NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

George C. Marshall Space Flight Center
Huntsville, AL 35812 USA

Dr. Stephen L. O'Dell
NASA / MSFC / VP62
National Space Science and Technology Center
320 Sparkman Drive
Huntsville, AL 35805-1912 USA

E-Mail: Steve.O'Dell@NASA.gov
Stephen.L.ODell@NASA.gov

Voice: (1) 256-961-7776
Facsimile: (1) 256-961-7213

MEMORANDUM

SUBJECT: TRAPPED-RADIATION ENVIRONMENT III
PROJECT: CHANDRA X-RAY OBSERVATORY
DATE: 2006.12.04

SUMMARY

In a memorandum dated 2006.01.31, Project Science presented computations of the long-term external fluence of trapped protons in the evolving orbit of the *Chandra X-ray Observatory* through the AP8 environment. Subsequently, in a memorandum dated 2006.10.31, Project Science addressed uncertainties in the calculated external fluence due to temporal variations and to rotation of the Earth's slightly asymmetric magnetic field, concluding the following:

1. Temporal variations in the orbital 100–200-keV proton fluence are about a factor of 2 (geomagnetic quiet) up to 4 (geomagnetic active).
2. Rotation of the Earth's magnetic field effects changes in the orbital 100–200-keV proton fluence that are typically less than a factor of 2 orbit-to-orbit, much less for the average of 3 consecutive orbits (≈ 8 days).

Consequently, we recommended a factor-of-3 margin over the fluence estimates previously presented. Based upon additional analyses by Project Science and MSFC's Natural Environments Branch, this memorandum further documents and assigns a confidence level to the recommended margin. In addition, it provides an AP8-predicted proton fluence for each of the first 20 orbits of Observatory operations, for comparison to CTI measurements reported by the ACIS Team.

DISCUSSION

This brief discussion summarizes the results of our recent supplemental analyses, reported in Supporting Documents.

1. The most intense regions of the Earth's trapped-proton belts are fairly stable. Thus, for elliptical orbits which transit this region, the external proton fluence is fairly predictable — albeit high. We utilized L-shell-sorted data from the *Polar* spacecraft to quantify 100–200-keV trapped-proton intensity variations during 4 years (1996–1999) that included geomagnetically quiet and active periods. Based upon this analysis (`Ip-t_100keV.pdf`), we determined that the (spatially)

peak intensity exceeds 3 times its (temporally) average value about 1% of the time; exceeds 2 times, about 8% of the time.

2. Orbit-to-orbit differences in orbital fluence result from rotation of the Earth's slightly asymmetric magnetic field. Such differences are typically not large when the orbit penetrates deeply into the proton belt and the fluence is consequently high. Importantly, this contribution to the "uncertainty" is deterministic — i.e., given the date of a perigee pass, we can calculate the AP8-predicted fluence for that specific orbit. Thus, we calculated (`orbs_1-20.pdf`) the AP8 fluence for each of the first 20 *Chandra* orbits after opening of the Observatory's door on 1999.08.12, allowing a direct correlation with the initial ACIS CTI measurements. In particular, the orbital fluence of >100-keV protons for the 7^{th} ACIS-exposed transit (orbit #12) was 0.65 that of the average for the first 6 ACIS-exposed transits (orbits ##1–2, 4–6, & 11).

In conclusion, our recommended factor-of-3 margin represents a 99%-confidence limit over the mean fluence calculated for a specific orbit. For an annually-averaged orbit, we suggest de-rating the factor-of-3 margin to a 95%-confidence limit.

SUPPORTING DOCUMENTS

The attached files comprise the supporting data products from this study:

1. `Ip-t_100keV.pdf` plots and tabulates the ratio of the 100–keV-proton spectral intensity to its (temporally) average value, versus percentile rank for obtaining this ratio or less. The plotted lines are for McIlwain L values (magnetic-shell equatorial radius) near 4.25 R_e, corresponding to the (spatial) maximum in the intensity of 100–200-keV trapped protons. The *Polar* Comprehensive Energetic Particle and Pitch Angle Distribution (CEPPAD) Imaging Proton Spectrometer (IPS) obtained these data during 1996–1999. (See also `polar_100keV.pdf`, from memorandum `20061031_slo.pdf`).

2. `orbs_1-20.pdf` give the proton fluence for each of the first 20 *Chandra* orbits after opening the Observatory's door. As before (memoranda `20061031_slo.pdf` and `20061031_slo.pdf`), we used the SPENVIS tool to propagate the *Chandra*'s orbit in the AP8 environment. The larger table gives the integral fluence (for 17 proton energies E_p ranging from 0.1 MeV to 10 MeV), both cumulative and per-orbit, along with various parameters characterizing the statistical distribution of calculated orbital fluence. The smaller table and plot display the fluence for each orbit scaled to the average over the 20 orbits. For E_p > 0.1 MeV, the statistical distribution of the ratio of orbital fluence to average fluence (over 20 orbits) has a mean 1.0 (by definition), standard deviation 0.3, maximum 1.5, and minimum 0.6. For a given orbit, however, the model fluence is deterministic. Thus, for example, we find that the AP8-estimated >100–keV-proton fluence for orbit #12 was 0.65 times that of the average over orbits ##1–2, 4–6, & 11. That for orbit #13 was 1.38 times that average. (NB: These are the 8 orbits for which ACIS was exposed during radiation-belt transits.)