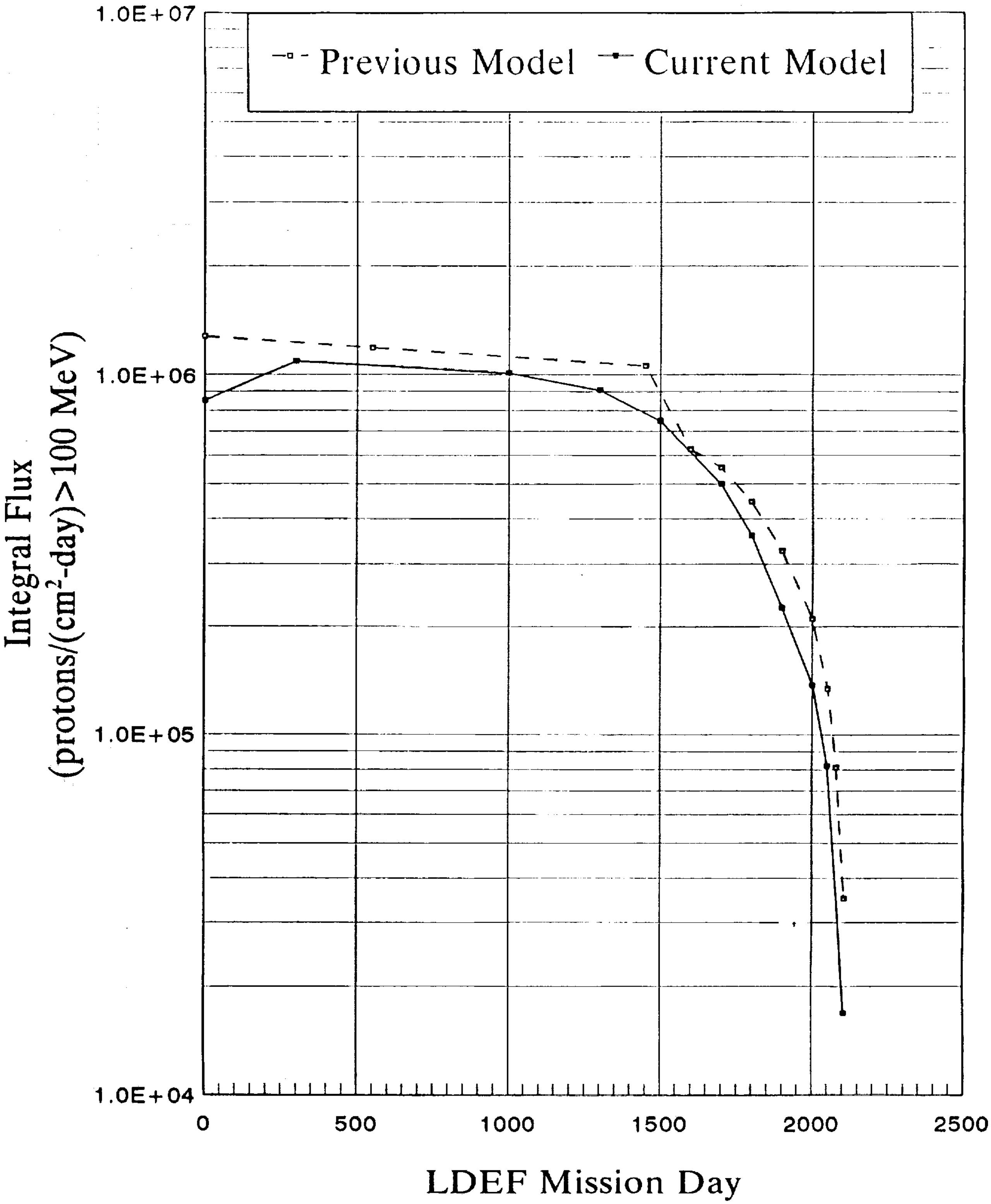

Figure 3. Current model proton flux > 100 MeV compared to previous model predictions (ref. 5).

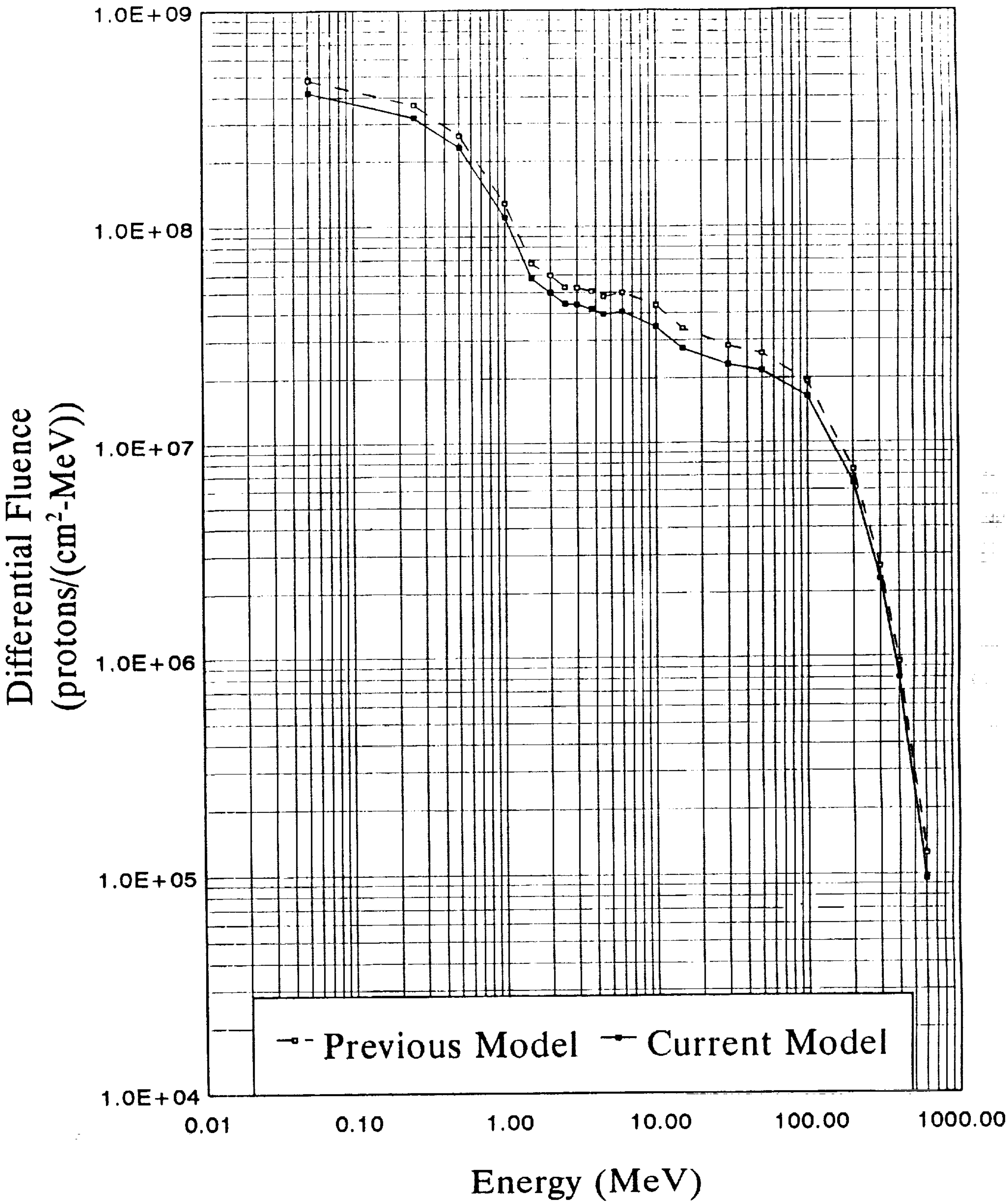

Figure 4. Current model proton mission fluence compared to previous model predictions (ref. 5).

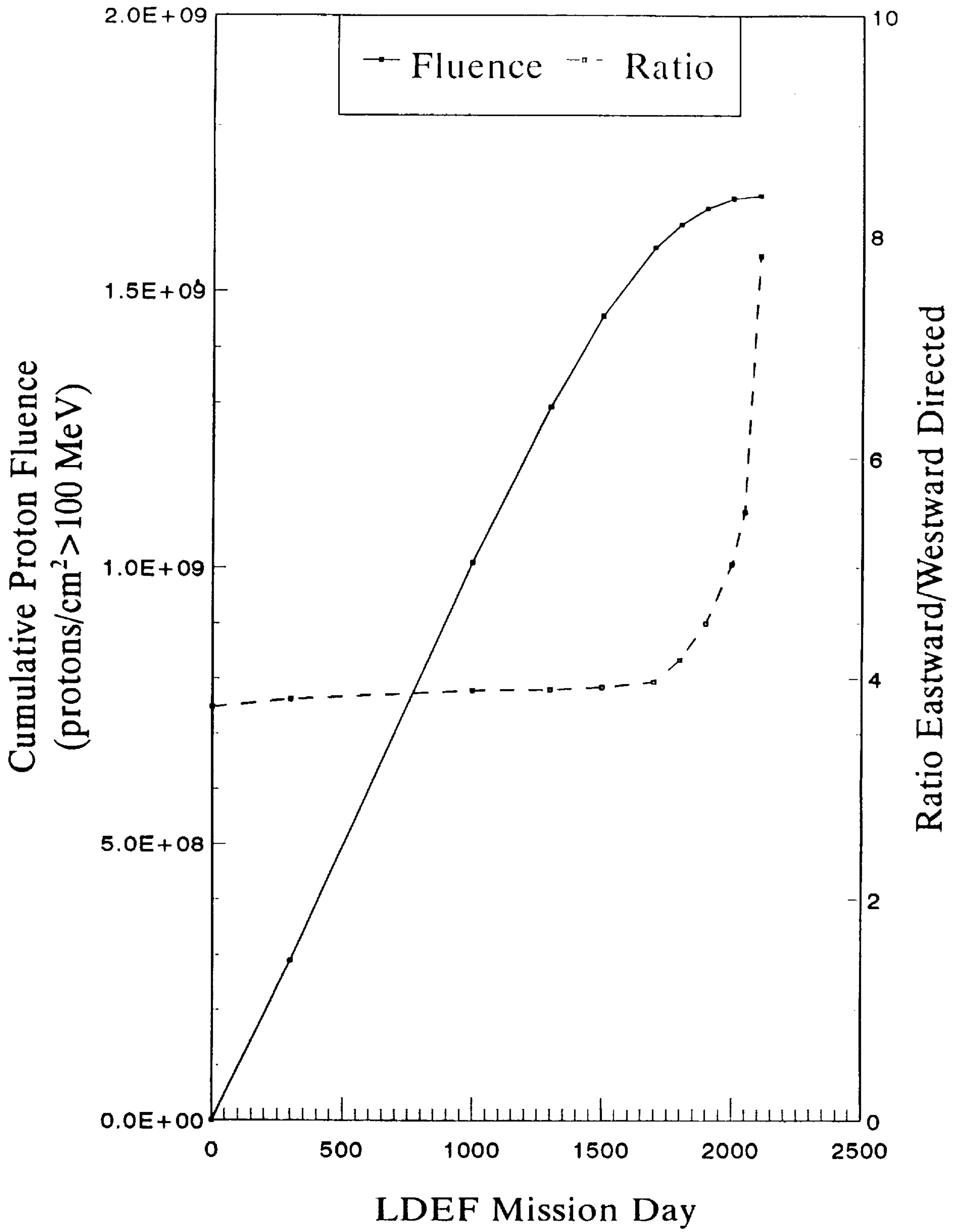

Figure 5. Cumulative mission fluence and ratio of eastward/westward directed integral flux > 100 MeV versus mission day.