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RADIATION ENVIRONMENT AND HAZARDS FOR A GEOSYNCHRONOUS SPACE STATION

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16. ABSTRACT

This study is an evaluation of the potential radiation hazards to the crew and equipment of a geosynchronous space station. Tissue dose rates for electron, bremsstrahlung, galactic cosmic rays, and solar proton events are included for parking longitudes of 110 and 290 degrees at orbit inclinations of 0, 30, and 45 degrees.

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RADIATION ENVIRONMENT AND HAZARDS FOR A GEOSYNCHRONOUS SPACE STATION

I. INTRODUCTION

The Payload Studies Office in the Program Development Directorate of the Marshall Space Flight Center (MSFC) is currently evaluating program and mission options for a manned geosynchronous space station for the 1985 to 2000 time period. One concern for such a space station is the potential radiation hazard; manned operations have never been performed at geosynchronous altitudes for extended periods. At the request of the Payload Studies Office, several aspects of the radiation problem have been studied. This report provides: (1) a cursory description of the radiation environment at geosynchronous altitude, (2) estimates of absorbed doses behind shielding of various thicknesses and other considerations of shielding design for a space station, and (3) a summary of findings and conclusions. An extensive bibliography, included as an Appendix, may be referred to for more specific data on topics covered in this report.

II. RADIATION ENVIRONMENT

The possible sources of damaging radiation at the synchronous altitude are geomagnetically trapped electrons and protons, galactic cosmic ray particles, and solar flare proton events. Because the magnetic rigidity cutoff for the equatorial synchronous altitude is approximately 30 MeV, solar wind particles will not be important since their average energy is in the keV range. Galactic cosmic ray particles provide a background radiation varying about a factor of two over the solar cycle. The flux magnitude is approximately 4 particles/cm^2-s during solar minimum. The energy spectrum is very hard, causing a small variation in dose rates behind very thick shields. Reference 1 gives a thorough description of energy spectra and dose levels for galactic cosmic ray particles.

The trapped particle flux encountered during the synchronous missions will have two types of temporal variations. A short-term variation is the diurnal variation due to the solar wind, causing the electron flux to vary a factor of 2 for electrons with energies above 300 keV to a factor of 10 for electrons with energies above 1.9 MeV. Moderate magnetic disturbances also cause the same order-of-magnitude decrease in the electron flux (E > 1.9 MeV). A long-term variation is associated with the 11-year solar cycle. There is an enhancement of the proton belt by a factor of 2 and a factor of 5 for the electrons during the quiet part of the cycle as a result of changes in the high atmosphere density [2]. Figures 1 through 8 show the average trapped electron and proton omnidirectional differential and integral fluxes for parking longitudes of 110 and 290 degrees east and orbit inclinations of 0-, 30-, and 45-degree synchronous circular orbits. The fluxes were obtained by using Vette's model environment, epoch 1975.5, [3,4] in a program [5] that averages the flux along the orbital trajectory for several orbits.

Figures 9 through 14 show the total physical dose rates (30 days) received behind aluminum shields of various thicknesses for the trapped electron, bremsstrahlung, and galactic cosmic rays at parking longitudes of 110 and 290 degrees east and orbit inclinations of 0, 30, and 45 degrees. The trapped proton dose rate was nil. The geometry for the trapped proton and cosmic ray dose rate calculations consisted of a point tissue receiver at the center of a spherical aluminum shell of the given thickness. The techniques used for the proton dose rate calculation are described in Reference 6. The cosmic ray dose rates were obtained from tabular data in Reference 1. In general, for electron and bremsstrahlung (except low energy), the quality factor is approximately 1. Thus, the rem (radiation equivalent man) and rad dose rates are the same. For the total galactic cosmic radiation, the rem dose is about six times the rad dose. The geometry for the electron and bremmstrahlung dose rates is different. In these calculations, the electrons are assumed to be isotropically incident on an infinite aluminum plane shield rather than a sphere. The differences in dose rates for the two geometries are insignificant when compared to the environmental uncertainties. The methods used are described in Reference 7.

III. SOLAR PROTON EVENTS

Because of the importance of solar proton events in the manned space flight program, it seems justifiable to discuss the methods and status of flare predictions. The capability to predict solar proton events for time intervals in excess of a few months to a number of years is needed for synchronous altitude missions. At present, this capability is based on the relationship between the rates of occurrence of solar particle events and sunspot number.

In the time scale of a few months, it is possible to use earth-based observable conditions on the sun to greatly improve the probability of making a specific mission without encountering a hazardous solar proton event. Because of the rotation of the sun an east-west asymmetry of solar proton events exists. For events occurring on the eastern hemisphere of the sun, the probability of solar protons reaching the earth is one-third that of events occurring on the western hemisphere [8]. If an event does occur on the eastern hemisphere, the corresponding onset, rise, and decay times are three times greater than for events on the western half, giving astronauts more time to prepare for the oncoming event. The presence and development of an active region with its associated sunspots and complex magnetic field is the basic part of the process which leads to a solar proton event. Thus, there are two aspects of primary importance for flare prediction [8] and warning capabilities: (1) the persistence of single active centers and (2) the magnetic configuration of these active centers. Regarding the persistence of single active centers, Guss [9] has pointed out that a single fixed location in solar longitude produced most of the major events in cycle 19. If a "hot" region exists and can be identified early in the solar cycle, the prediction of large events will probably be concerned with the study of this one region. Figure 15 gives the dose received on a 2- and 52-week mission as a function of shield thickness for various cumulative probabilities [10] based on cycle 19 data. According to Reference 11, the sunspot number for cycles 20 and 21 should be approximately half the value in cycle 19, and the corresponding number of large events should also be less, thus leading to a higher probability of receiving smaller doses per mission behind various shields. Thus, Figure 15 should give extreme values for missions during solar cycle 21.

IV. DOSE LIMITS

Table 1 gives the dose limits for 30- to 60-day missions [10] and should not be used for missions longer than 60 days. These dose limits [12] were established for the Apollo program on the assumption that the crew would be exposed to small increments of dose of approximately equal size. Additional dose limits for specific applications may be found in References 13 and 14.

If one wishes to investigate missions of long duration (1 or 2 years), he may assume that the body does indeed repair some of the damage; however, it would be presumptuous to extend the acceptable dose levels without more knowledge. It is conceivable that a total allowable accumulated dose may, in fact, be doubled for a mission of 1 or 2 years. Such an assumption, however, must

TABLE 1. RADIATION DOSE LIMITS FOR 30- TO 60-DAY MISSIONS [12]

Tissue	Depth	Planned Operational Dose[a]	Maximum Operational Dose[b]
Skin	0.1 mm	2.5 rad[c]/day	5 rad/day
Eye	0.3 mm	1.25 rad/day	2.5 rad/day
Bone Marrow	5.0 cm	0.6 rad/day	1.0 rad/day

a. Planned Operational Dose: The dose which should not be exceeded without requiring a mission modification of some degree. The degree of modification would be a function of the magnitude of the excess dose. This dose would be used for mission planning purposes to determine if proposed trajectories and time lines are acceptable.

b. Maximum Operational Dose: The dose which should not be exceeded without specific modification of the mission to prevent further radiation exposure. Such an exposure would be considered to result in a potentially harmful inflight response in terms of crew safety and post-flight response in terms of delayed radiation injury.

c. Rad: A basic unit of dose equal to an absorbed energy of damaging radiation of 0.01 J/kg in any material.

embody the concept of a fairly constant or uniform radiation exposure over the total period. This is probably not a valid assumption for deep space flight, since one could conceivably receive 90 percent of his allowable dose during one large solar proton event lasting (at most) 3 days.

V. SHIELDING CONSIDERATIONS

From experience with Skylab and Apollo, it has been determined that the effective shielding for a typical point inside a spacecraft is considerably higher than the spacecraft wall thicknesses alone. For Skylab, the wall thickness was approximately 1.0 g/cm^2, whereas typical points in the workshop had effective average shielding of approximately 10 to 15 g/cm^2 [15]. On smaller structures, such as the Spacelab, the wall thickness will be similar. Many directions will have effective shielding thicknesses of >20 g/cm^2, in which case most of the absorbed dose will be received from the directions which have only the wall thickness shielding. Figure 16 shows percent distribution of shielding thicknesses for the Apollo Command Module and Service Module. This distribution is representative of, although probably greater than, that for a geosynchronous space station.

If sensitive photographic films are present, extra precautions must be taken. Some films are as much as 30 to 40 times as sensitive to gamma rays as to protons. (Their sensitivity is also highly energy dependent.) Biological effects are better measured in terms of rems, which includes a quality factor depending on the type and energy radiation depositing the dose (rem = rad X quality factor). For example, cosmic rays have an unusually high quality factor due to the heavy particle component; thus, cosmic ray doses in rems are 6 or 7 times as high as doses in rads [1]. Special vaults may be needed for storage of sensitive films.

VI. SOLAR CELL DEGRADATION

If solar cells are used for auxiliary power, consideration should be given to possible power degradation due to the trapped radiation. One of the authors (J. J. Wright) has made preliminary calculations on an 8 mil N on P silicon solar cell with a 6 mil fused silica cover plate. The calculations show insignificant power loss at the synchronous altitude due to the trapped radiation; however, if a large solar flare is encountered, considerable power degradation could result to unshielded solar cells.

VII. EVA

From Figures 9 through 14, assuming a minimum of 2 g/cm^2, the effective shield thickness of the spacecraft gives a 30-day dose rate of 32 to 14 rads, or 1.07 to 0.47 rads/day, depending on parking longitude and orbit inclination. Thus, according to Table 1, the planned operational dose would not be exceeded inside the spacecraft. However, during an EVA with a spacesuit thickness of 0.2 g/cm^2, the bone marrow dose rate would not be exceeded but the eye and skin dose rates would be. For the planned operational dose rate to be less than the dose rate limit for the skin during an EVA mission, the spacesuit would have to be approximately 1.3 g/cm^2 thick.

VIII. SUMMARY AND CONCLUSIONS

A. Radiation Environment

1. The geosynchronous orbit is usually in the outer regions of the magnetosphere. Thus, the particle environment is governed more by earth-trapped particles than solar-generated particles. Several times each year, during solar activity, the geosynchronous altitude is outside of the magnetosphere on the dayside of the orbit. Intense solar proton events will produce large solar proton fluxes at synchronous altitudes.

2. At geosynchronous altitude, the trapped particle radiation consists mainly of low energy electrons with a soft spectrum; trapped proton fluxes are negligible.

3. The cosmic ray flux is significantly higher than that in low-earth orbit due to the increased number of low-energy cosmic rays accessible to the higher altitude.

4. It is expected that a significant dose will be received going from low-earth orbit to geosynchronous altitude since regions of high fluxes of high energy trapped protons will be crossed. The dose will be highly dependent upon the trajectory and may, in fact, be a major factor in the trajectory selection.

B. Shielding

1. Approximately 2 g/cm^2 of shielding is required to eliminate the trapped electron fluxes. It is important that a minimum thickness of approximately 1.5 g/cm^2 be maintained around the entire space station since even a small solid angle of thinner shielding would lead to large low-energy fluxes. The space station walls may provide this minimum shielding, in which case the crew will receive less than the planned operational dose.

2. For shielding thicknesses greater than approximately 10 g/cm^2, little additional shielding benefits are realized since the major radiation dose is due to high-energy cosmic rays which have an interaction length of approximately 100 g/cm^2 in light materials. Additional shielding beyond approximately 2 g/cm^2 may actually be detrimental due to the production of secondary radiation produced by cosmic ray primaries.

3. Shielding for solar cells and other sensitive components of a geosynchronous space station is within present technology.

C. Solar Flare Hazard

1. Solar flare particle radiation may reach geosynchronous altitude since the earth's field is weak there. The mission risk due to solar flares is similar to or less than that in the Apollo program, although allowances must be made for the increased mission duration and differences in the solar cycle.

2. A storm shelter approach to solar flare protection may be advisable; i.e., providing an area within the space station where shielding is much greater than average and with a minimum of approximately 10 g/cm^2 in all directions. Due to weight limitations, mass available from existing hardware should be used rather than "dead weight" mass. Since solar proton fluxes are highly directional, a partial "shadow shield" may provide adequate shielding in the expected direction of incidence.

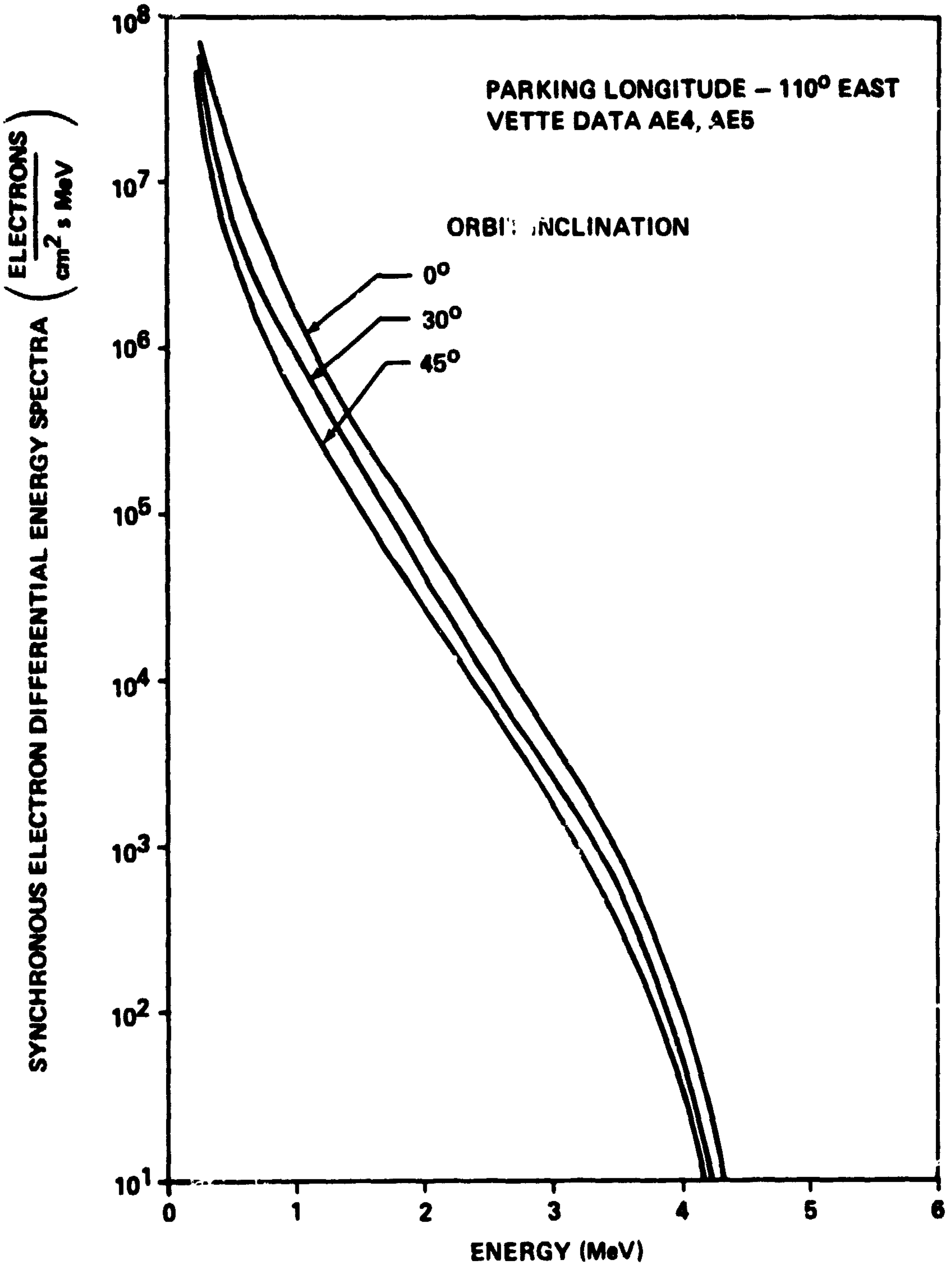

Figure 1. Geosynchronous altitude trapped electron differential energy spectra for 110 degrees East parking longitude.

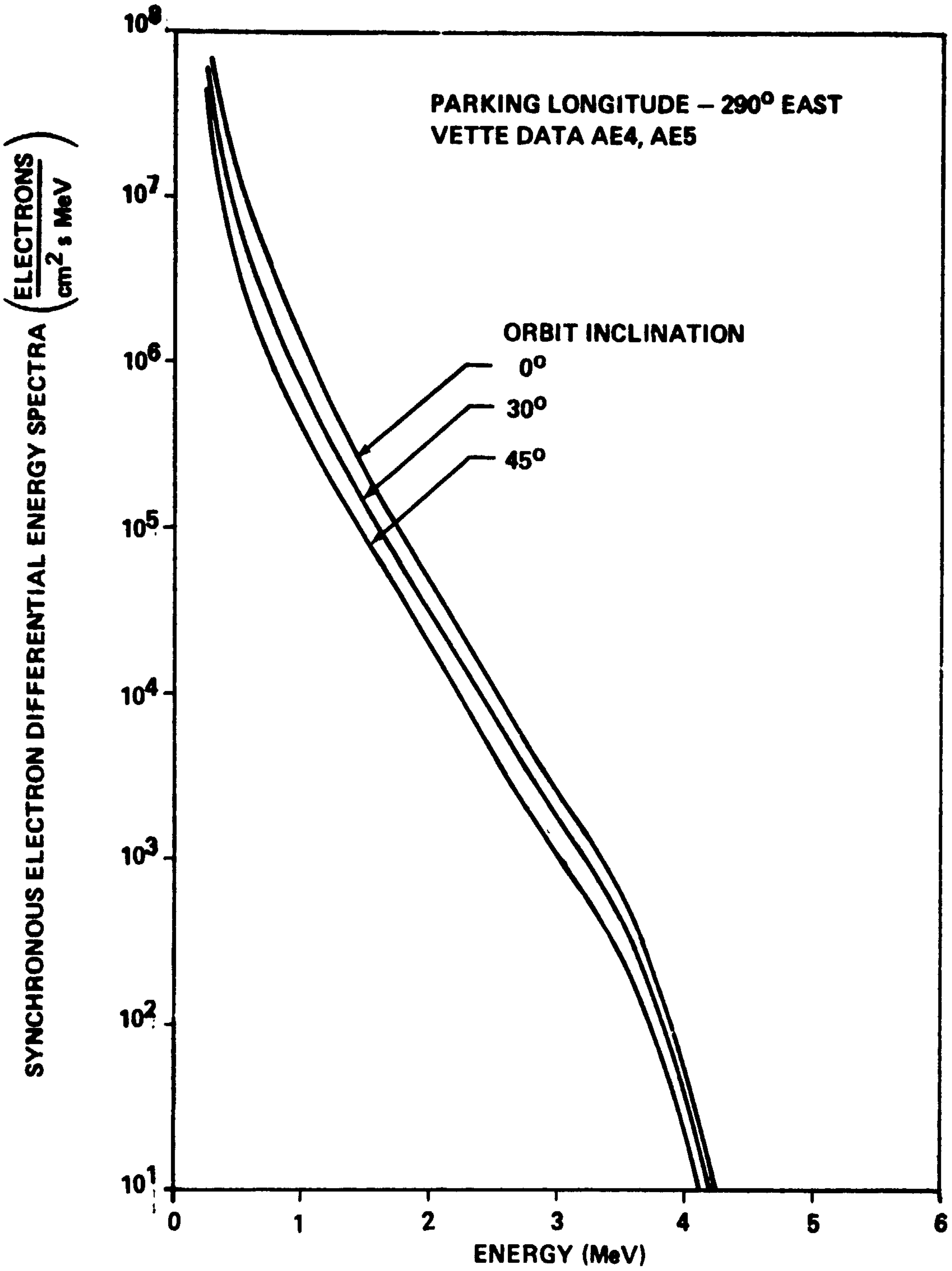

Figure 2. Geosynchronous altitude trapped electron differential energy spectra for 290 degrees East parking longitude.

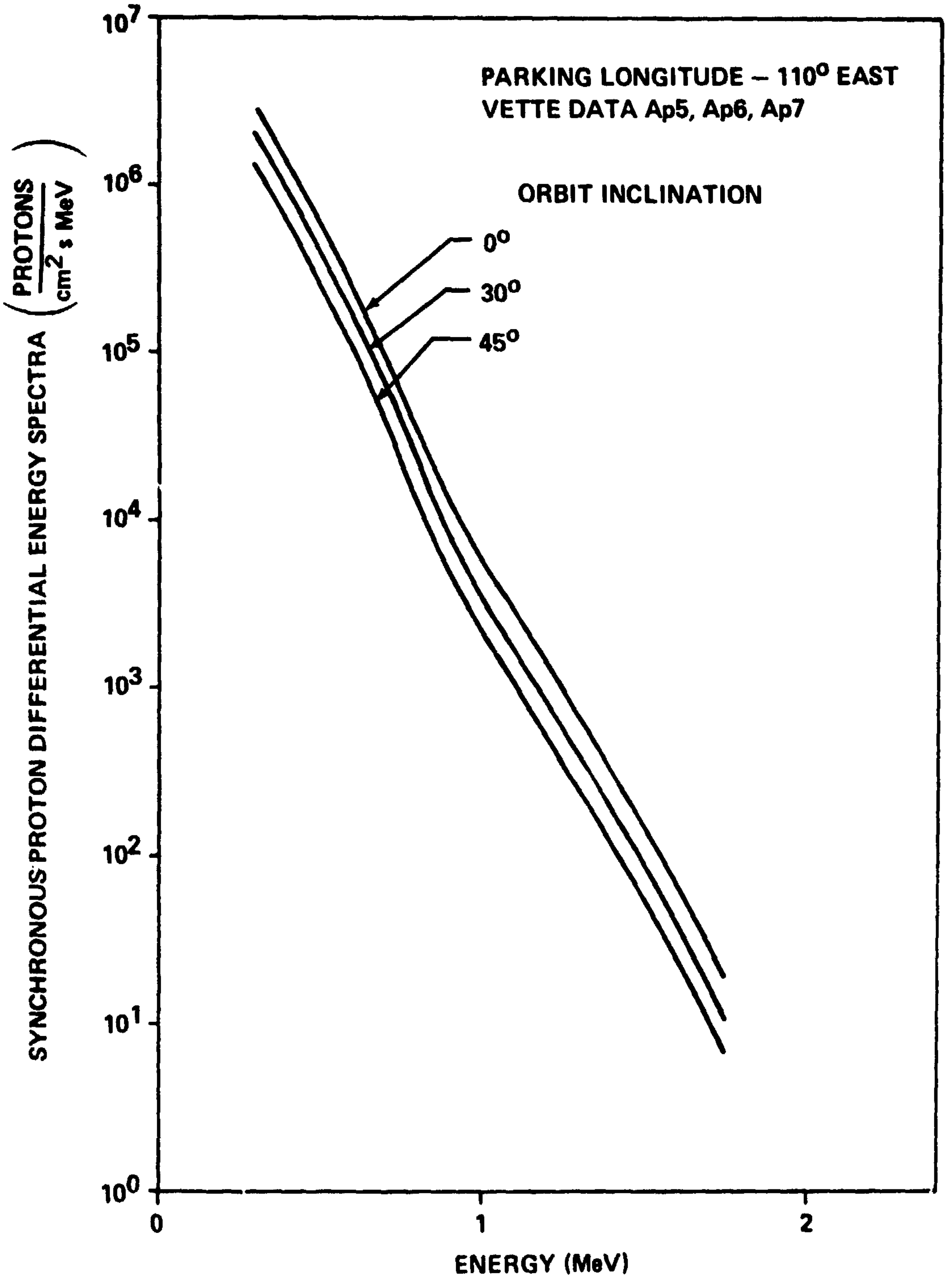

Figure 3. Geosynchronous altitude trapped proton differential energy spectra for 110 degrees East parking longitude.

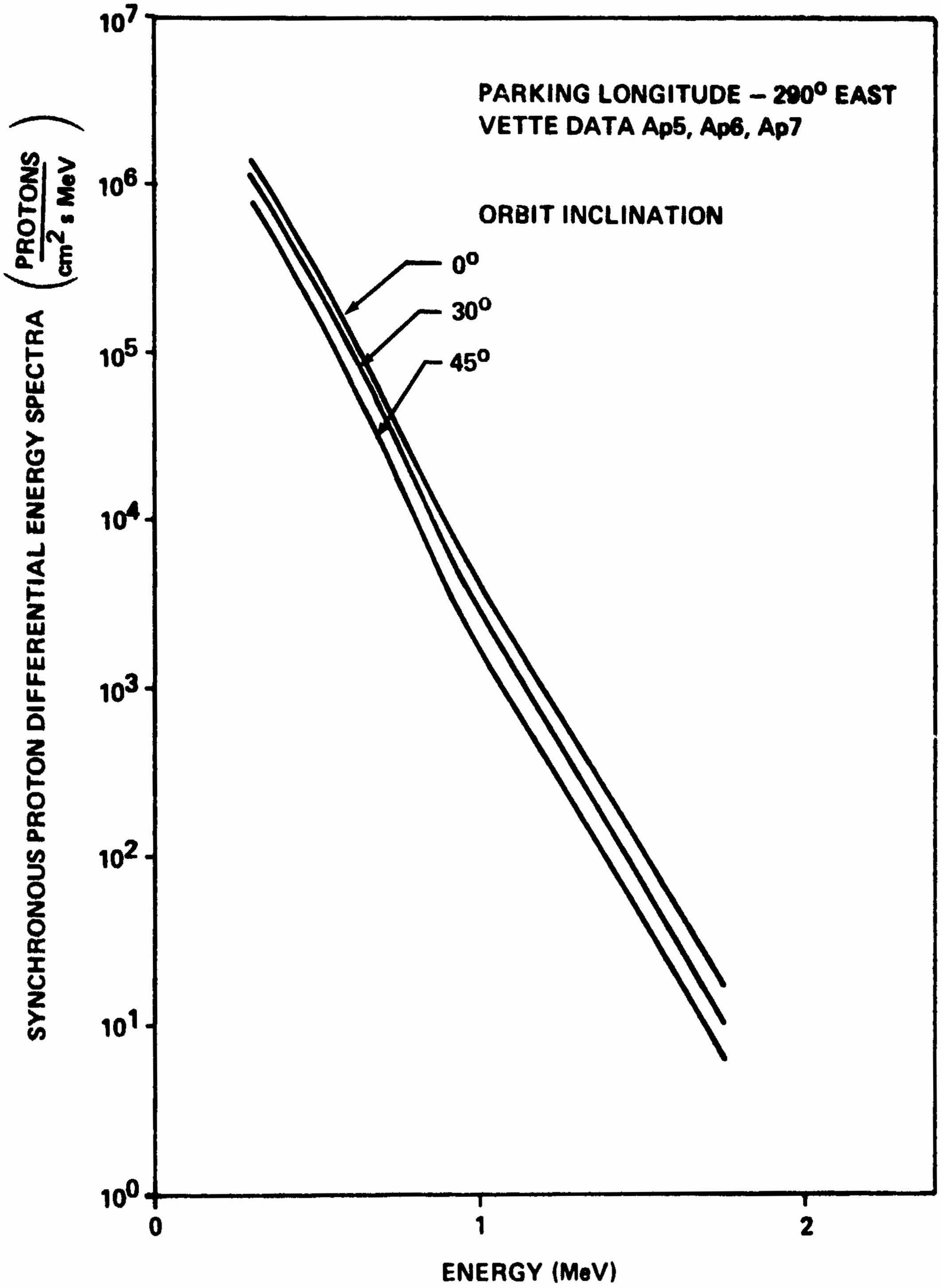

Figure 4. Geosynchronous altitude trapped proton differential energy spectra for 290 degree East parking longitude.

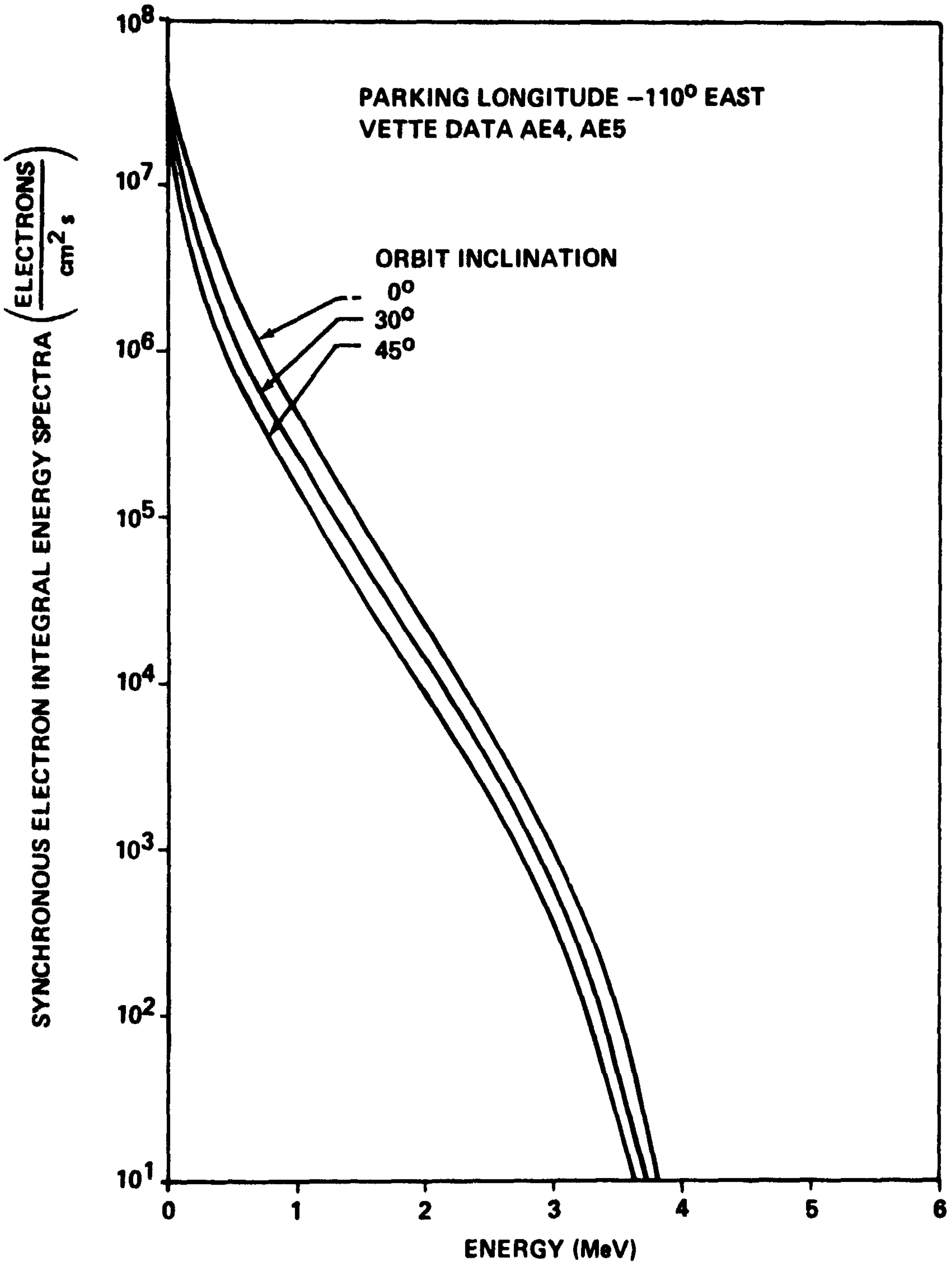

Figure 5. Geosynchronous altitude trapped electron integral energy spectra for 110 degrees East parking longitude.

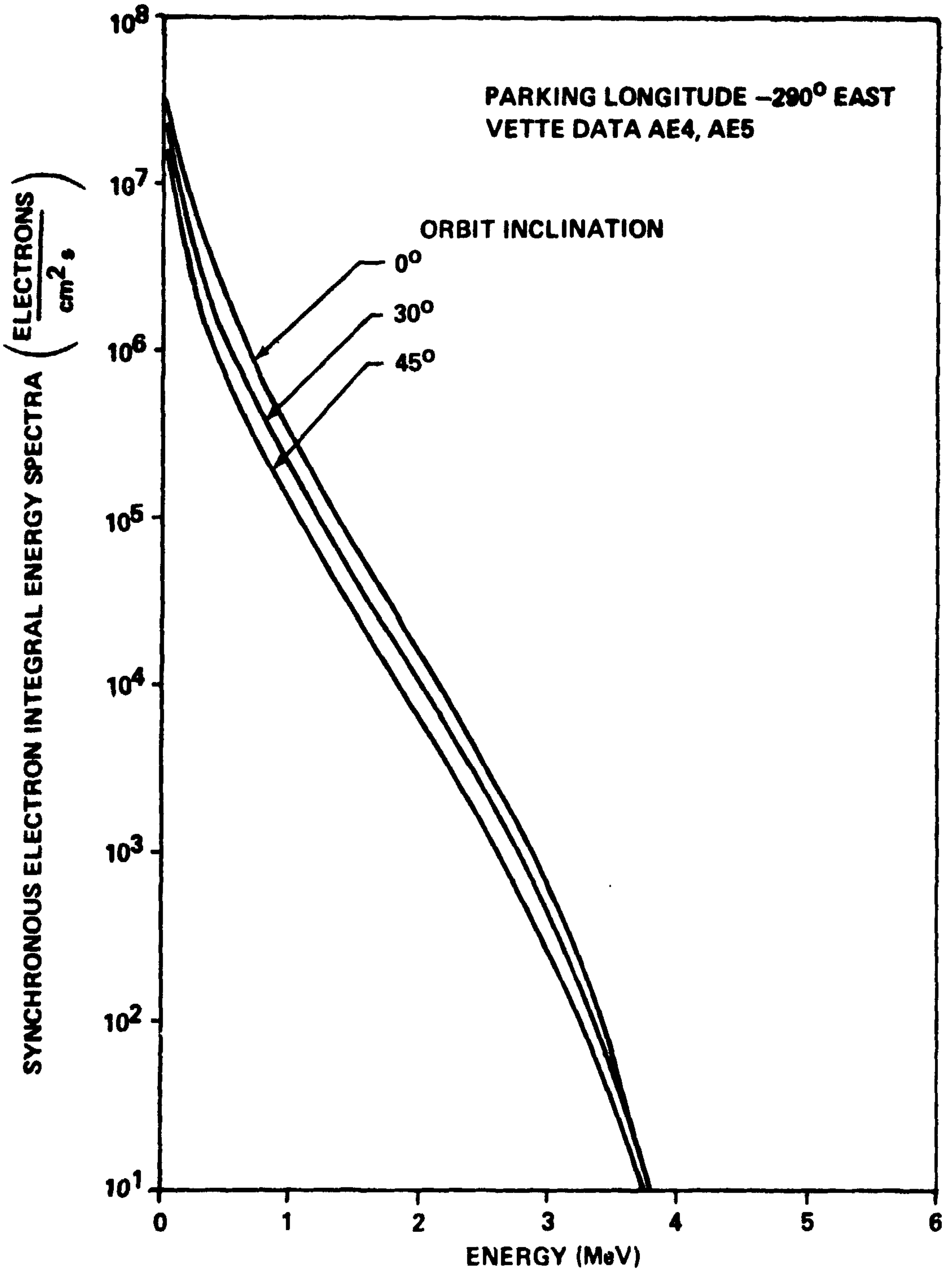

Figure 6. Geosynchronous altitude trapped electron integral energy spectra for 290 degrees East parking longitude.

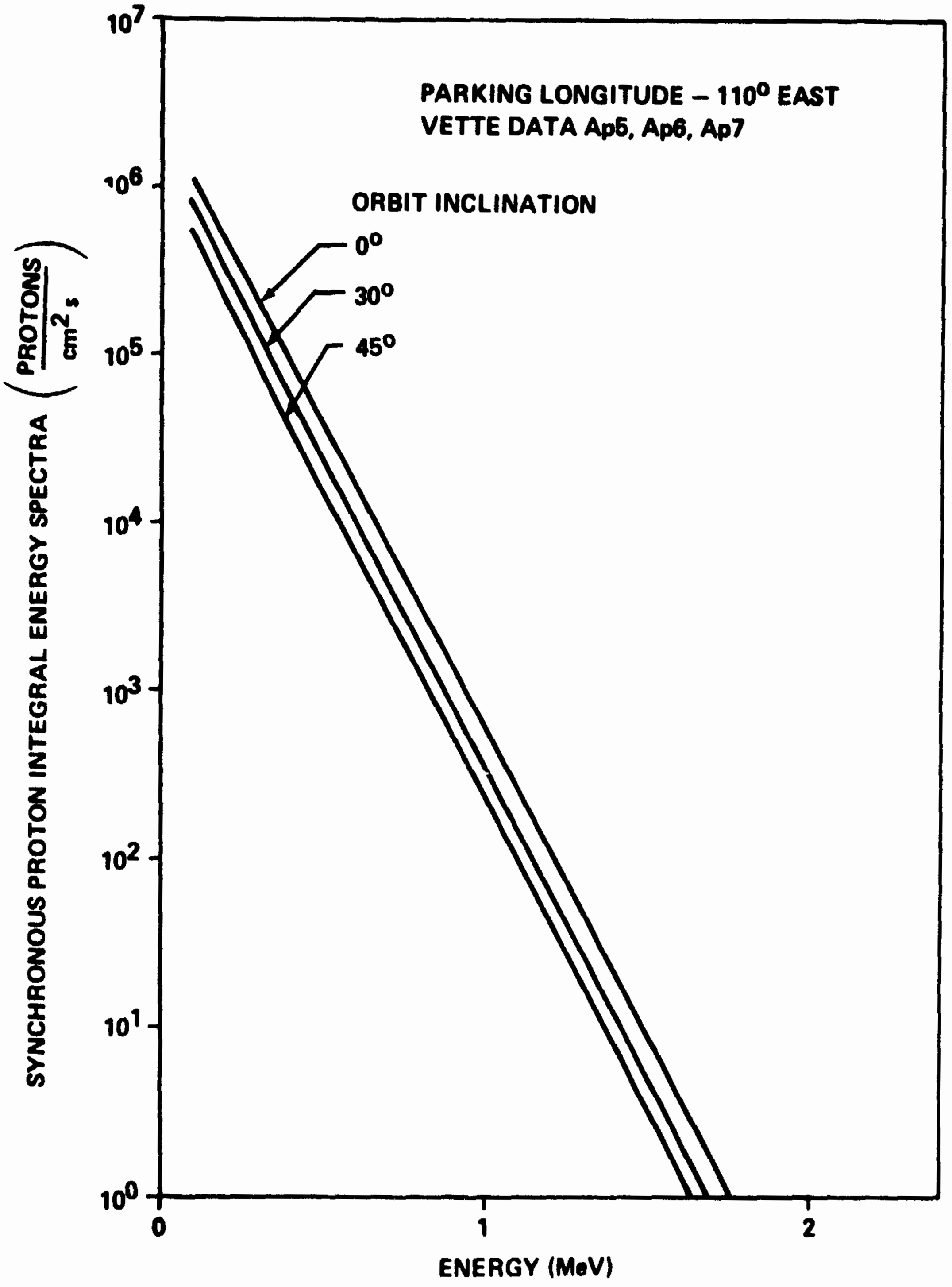

Figure 7. Geosynchronous altitude trapped proton integral energy spectra for 110 degrees East parking longitude.

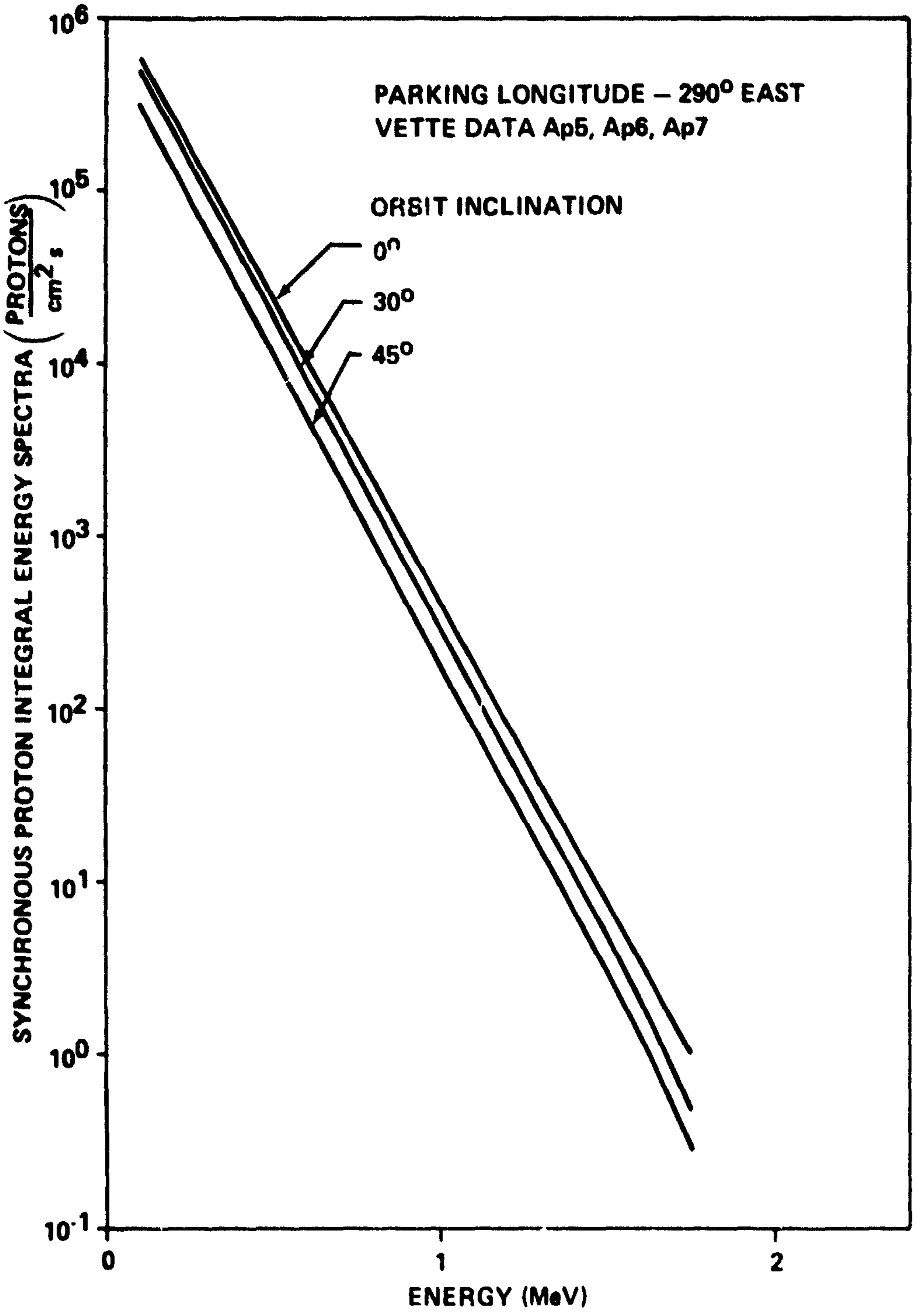

Figure 8. Geosynchronous altitude trapped proton integral energy spectra for 290 degrees East parking longitude.

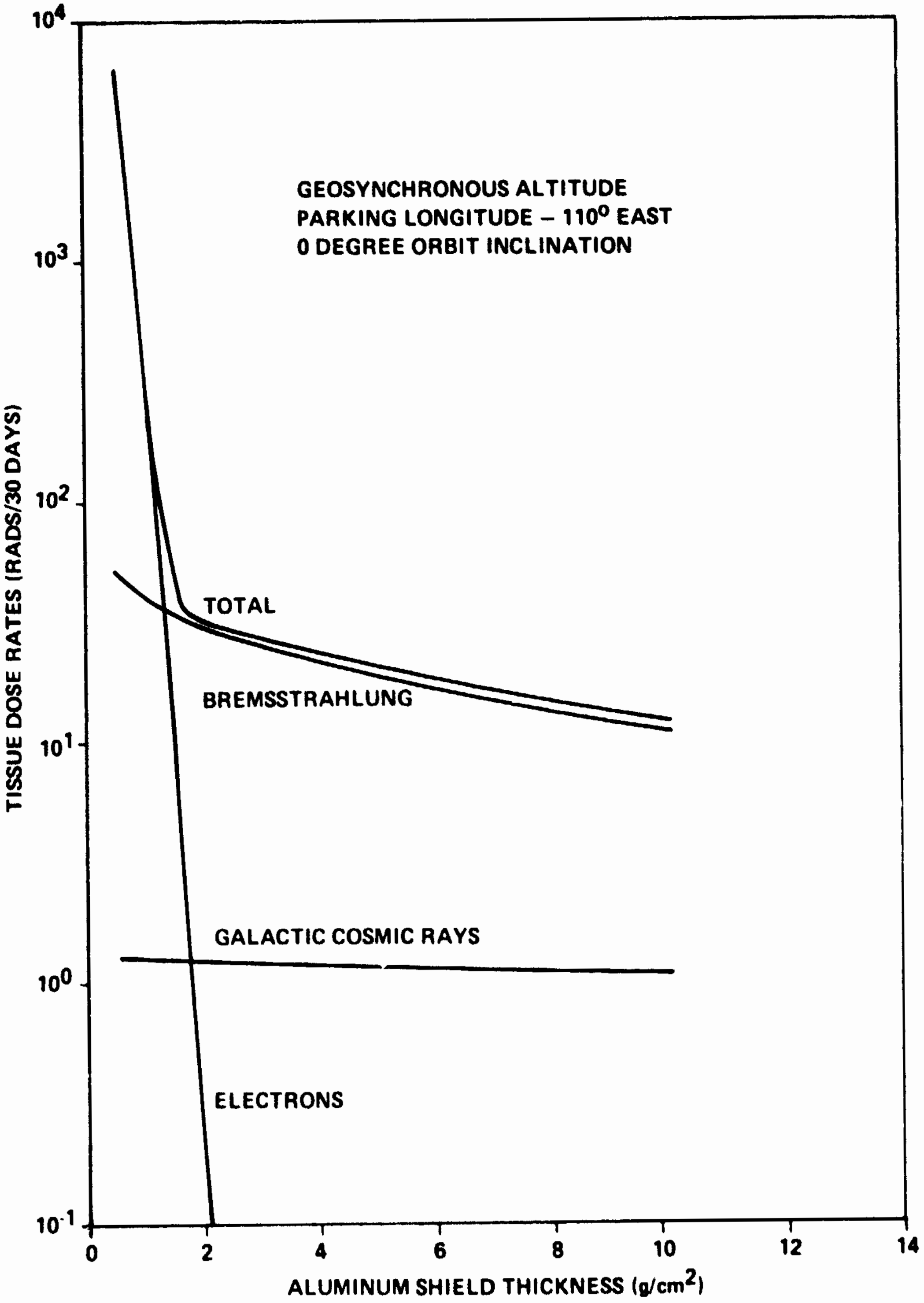

Figure 9. Geosynchronous altitude total dose rates behind various shield thicknesses for 110 degrees East parking longitude and 0 degree orbit inclination.

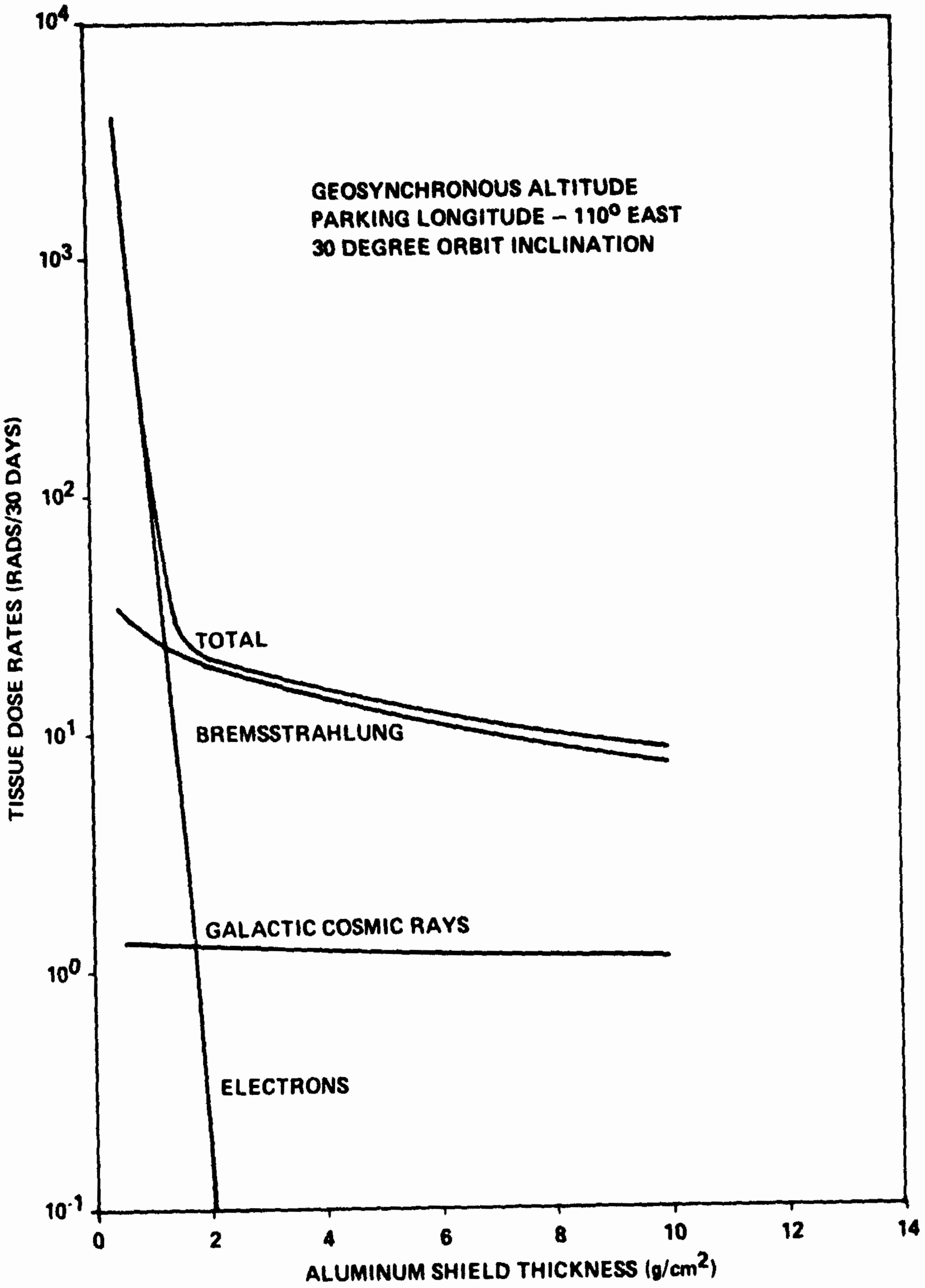

Figure 10. Geosynchronous altitude total dose rates behind various shield thicknesses for 110 degrees East parking longitude and 30 degrees orbit inclination.

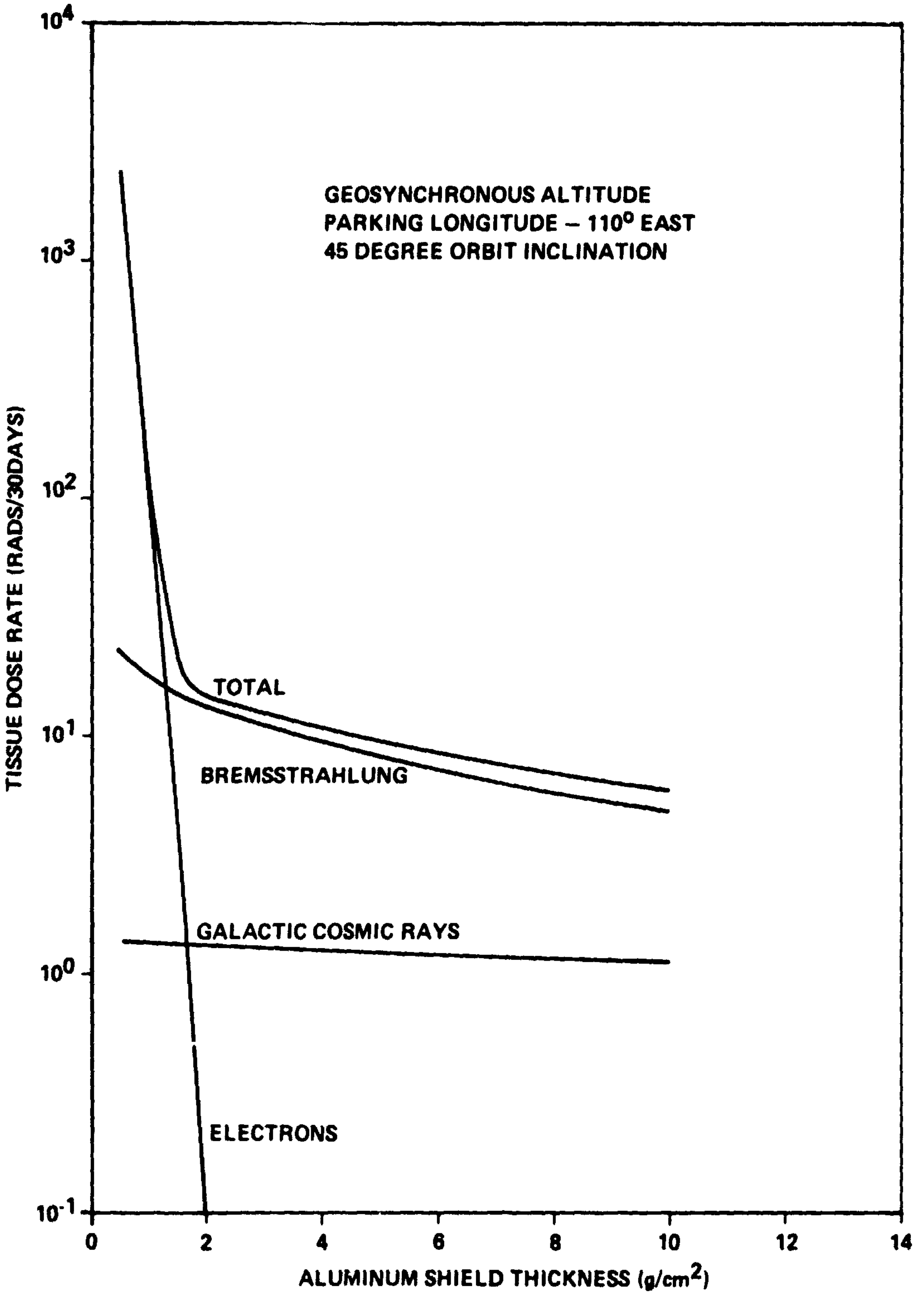

Figure 11. Geosynchronous altitude total dose rates behind various shield thicknesses for 110 degrees East parking longitude and 45 degrees orbit inclination.

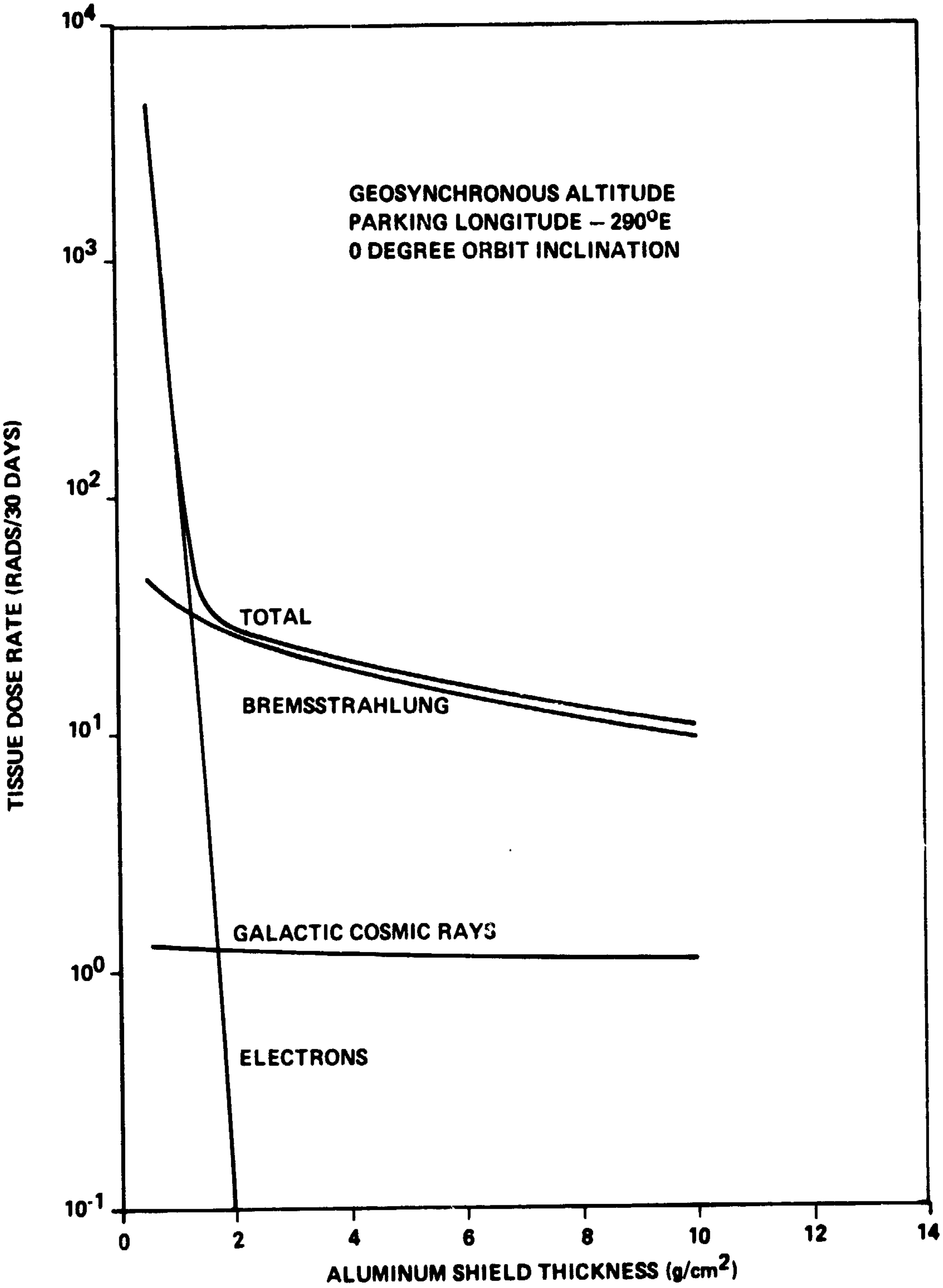

Figure 12. Geosynchronous altitude total dose rates behind various shield thicknesses for 290 degrees East parking longitude and 0 degree orbit inclination.

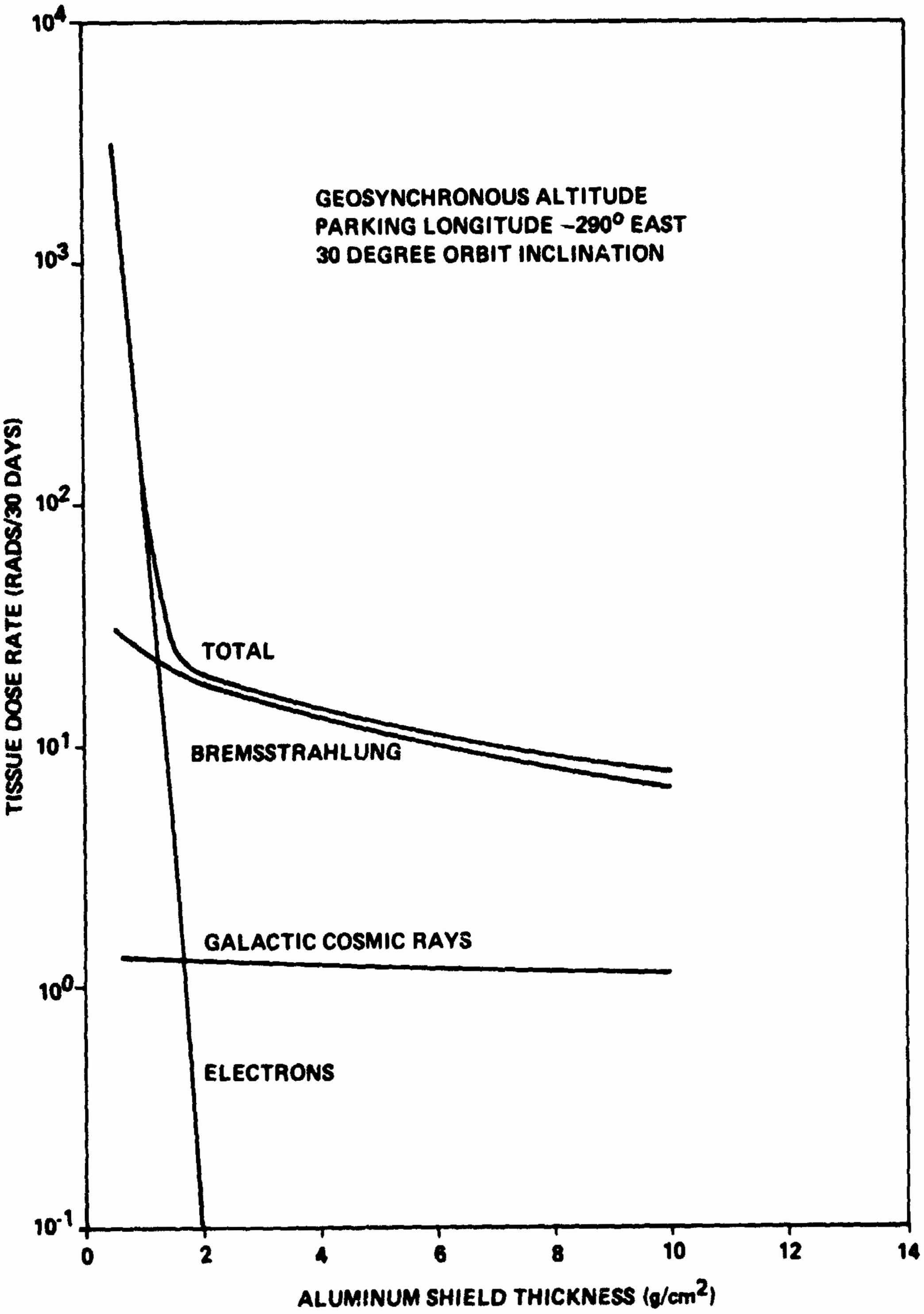

Figure 13. Geosynchronous altitude total dose rates behind various shield thicknesses for 290 degrees East parking longitude and 30 degrees orbit inclination.

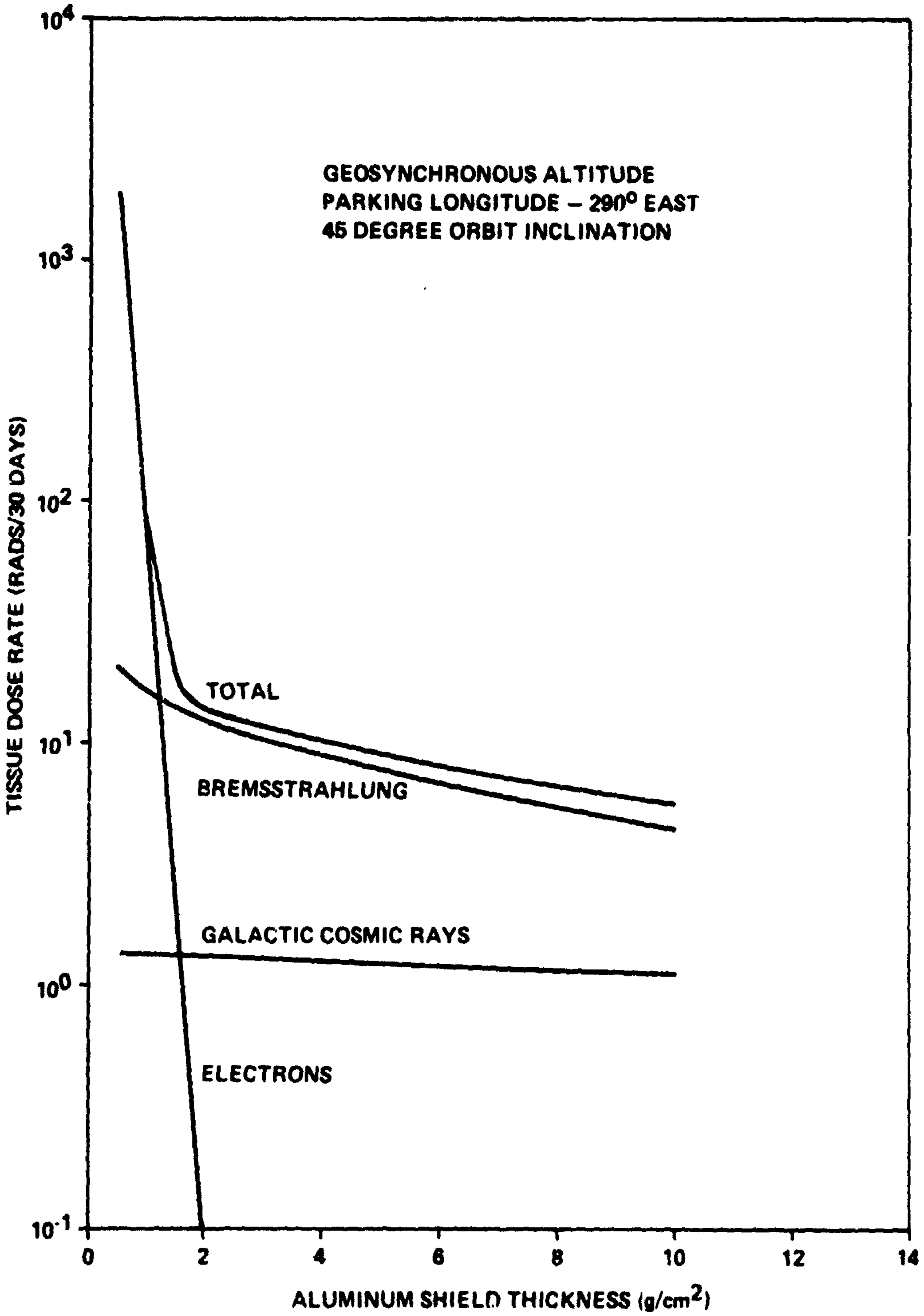

Figure 14. Geosynchronous altitude total dose rates behind various shield thicknesses for 290 degrees East parking longitude and 45 degrees orbit inclination.

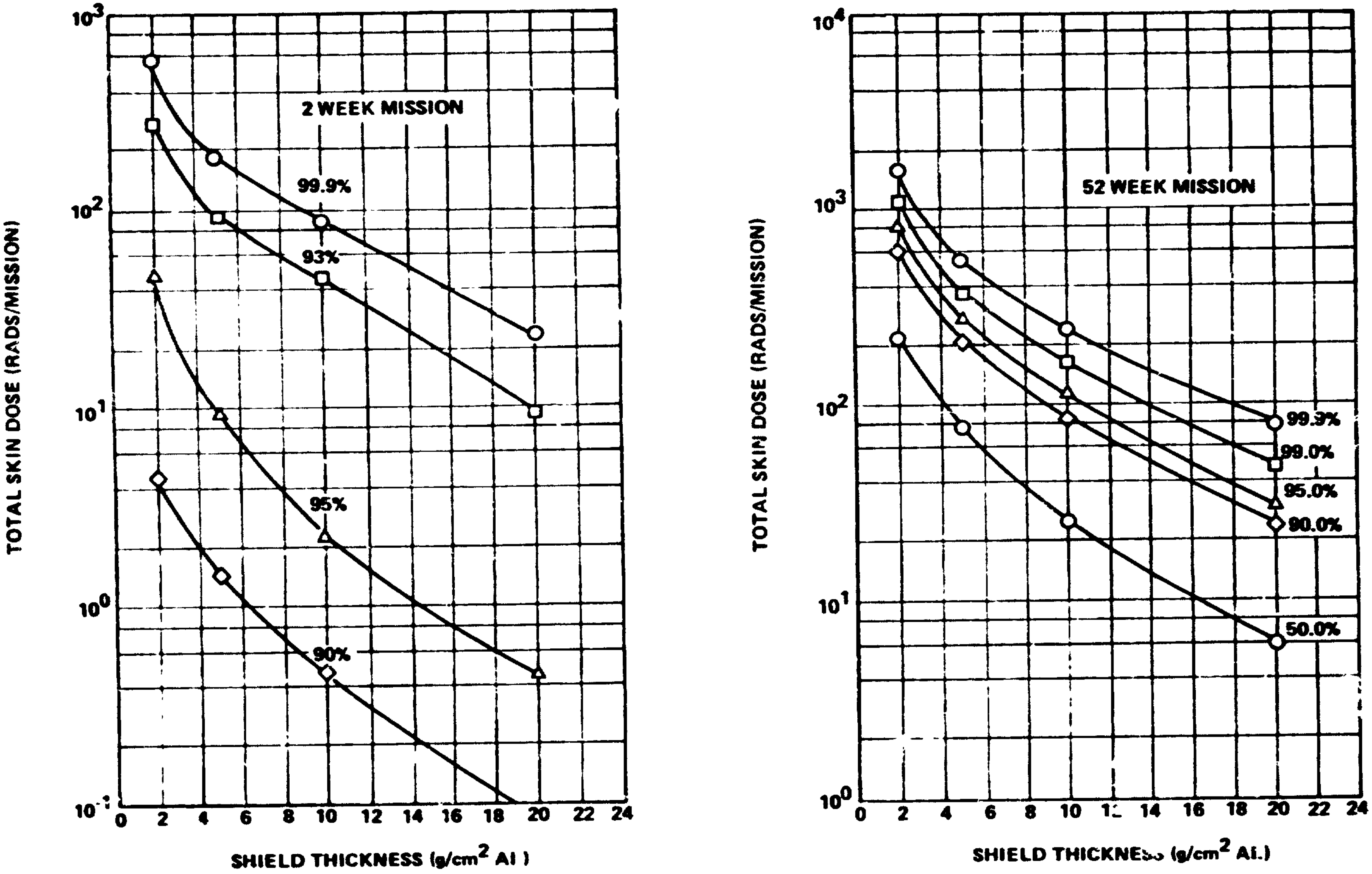

Figure 15. Doses received on 2- and 52-week missions as a function of shield thickness for various cumulative probabilities.

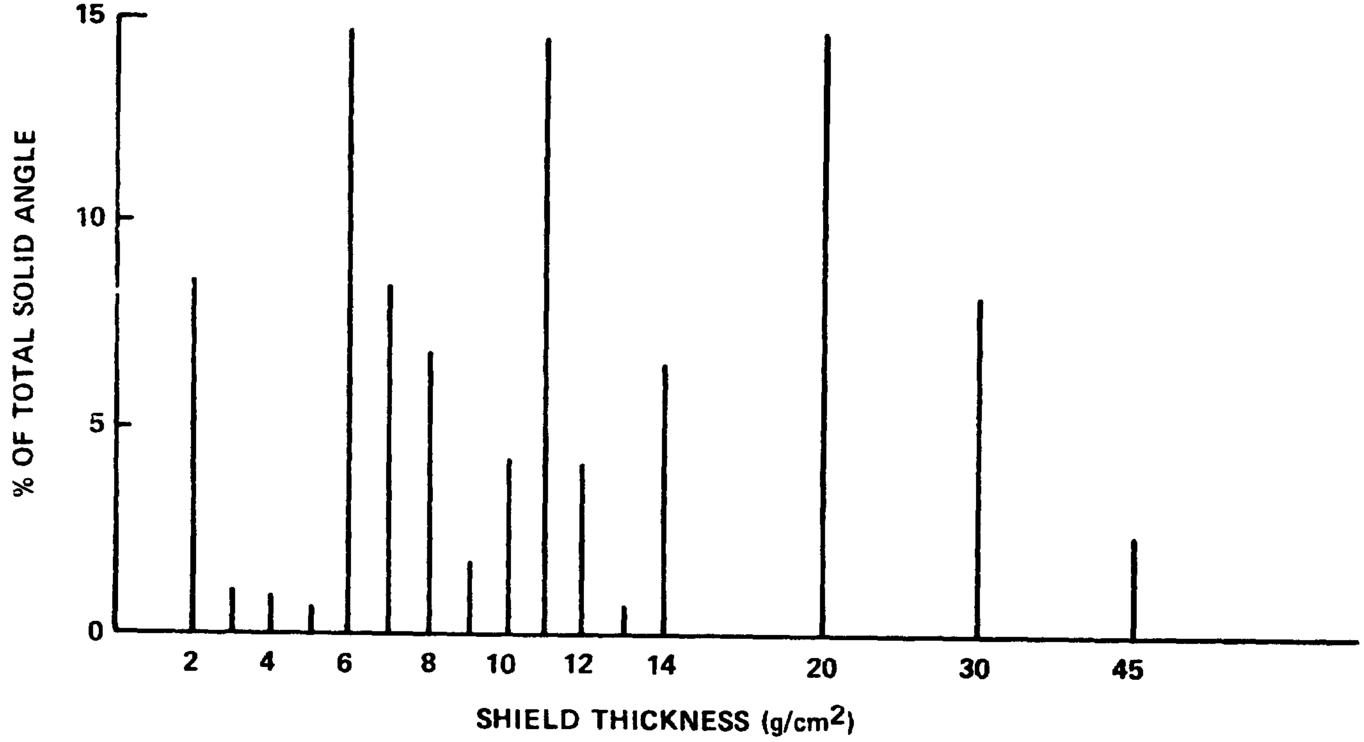

Figure 16. Percent distribution of shield thicknesses for the Apollo Command and Service Module.

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APPROVAL

RADIATION ENVIRONMENT AND HAZARDS FOR A GEOSYNCHRONOUS SPACE STATION

By J. J. Wright and G. J. Fishman

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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