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FILM DEGRADATION RESULTING FROM MAGNETICALLY TRAPPED PROTONS IN ATM ORBITS

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ABSTRACT

Film degradation resulting from trapped protons in the ATM orbit is considered for five films: 103-0, Plus X, Panatomic-X, SWR, and SO-375. The latest Kodak analysis of the NASA data is used to determine film densities as a function of time in a 210 nautical mile (389 km), 35° circular orbit for the films. Dose rates as a function of orbital altitude, inclination, and shield thickness are presented that should be useful in determining film degradation in orbits near the one presented. Film selection is concluded to be the single most important criteria in minimizing data loss due to radiation damage.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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INTRODUCTION

As the mission is presently planned, the ATM Workshop cluster will be flying in a circular orbit inclined at between 30° and 35° and at altitudes between 180 and 220 nautical miles (333 and 407 km). This region is in the lower fringes of the Van Allen radiation belt which consist of magnetically trapped, high-energy protons and electrons that can damage sensitive photographic film. An initial investigation [1] showed that most of the radiation dose received at these altitudes and inclinations is due to protons (Fig. 1). Several films proposed for use on the ATM cluster were radiated with monoenergetic protons to determine the film response[1] variation with proton energy.

One set of this irradiated film was brought back to Marshall Space Flight Center, developed, and analyzed here. Reference 2 describes the results for this batch of film. Another set of film was sent to Kodak for their analysis. The results of Kodak's analysis are now available [3].

There were two major differences in Kodak's treatment of the data. First, they corrected the response curves for the beam profile. Second, for most of the films, Kodak determined the response curves by shifting the response curve shape for 80-KeV X-rays along the dose axis to obtain a best fit to the measured points for protons. The response curve shape for the films SWR and SO-375 differed from 80-KeV X-ray shape so smooth curves were drawn through the actual data points.

This report uses the Kodak data to reanalyze the radiation problems in the ATM orbit for five films, Panatomic-X, SWR, 103-0, SO-375, and Plus-X. It should be useful in the selection of films for future missions.

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[1] By film response we mean the film density as a function of radiation exposure. Film density is defined as minus the logarithm to base ten of the film transmission.

DETERMINATION OF NET FILM RESPONSE

Kodak's data are in the form of film density versus rad dose in air at constant proton energies. The proton energy spectrum at the location of the film must be folded in with the film response as a function of energy to determine the net response of the film. Reference 4 describes a method for performing this calculation.

To transform the spectrum exterior to the spacecraft into the spectrum at the film, the "straight-ahead" approximation with a correction for secondary induced radiation is used. Basically, the protons are assumed to be unscattered by the shielding material and to travel straight ahead through the shield, losing energy according to the stopping power and thickness of the material encountered. This method, described in detail in reference 5, has proved fairly accurate when compared with considerably more sophisticated computations. The free-space spectra are obtained using the James Vette trapped particle environment [6] in a computer program [7] which time averages the spectra over several orbits.

A spherically symmetrical geometry is used for ease of comparison and calculation. Both doses and densities are calculated for a point piece of film at the center of a spherical aluminum shell of uniform thickness. Thus the film provides no shielding for itself.

RESULTS AND CONCLUSIONS

Figures 2 through 6 show film density versus time in orbit for various shield thicknesses in a 210 nautical mile (389 km), 35° inclination, circular orbit. There is a factor of 20 in radiation sensitivity between the least sensitive film, SO-375, and the most sensitive film, 103-0. Doubling the shielding that surrounds a given piece of film no more than doubles the time required to achieve the same density. Thus careful film selection is perhaps the most effective means of minimizing radiation damage in a fixed radiation environment. Shielding is helpful, but in most cases the amount of additional shielding required to be really effective is prohibitively heavy and bulky.

Since a simple spherical geometry has been used to eliminate the difficulty of calculating the angular dependence of the flux, extreme caution should be used in attempting to determine actual film degradation in a complex spacecraft from the results presented. Rather, the results should be used to point out where problem areas exist. For example, if a film is to be stored next to a spacecraft wall 2.0 g/cm^2 thick and the spherical shell calculation shows an unacceptable density for the expected storage period, then an accurate complex geometry calculation should be performed for the film.

Most of the problems and uncertainties in the calculation of film degradation due to radiation during an actual mission are in the determination of the proton energy spectrum at the location of the film. The film may be moved several times during a flight, and the spectrum at a given point in the spacecraft is a function of the spacecraft geometry and the orientation and position of the vehicle in the magnetic field of the earth. For a really accurate computation, detailed knowledge concerning the movement of film and equipment that might shield the film is required. As a matter of fact, there can be significant variations in density between portions of a single roll of film, depending on how it is exposed. Even if the spacecraft geometry and film position are well known, there are still large uncertainties in the determination of the proton spectrum exterior to the craft and some difficulty in transforming the exterior spectrum into a spectrum at the film.

For the orbits of interest, most of the radiation is received in passes through the South Atlantic Anomaly, a distortion of the geomagnetic field that results in high proton fluxes at relatively low altitudes (Fig. 7). In this region most of the protons are near their mirror points (that is, they are traveling almost perpendicularly to magnetic field lines). Thus, one would expect the proton flux to be highly angular dependent. Unfortunately, most of the data presently available is integrated over all directions and even these data have an uncertainty factor of two.

Since flights at around 200 nautical miles (370 km) are flying through the lower fringes of the belt, a change in altitude may result in large changes in the proton flux encountered. Figure 8 shows the proton dose as a function of altitude in a 35° orbit for various shield thicknesses. Changes in orbital inclination also result in dose variations since the belts are not symmetrical. Figure 9 shows the proton dose as a function of orbital inclination at 210 nautical miles (389 km) altitude for various shield thicknesses. From these two figures one draws the conclusion that low-altitude, low-inclination orbits are preferable if film degradation is to be minimized. One should remember that the spectra used in these calculations have been averaged over several orbits. At any specific time, dose rates many times higher or lower than these averages may be observed.

In conclusion, radiation problems for film can be minimized in the following way. Select the least radiation-sensitive film that will still perform the task required. (Figure 10 shows a comparison of proton dose sensitivity for the five films in this report.) Determine the radiation degradation that can be tolerated without major loss of data. For a rough estimate, see if this tolerance is met during the mission life behind some nominal shield (2 to 5 g/cm^2). If the tolerance is exceeded or if the film is to be placed in some very thinly shielded area during any major portion of the mission, a more detailed analysis should be performed considering the time lining of film position and spacecraft geometry. If the tolerance is still exceeded, consideration should be given to placing additional shielding around thinly shielded locations and relocating the film to safer positions.

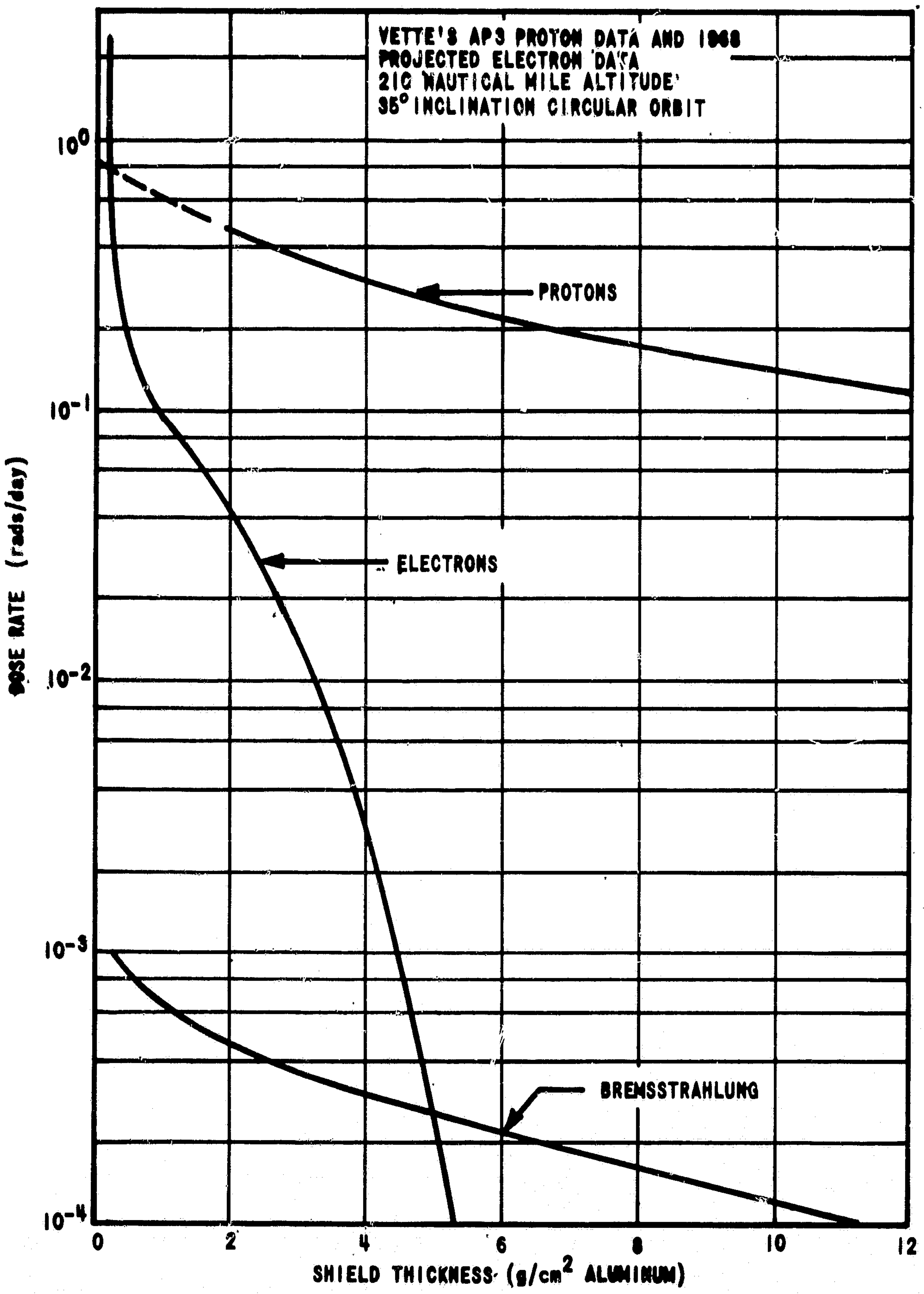

FIGURE 1. DOSE VERSUS SHIELD THICKNESS FOR PROTONS, ELECTRONS AND BREMSSTRAHLUNG IN A 210-NAUTICAL MILE (389 km), 35° CIRCULAR ORBIT

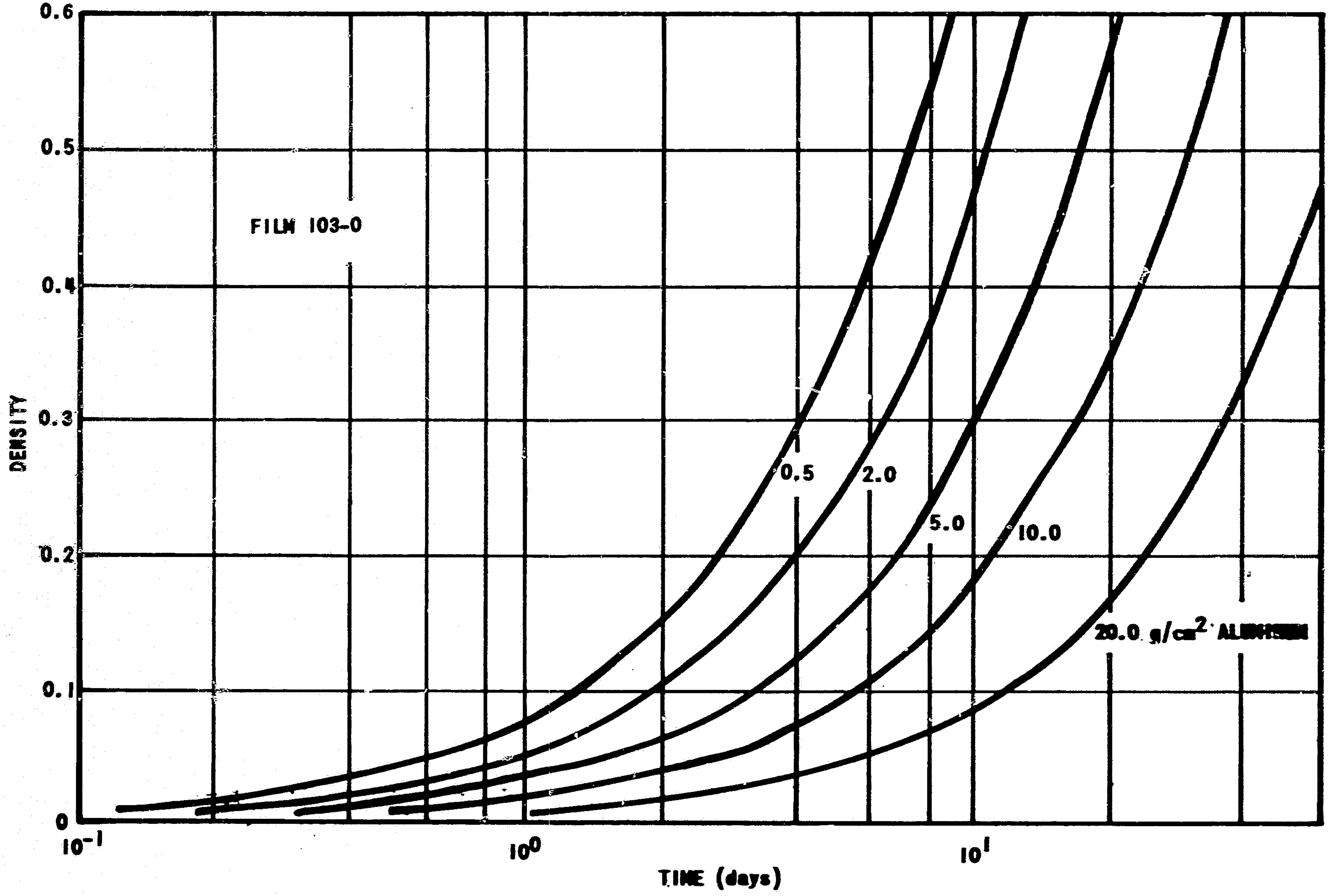

FIGURE 2. FILM DENSITY VERSUS TIME IN ORBIT FOR THE FILM 103-0 IN A 210-NAUTICAL MILE (389 km), 35° CIRCULAR ORBIT

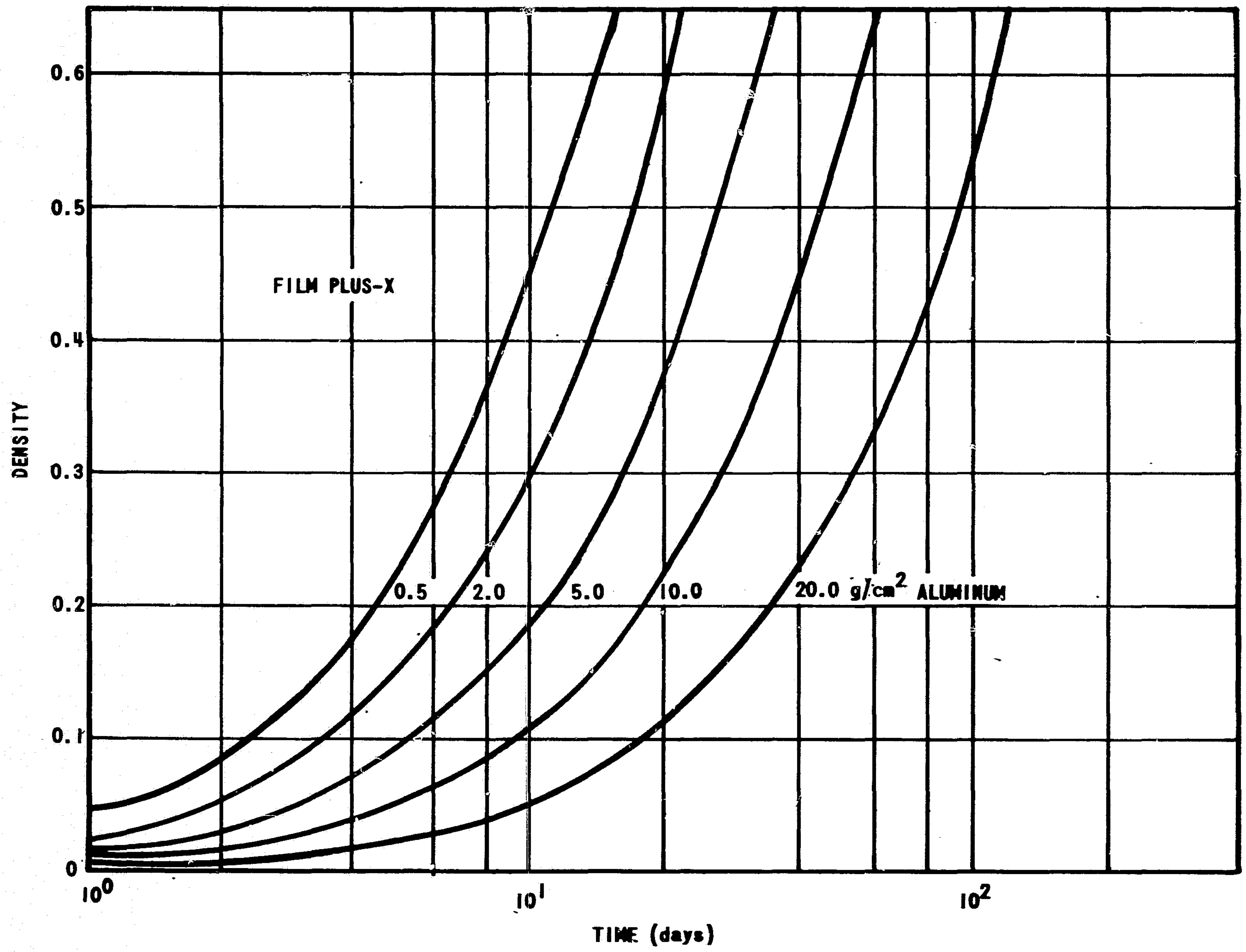

FIGURE 3. FILM DENSITY VERSUS TIME IN ORBIT FOR THE FILM PLUS-X

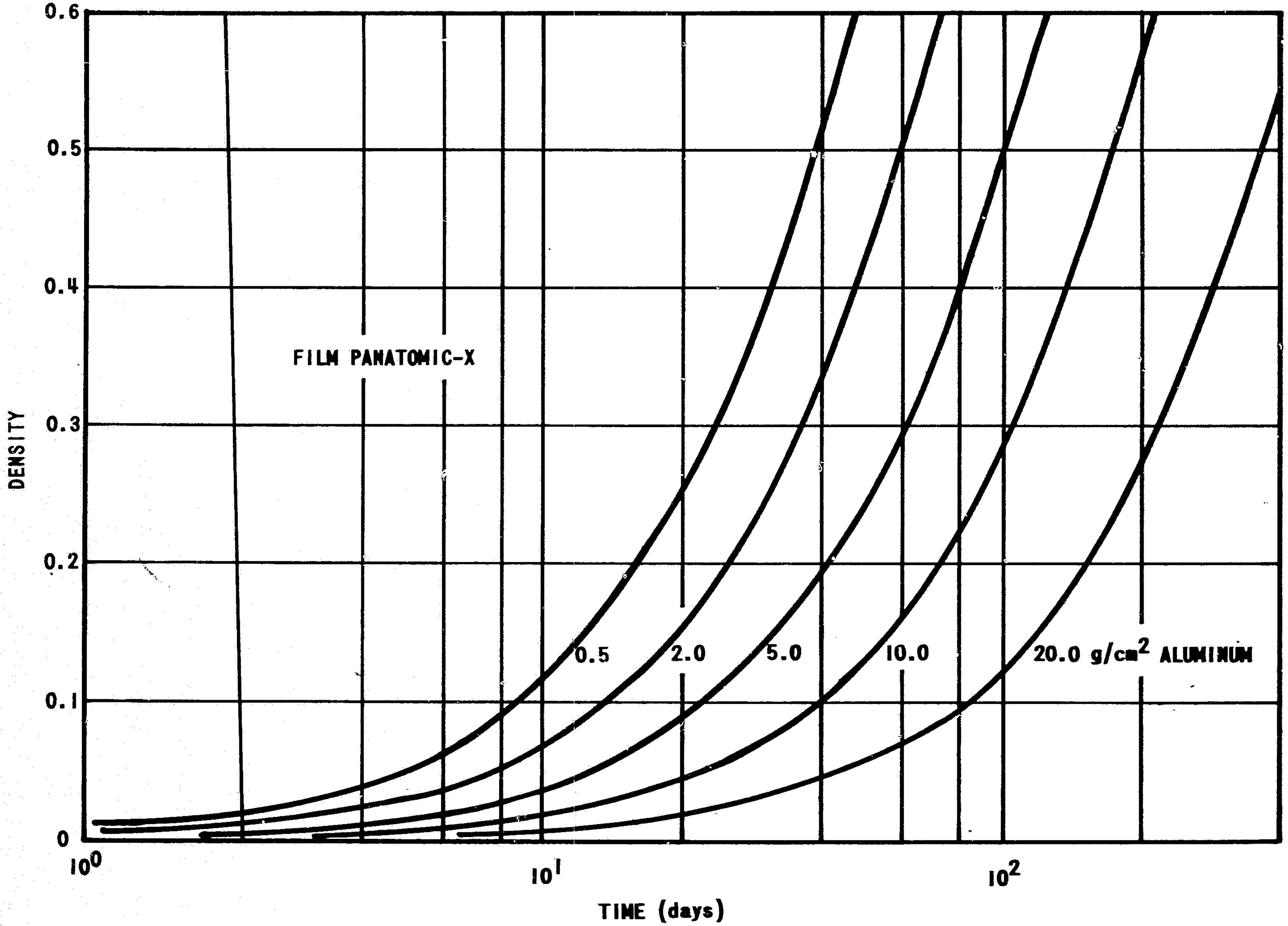

FIGURE 4. FILM DENSITY VERSUS TIME IN ORBIT FOR THE FILM PANATOMIC-X

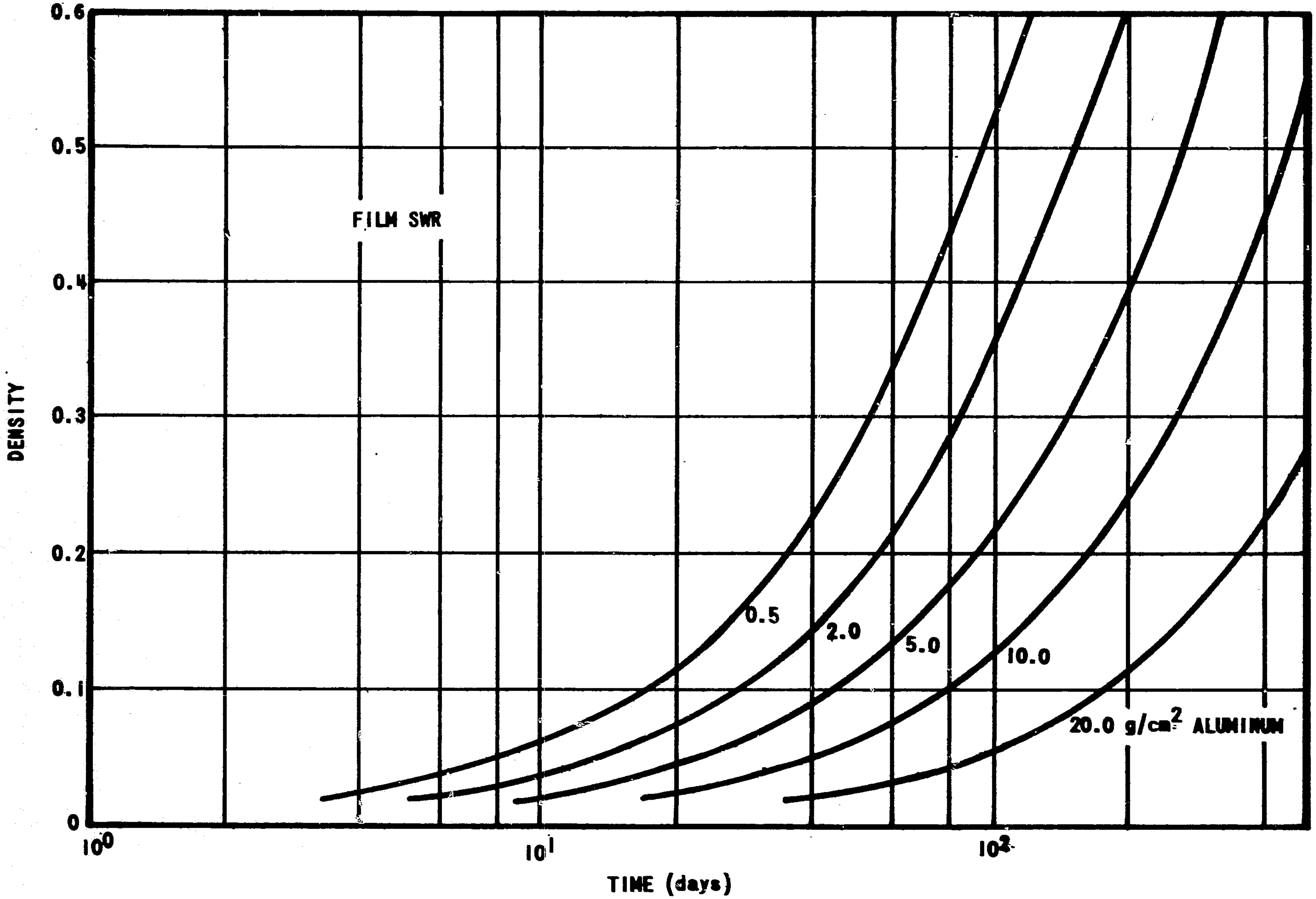

FIGURE 5. FILM DENSITY VERSUS TIME IN ORBIT FOR THE FILM SWR

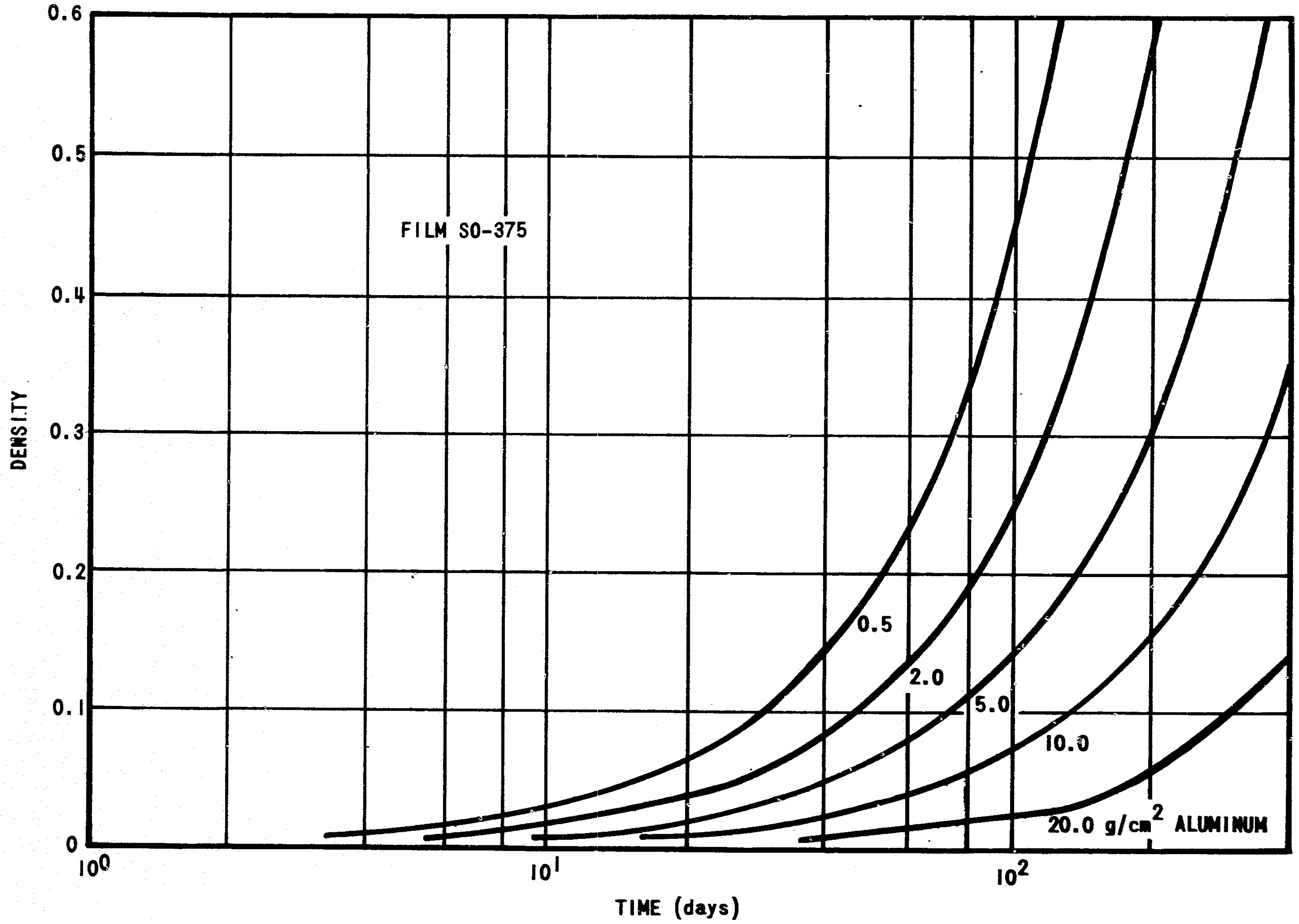

FIGURE 6. FILM DENSITY VERSUS TIME IN ORBIT FOR THE FILM SO-375

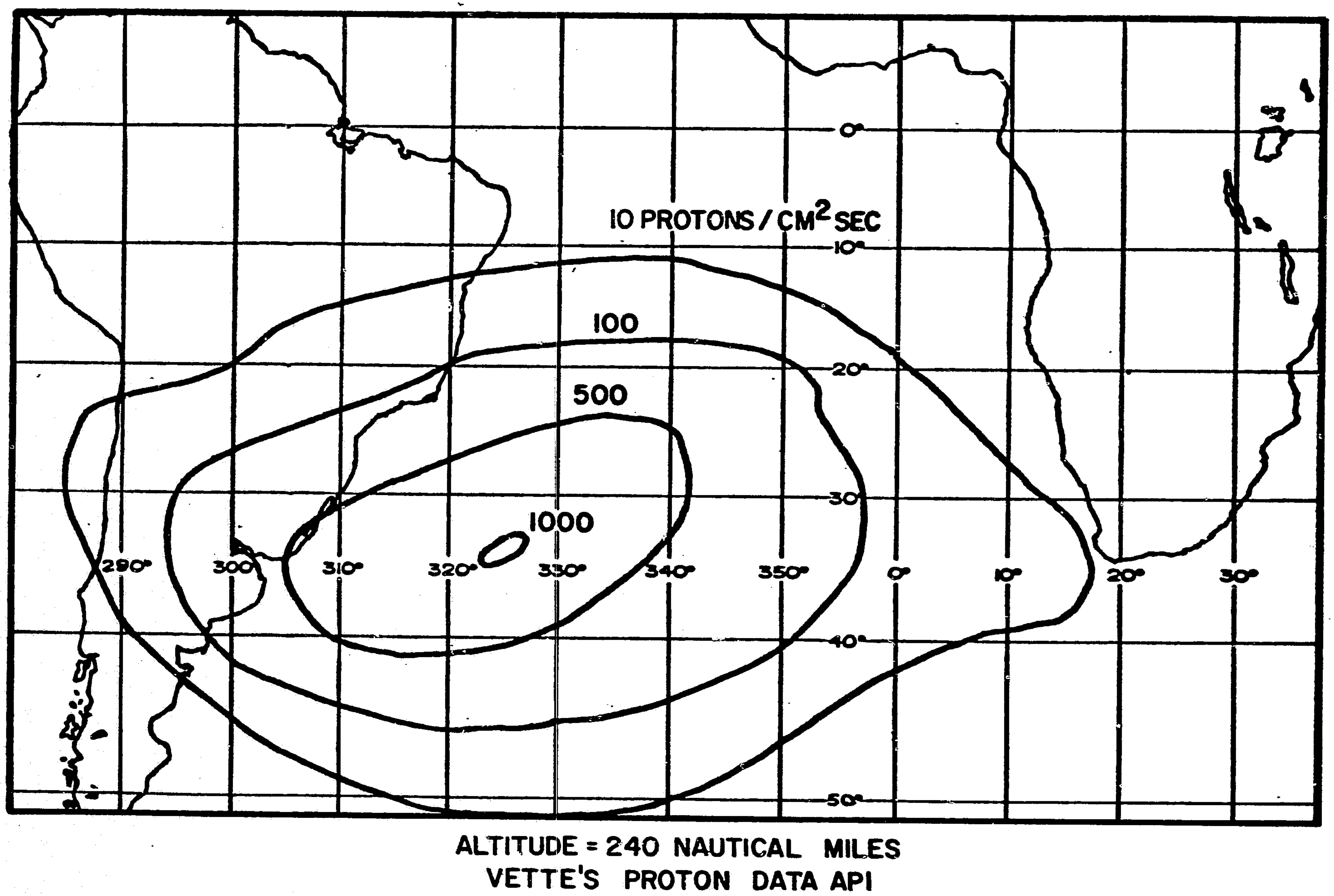

FIGURE 7. AN ISOFLUX PLOT FOR PROTONS WITH ENERGIES GREATER THAN 34 MeV IN THE SOUTH ATLANTIC ANOMALY AT AN ALTITUDE OF 240 NAUTICAL MILES (444 km)

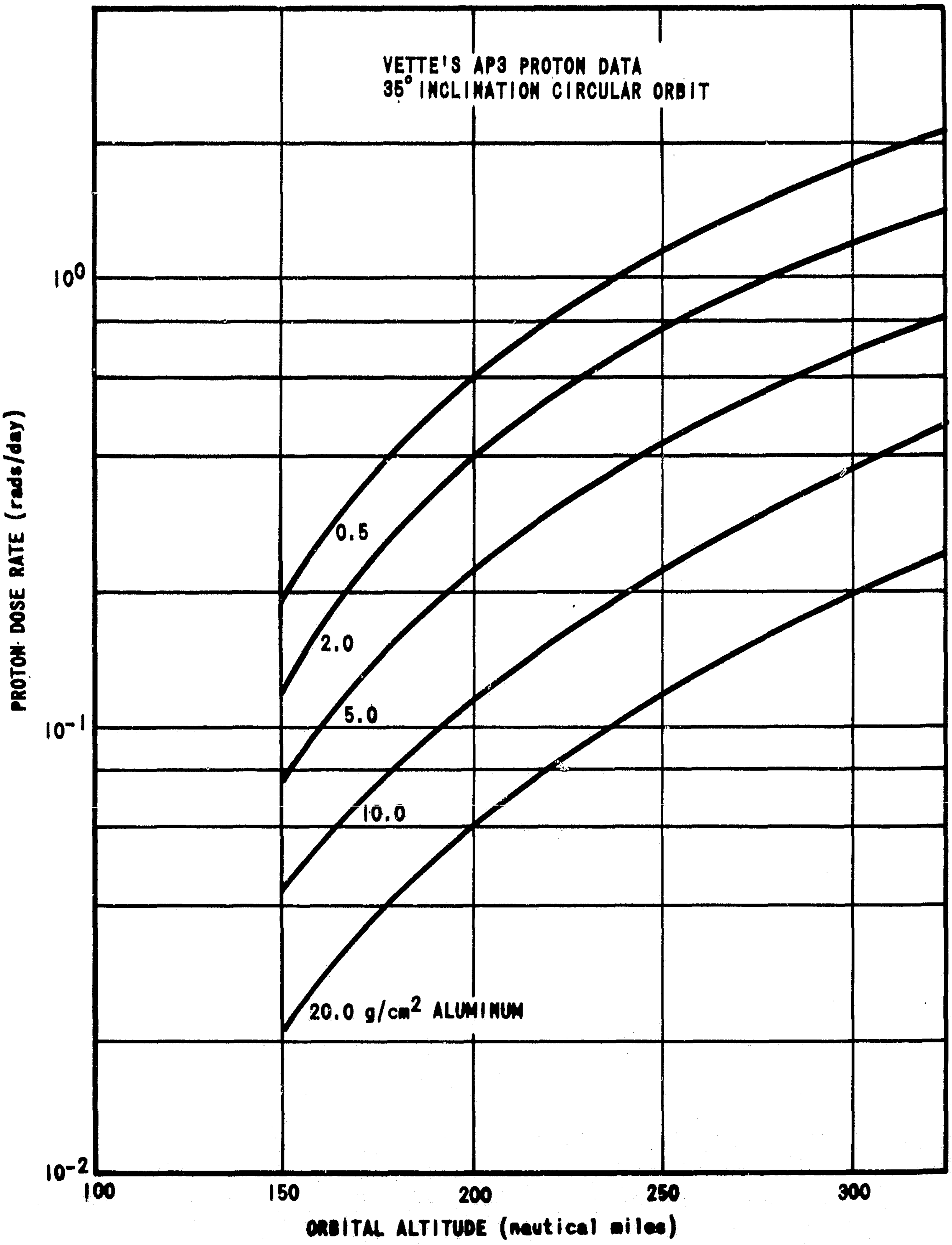

FIGURE 8. PROTON DOSE VERSUS ALTITUDE FOR VARIOUS SHIELD THICKNESSES AT 35° ORBITAL INCLINATION

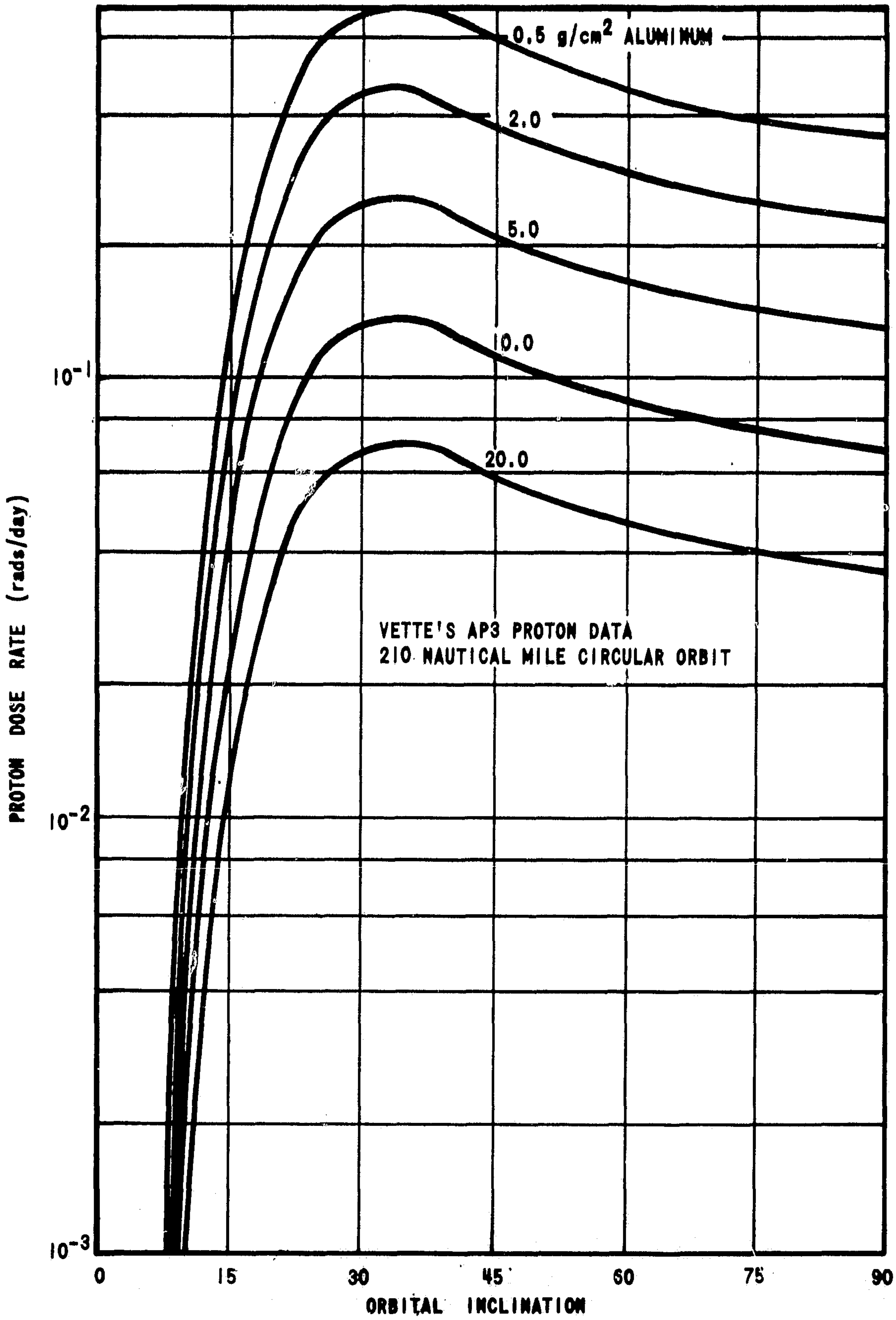

FIGURE 9. PROTON DOSE VERSUS INCLINATION FOR VARIOUS SHIELD THICKNESSES AT 210 NAUTICAL MILES (389 km)

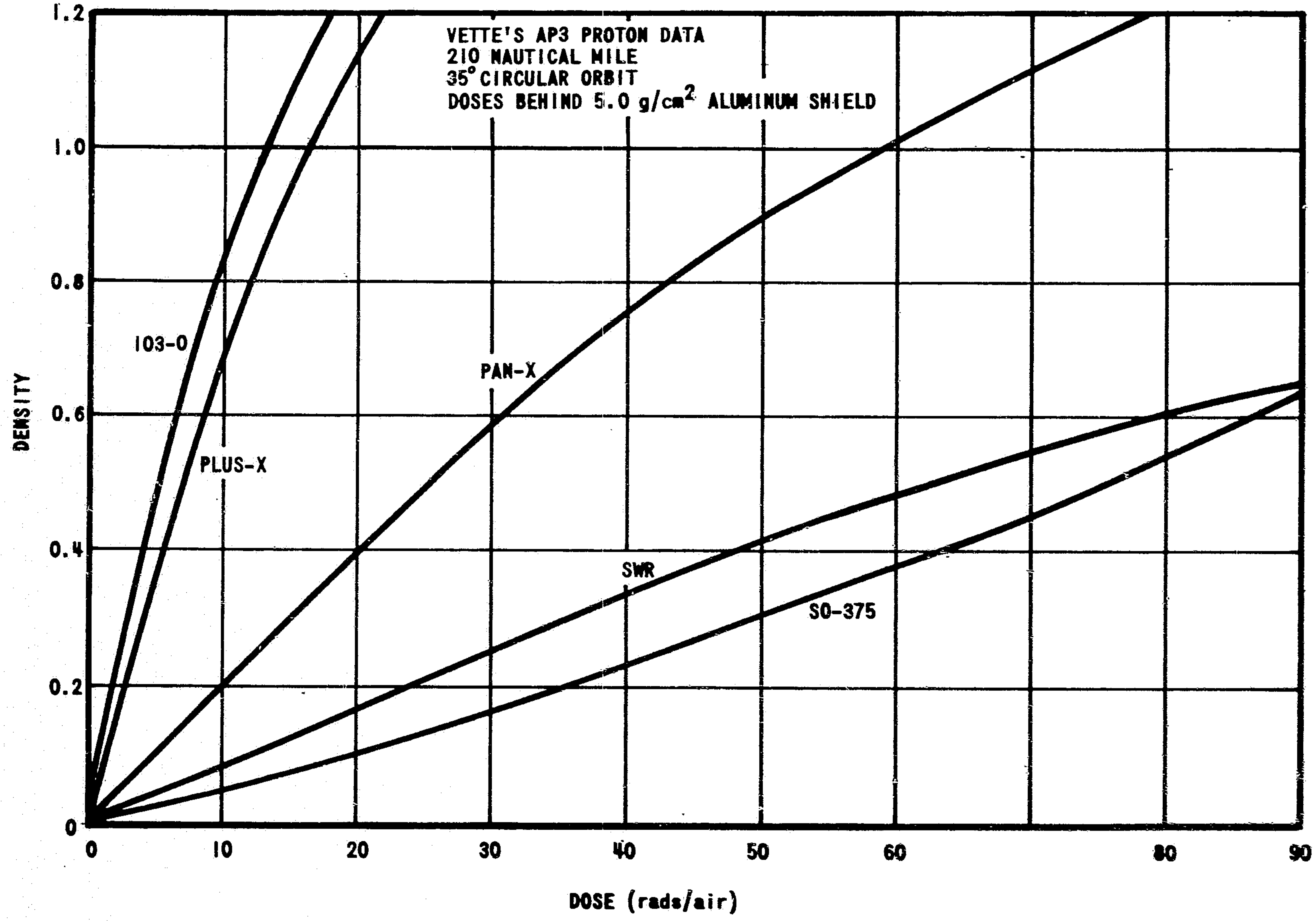

FIGURE 10. FILM DENSITY VERSUS PROTON DOSE IN RADS FOR THE FIVE FILMS WHERE THE FILM IS BEHIND 5.0 g/cm^2 OF ALUMINUM IN A 210 NAUTICAL MILE (389 km), 35° INCLINATION, CIRCULAR ORBIT

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