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THE CHARGED PARTICLE RADIATION ENVIRONMENT FOR AXAF

By Marshall Joy

Space Science Laboratory
Science and Engineering Directorate

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16. Abstract

The Advanced X-Ray Astrophysics Facility (AXAF) will be subject to several sources of charged particle radiation during its 15-year orbital lifetime: geomagnetically-trapped electrons and protons, galactic cosmic ray particles, and solar flare events. The purpose of this report is to estimate these radiation levels for the AXAF orbit for use in the design of the observatory's science instruments.

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I. INTRODUCTION

The Advanced X-Ray Astrophysics Facility (AXAF) will be subject to several sources of radiation during its 15-year orbital lifetime: geomagnetically–trapped electrons and protons, galactic cosmic ray particles, and solar flare events (see Noll and McElroy, 1975 for an overview of the near-earth radiation environment). The purpose of this report is to estimate these radiation levels for the AXAF orbit (nominal altitude= 320 n.mi. = 600 km, inclination = 28.5°) for use in the design of the observatory's science instruments.

II. THE RADIATION ENVIRONMENT

A. Geomagnetically–Trapped Charged Particles

Estimates of trapped proton and electron irradiation in the AXAF orbit were obtained from the AP8 and AE8 environments (Sawyer and Vette, 1976; Teague and Vette, 1974; Teague, Chan, and Vette, 1976) with separate calculations for maximum and minimum levels of solar activity. The particle fluxes are calculated in both differential and integral form, and are presented in Figures 1-4 and Tables 1 and 2. Note that the fluxes presented here are <u>average</u> values, and that the instantaneous flux can deviate greatly from the mean (see section III). The variation of particle flux with altitude and orbital inclination is discussed by Watts and Wright (1976).

B. Solar Flare Events

Solar flares are relatively rare and unpredictable events which can be copious sources of high energy particles; for example, three solar flares during the fall of 1989 delivered a total of ~7 x 10^9 protons cm^{-2} (Withbroe, 1989). The geomagnetic field will effectively shield AXAF from the solar flare proton flux, but this geomagnetic shield is much less effective for heavy solar flare particles, which are only partially ionized (see Adams, 1986, sections 2.1 and 8.0).

C. Cosmic Rays

The galactic cosmic ray flux in free space (outside the geomagnetosphere) is approximately 4 particles cm^{-2} s^{-1} (Burrell and Wright, 1972). This flux is reduced during the active part of the solar cycle and, in the AXAF orbit, the low energy portion of the spectrum will be attenuated by the geomagnetic field. The cosmic ray flux is orders of magnitude smaller than the geomagnetically-trapped proton and electron fluxes (see section II.a), but the cosmic ray spectrum has an abundance of high-energy particles and heavy ions which are not easily attenuated by shielding. The effects of these highly penetrating cosmic rays on spacecraft microelectronics are significant, and can be evaluated using the methods described by Adams (1986).

D. Shielding

Figure 5 presents a schematic diagram of the radiation shielding provided by the AXAF observatory. The spacecraft "cradle" and the High Resolution X-Ray Mirror Assembly (HRMA) will both provide substantial shielding, but much of the observatory consists only of an open frame covered by a thin thermal blanket. In particular, there is very little shielding on the outer side or back of the science instrument compartment; most of the radial and rear-facing shielding will be provided by the science instrument itself.

Simple shielding calculations are presented for a point detector inside a spherical shell in Figures 6 and 7 and in Tables 3 and 4. The figures present total dose curves, which include ionization by primary protons and electrons (see Tables 3 and 4) as well as energy deposition from secondary protons, alpha particles from primary protons, and electron-induced Bremsstrahlung (Burrell, 1964; Watts and Burrell, 1971). The trapped proton component is dominant for most practical shield thicknesses, from 1.0 to 30 g/cm^2. More detailed calculations can be done using the compilations of energy loss and penetration data for protons (Janni, 1966) and for electrons and Bremsstrahlung radiation (Watts and Burrell, 1971; Berger and Seltzer, 1964).

III. RELIABILITY

It is important to understand the limitations of the present models. The geomagnetically-trapped charged particle models are based on data that were taken more than a decade ago, and are estimated to be uncertain by <u>at least</u> a factor of 3. Additional uncertainties arise from the fact that the present models are averaged over space and time. For example, nearly all of the trapped particle flux is encountered as the spacecraft passes through the South Atlantic Anomaly. The orientation of the observatory can also yield particle fluxes very different from the 'omnidirectional' values presented here, since the angular distributions of trapped particles are pancake shaped, with most of the particles arriving from directions perpendicular to the earth's magnetic field lines. In the presence of heavy shielding, the radiation dose can be further increased by cosmic ray particle cascades which are not included in the present calculations. In view of these uncertainties, it would be prudent to conservatively design the AXAF detectors and electronics to withstand radiation levels several times higher than those estimated here.

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Table 1. Proton Flux (z=600 km, i=28.5°)

Energy	Integrated Flux > E (protons cm^{-2} day^{-1})		Differential Flux (protons cm^{-2} MeV^{-1} day^{-1})	
(MeV)	Solar Minimum	Solar Maximum	Solar Minimum	Solar Maximum
0.05	1.07e+07	7.00e+06	8.25e+05	5.20e+05
0.25	1.06e+07	6.90e+06	6.38e+05	3.78e+05
0.50	1.04e+07	6.83e+06	4.58e+05	2.82e+05
1.00	1.02e+07	6.69e+06	2.41e+05	1.67e+05
1.50	1.01e+07	6.64e+06	1.39e+05	9.71e+04
2.00	1.01e+07	6.59e+06	1.31e+05	9.30e+04
2.50	1.00e+07	6.54e+06	1.24e+05	8.91e+04
3.00	9.96e+06	6.50e+06	1.23e+05	8.83e+04
3.75	9.86e+06	6.43e+06	1.23e+05	8.71e+04
4.50	9.77e+06	6.37e+06	1.23e+05	8.58e+04
6.00	9.59e+06	6.24e+06	1.26e+05	8.69e+04
10.0	9.08e+06	5.89e+06	1.11e+05	7.07e+04
15.0	8.60e+06	5.61e+06	8.54e+04	5.17e+04
30.0	7.50e+06	4.93e+06	6.62e+04	3.97e+04
50.0	6.32e+06	4.24e+06	5.71e+04	3.35e+04
100.0	3.93e+06	2.81e+06	3.87e+04	2.48e+04
200.0	1.42e+06	1.09e+06	1.44e+04	1.06e+04
300.0	5.19e+05	4.02e+05	5.18e+03	3.98e+03
400.0	1.93e+05	1.51e+05	1.90e+03	1.48e+03
600.0	2.73e+04	2.15e+04	2.67e+02	2.10e+02

Table 2. Electron Flux (z=600 km, i=28.5°)

Energy	Integrated Flux > E (electrons cm^{-2} day^{-1})		Differential Flux (electrons cm^{-2} MeV^{-1} day^{-1})	
(MeV)	Solar Minimum	Solar Maximum	Solar Minimum	Solar Maximum
0.05	5.51e+09	1.53e+10	5.57e+10	1.24e+11
0.25	7.31e+08	3.02e+09	6.04e+09	2.71e+10
0.50	1.35e+08	2.50e+08	6.48e+08	1.59e+09
1.00	2.46e+07	3.23e+07	6.34e+07	9.14e+07
1.50	9.26e+06	1.21e+07	1.64e+07	2.16e+07
2.00	4.14e+06	5.40e+06	6.53e+06	8.56e+06
2.50	1.91e+06	2.49e+06	4.45e+06	5.80e+06
3.00	3.32e+05	4.30e+05	1.33e+06	1.73e+06
3.75	1.06e+04	1.35e+04	4.88e+04	6.22e+04

Table 3. Proton Dose Rates vs. Shielding Thickness in the AXAF Orbit

	Solar Maximum		Solar Minimum	
Shield Thickness [g/cm^2]	Total Dose [Rad/day]	Primary Dose [Rad/day]	Total Dose [Rad/day]	Primary Dose [Rad/day]
0.00	2.12	2.12	3.24	3.24
0.001	2.11	2.11	3.22	3.22
0.002	2.10	2.10	3.21	3.21
0.003	2.10	2.10	3.20	3.20
0.004	2.09	2.09	3.19	3.19
0.005	2.08	2.08	3.17	3.17
0.006	2.07	2.07	3.16	3.16
0.007	2.06	2.06	3.15	3.15
0.008	2.05	2.05	3.14	3.14
0.009	2.04	2.04	3.13	3.13
0.01	2.04	2.04	3.11	3.11
0.02	1.96	1.96	3.02	3.02
0.03	1.88	1.88	2.90	2.90
0.04	1.81	1.81	2.81	2.81
0.05	1.75	1.75	2.73	2.73
0.06	1.70	1.70	2.66	2.66
0.07	1.65	1.65	2.60	2.6 0
0.08	1.61	1.61	2.54	2.54
0.09	1.58	1.58	2.49	2.49
0.1	1.54	1.54	2.45	2.44
0.2	1.30	1.30	2.09	2.09
0.3	1.17	1.16	1.89	1.88
0.4	1.10	1.09	1.77	1.76
0.5	1.04	1.04	1.68	1.67
0.6	0.997	0.991	1.61	1.60
0.7	0.959	0.952	1.54	1.53
0.8	0.926	0.919	1.49	1.48
0.9	0.898	0.890	1.44	1.43
1.0	0.873	0.864	1.40	1.39
1.5	0.782	0.770	1.25	1.23
2.0	0.718	0.704	1.14	1.12
3.0	0.628	0.610	0.989	0.960
4.0	0.566	0.543	0.878	0.844
5.0	0.516	0.491	0.792	0.754
6.0	0.476	0.448	0.722	0.680
7.0	0.441	0.411	0.633	0.618
8.0	0.411	0.379	0.613	0.566
9.0	0.384	0.351	0.568	0.519
10.0	0.360	0.326	0.528	0.478

Table 4. Electron Dose Rates vs. Shielding Thickness in the AXAF Orbit

	Solar Maximum			Solar Minimum		
Shield Thickness [g/cm^2]	Primary Dose [Rad/day]	Brems. Dose [Rad/day]	Total Dose [Rad/day]	Primary Dose [Rad/day]	Brems. Dose [Rad/day]	Total Dose [Rad/day]
0.00	3510.		3510.	1450.		1450.
0.001	1870.		1870.	726.		726.
0.002	1200.		1200.	429.		429.
0.003	879.		879.	292.		292.
0.004	759.		759.	243.		243.
0.005	694.		694.	219.		219.
0.006	643.		643.	200.		200.
0.007	598.		598.	184.		184.
0.008	557.		557.	170.		170.
0.009	519.		519.	157.		157.
0.010	484.		484.	145.		145.
0.02	252.	0.0079	252.	70.2	0.0024	70.2
0.03	152.	0.0066	152.	42.7	0.0020	42.7
0.04	99.6	0.0060	99.6	29.4	0.0019	29.4
0.05	67.2	0.0057	67.2	21.2	0.0018	21.2
0.06	46.6	0.0054	46.6	15.9	0.0017	15.9
0.07	33.4	0.0051	33.4	12.3	0.0016	12.3
0.08	24.7	0.0050	24.7	9.76	0.0015	9.76
0.09	18.8	0.0048	18.8	7.90	0.0015	7.90
0.1	14.7	0.0047	14.7	6.53	0.0014	6.53
0.2	2.79	0.0038	2.79	1.71	0.0012	1.71
0.3	0.991	0.0034	0.994	0.702	0.0010	0.70
0.4	0.491	0.0031	0.494	0.366	0.0010	0.36
0.5	0.283	0.0029	0.286	0.215	0.0009	0.21
0.6	0.173	0.0027	0.176	0.132	0.0008	0.13
0.7	0.109	0.0026	0.111	0.0831	0.0008	0.083
0.8	0.0690	0.0025	0.0715	0.0528	0.0007	0.053
0.9	0.0434	0.0024	0.0458	0.0333	0.0007	0.034
1.0	0.0267	0.0023	0.0290	0.0205	0.0007	0.021
1.5	0.0010	0.0019	0.0030	0.0008	0.0006	0.001
2.0	1.3e-05	0.0017	0.0017	1.02e-05	0.0005	0.0005
3.0		0.0014	0.00146		0.0004	0.0004
4.0		0.0012	0.00124		0.0003	0.0003
5.0		0.0010	0.00107		0.0003	0.0003
6.0		0.0009	0.00092		0.0002	0.0002
7.0		0.0008	0.00080		0.0002	0.0002
8.0		0.0007	0.00070		0.0002	0.0002
9.0		0.0006	0.00062		0.0001	0.0001
10.0		0.0005	0.00054		0.0001	0.0001

Figure 1

Integrated Proton Flux (Energy > E_1)

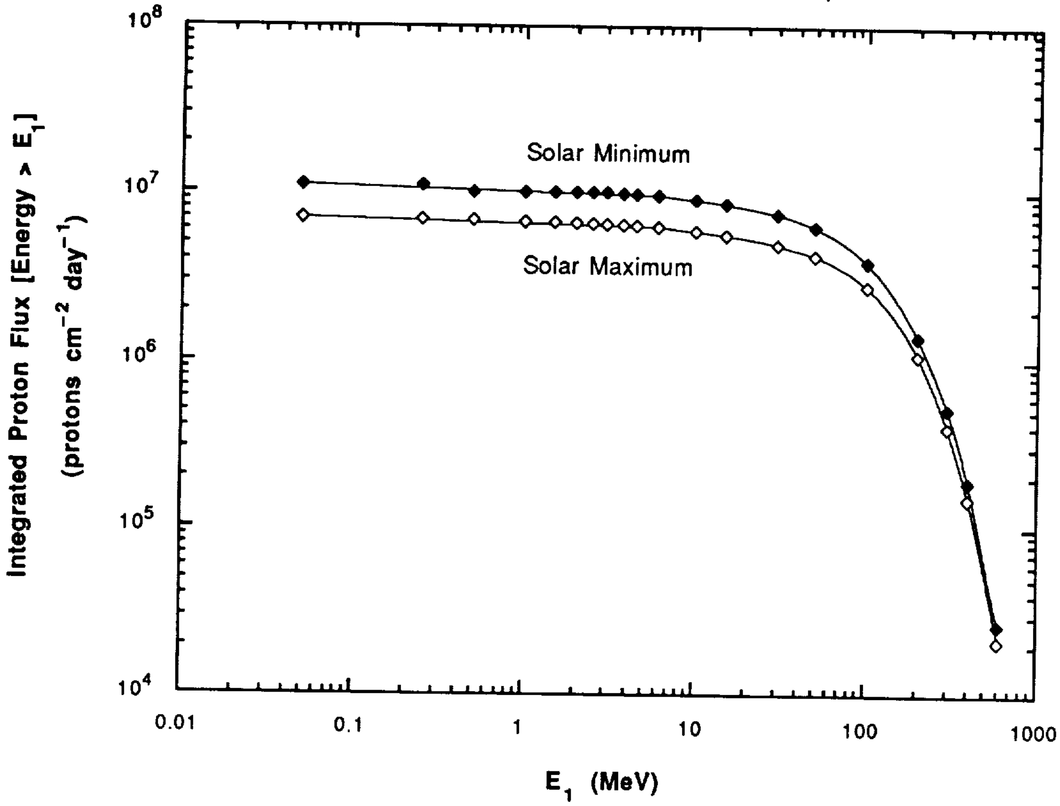


Figure 2

Differential Proton Flux

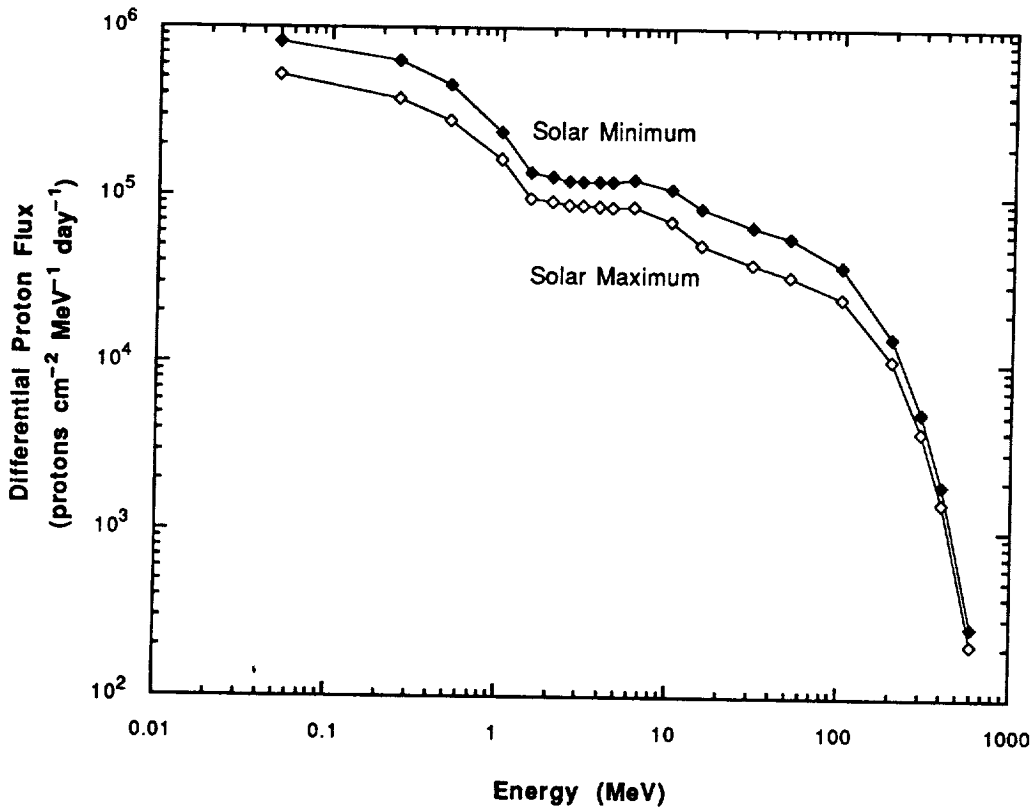


Figure 3

Integrated Electron Flux (Energy > E_1)

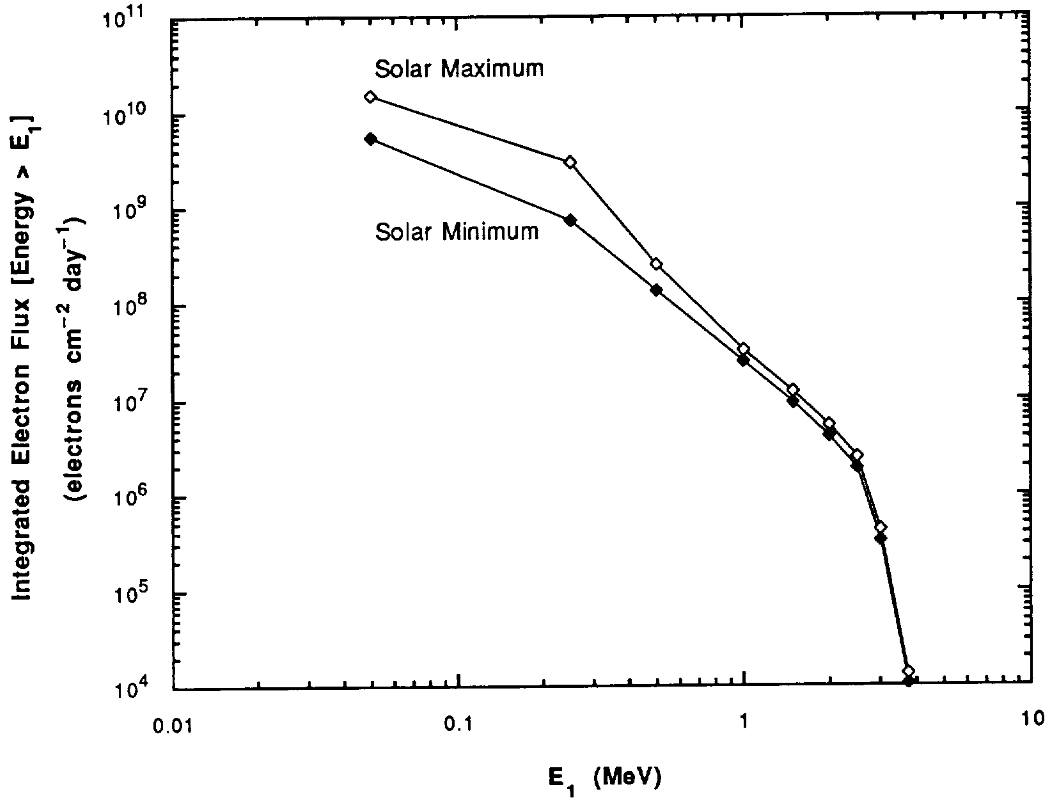
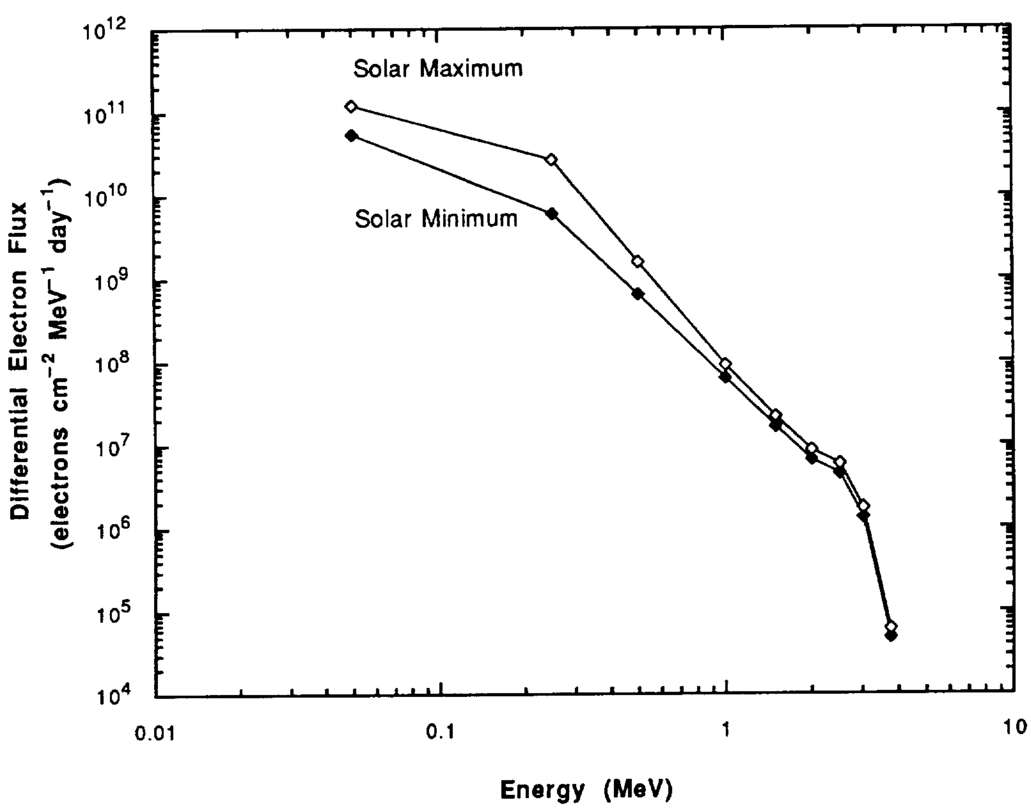


Figure 4

Differential Electron Flux



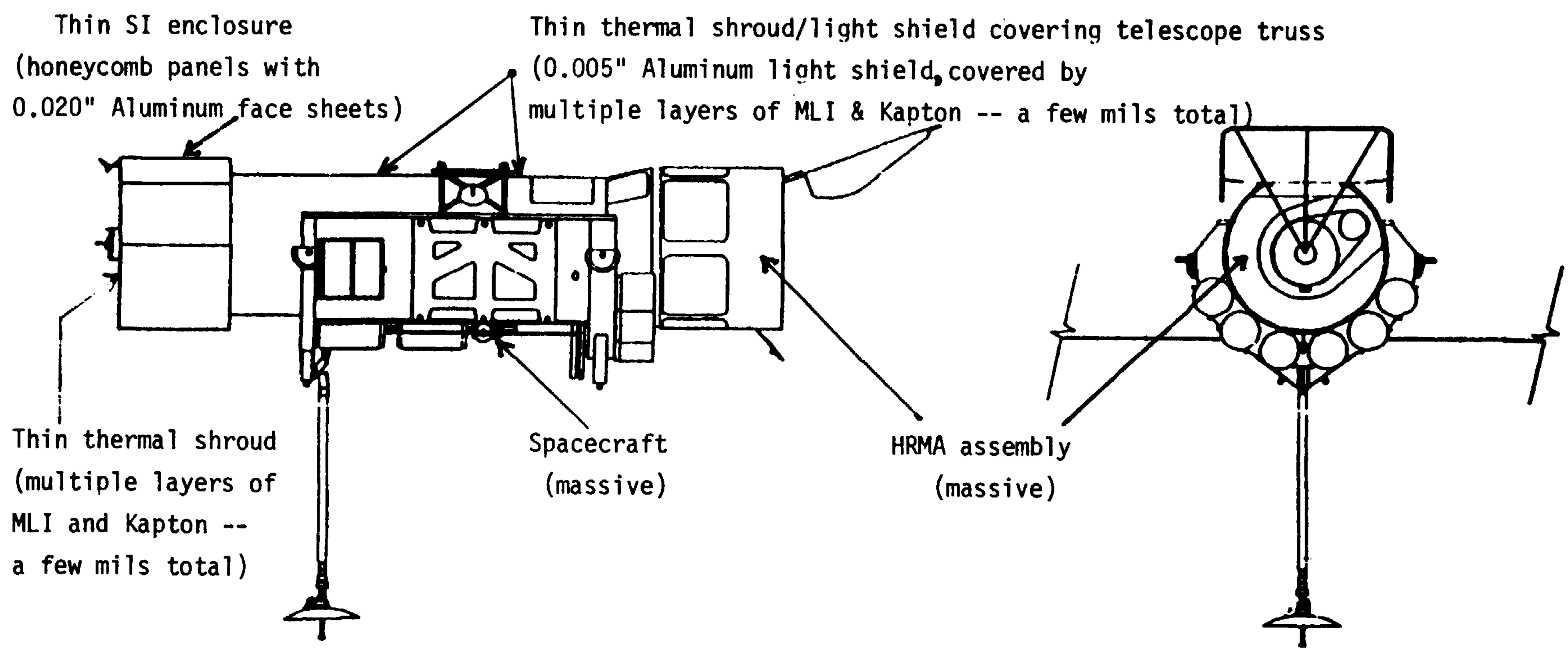


Figure 5. Shielding Provided by the AXAF Observatory.

Figure 6

Proton Dose vs. Shielding Depth

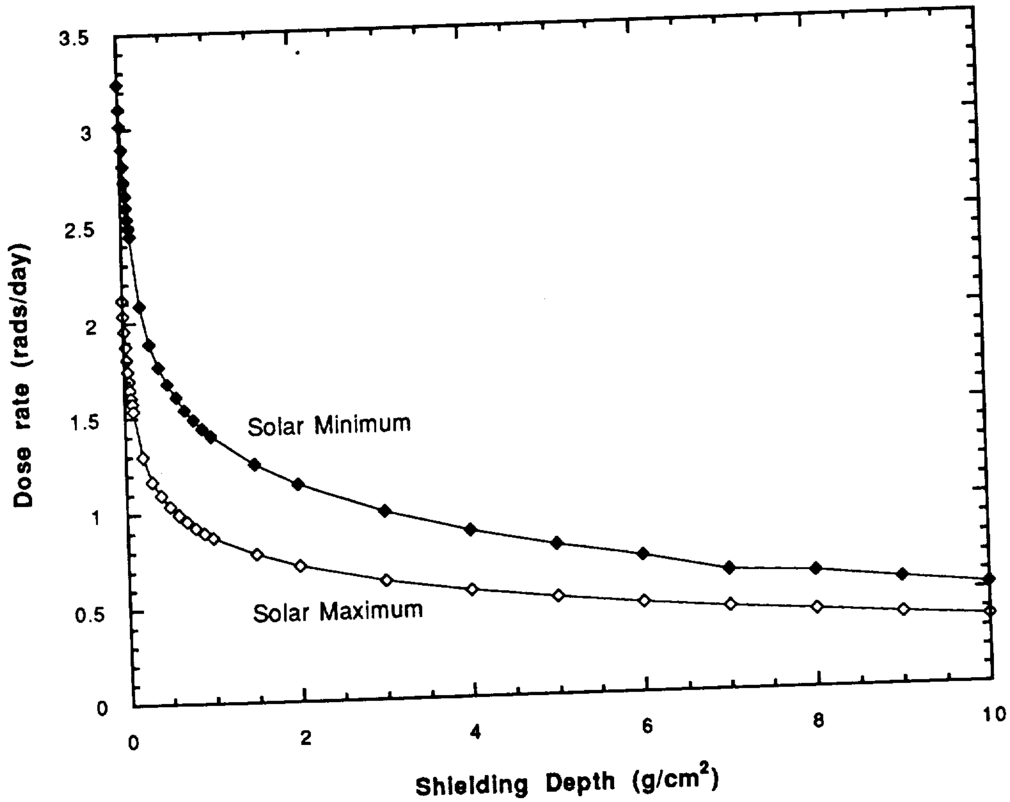
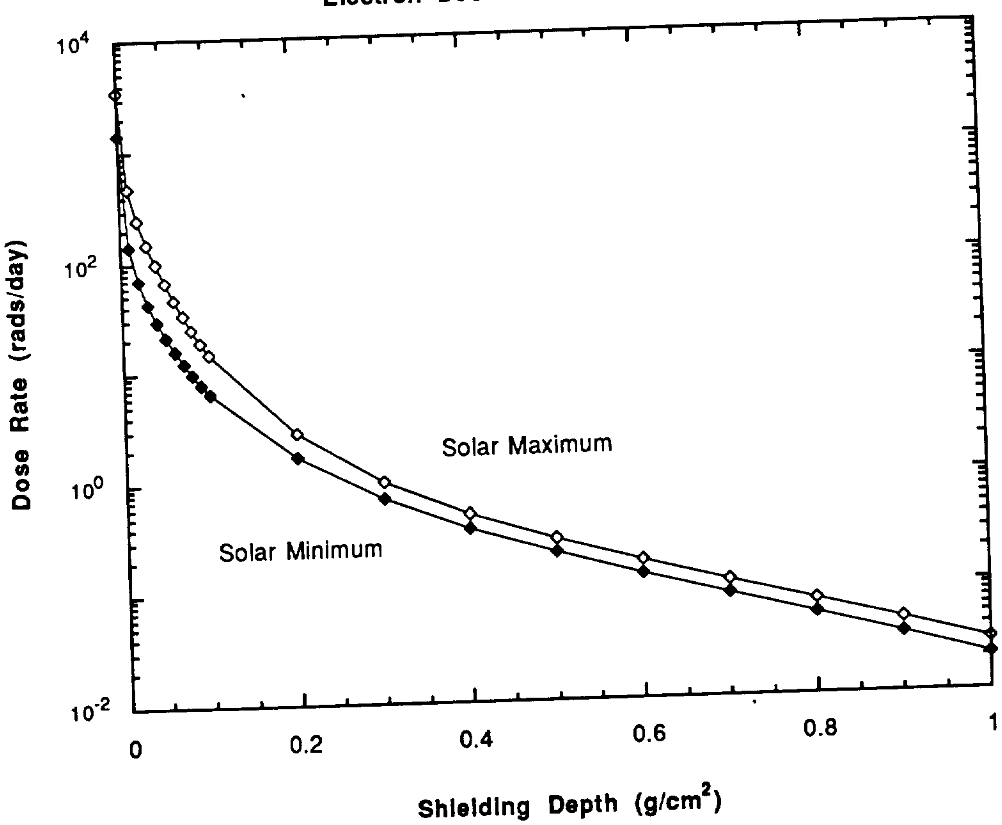


Figure 7

Electron Dose vs. Shielding Depth



APPROVAL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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Director
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