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MIDDLE ATMOSPHERE NO_x PRODUCTION DUE TO ION PROPULSION INDUCED RADIATION BELT PROTON PRECIPITATION

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Abstract—The suggestion that KeV Ar^+ resulting from ion propulsion operations during solar power satellite construction could cause energetic proton precipitation from the inner radiation belt is examined to determine if such precipitation could cause significant increases in middle atmosphere nitric oxide concentrations thereby adversely affecting stratospheric ozone. It is found that the initial production rate of NO (mole/cm³ sec) at 50 km is 130 times that due to nitrous oxide reacting with excited oxygen. However, since the time required to empty the inner belt of protons is about 1 second and short compared to the replenishment time due to neutron decay, precipitation of inner radiation belt protons will have no adverse atmospheric environmental effect.

Ion propulsion has been suggested as a means of transporting large space structures constructed in low Earth orbit to geosynchronous orbit. Such a propulsion system might utilize argon, producing a beam of 5 keV Ar^+ (1). Another study (2) suggests that such an Ar^+ beam could induce plasma turbulence causing precipitation of the Mev protons contained in the inner radiation belt. Protons of similar energy are produced during large solar flares. When these protons precipitate into the middle atmosphere at high geomagnetic latitudes, ionization occurs in the 30 to 100 km altitude range (3,4). One of the results of such ionization is the production of nitric oxide, which at altitudes below 50 km influences the distribution of ozone. In this paper NO production due to dumping of inner radiation belt protons by ion propulsion operations is compared with natural sources of nitric oxide in order to assess the influence of ion propulsion operations involved in the construction of the solar power satellite on the terrestrial NO budget and its possible consequences for stratospheric ozone.

The flux of protons within the inner radiation belt can be represented by

$$F(E) = F_0 e^{-E/E_0}\ \mathrm{cm^{-2}sec^{-1}MeV^{-1}} \tag{1}$$

with $F_0 = 2.5 \times 10^6$ and $E_0 = 6.1$ MeV for energies less than 30 MeV and with $F_0 = 2.1 \times 10^2$ and $E_0 = 98$ MeV for energies greater than 30 MeV using data given in (5). Following the energy degradation scheme for protons in the atmosphere developed by (6) we degrade the spectrum given in equation (1) and compute the ionization rate. The rate of ionization is approximately equal to the production of NO molecules (7,8). The production rate of 1.25 NO molecules per ion pair recommended in Ref. (6) is adopted. The resulting NO production rate as a function of altitude is displayed in Figure 1 for a time of 1 second.

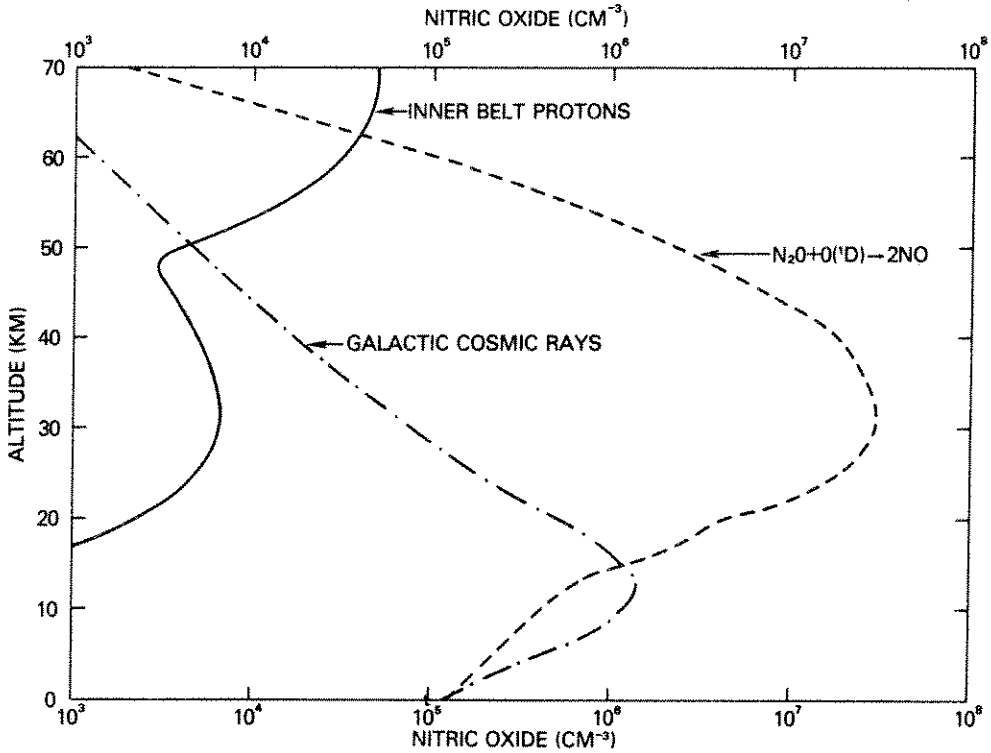

Fig. 1. NO production rates from three sources: 1) Solid line—NO production per second from the IBPs, 2) Dashed line—NO production per day from oxidation of nitrous oxide, 3) Dash-dot line—NO production per day from galactic cosmic rays.

For comparison purposes this NO production rate is shown with production due to galactic cosmic radiation and nitrous oxide destruction; the natural sources which are considered to account for most of the middle and lower atmosphere NO production. Galactic cosmic ray production follows that derived in Ref. (8). This source has its minimum production at the geomagnetic equator. Nitrous oxide is produced largely by biological activity and is transported to the stratosphere, where it interacts with excited atomic oxygen produced by photodissociation of ozone, water, and nitrous oxide. The governing reaction is

$$O(^1D) + N_2O \rightarrow 2NO \tag{2}$$

The result of the calculations which are made for the region where the geomagnetic and geographic equators coincide is given in daily production rates in Figure 1.

A critical factor in the problem is the duration of the proton precipitation. During SPS construction 90 days of ion propulsion are required to move from low to geosynchronous orbit. While it thus appears that proton precipitation would be a near-permanent feature at equatorial latitudes, in fact the time is determined by the inner radiation belt flux and population. Protons in the inner belt are produced mostly from the decay of neutrons of cosmic ray origin. Secondary sources include nuclear reactions involving collisions between protons and atmospheric gas atoms. Typical times to produce the present proton population are hundreds of years (9).

The time, T, to empty the inner belt of protons is

$$T = N/p \text{ seconds} \tag{3}$$

Here N is the total number of protons between magnetospheric shell $L=1$ and 2.

$$N = n\ V \text{ protons} \tag{4}$$

where

$$n = \int_0^\infty \frac{F(E)dE}{v(E)} \text{cm}^{-3} \tag{5}$$

is the number of protons cm^{-3} at any energy, E, with velocity $v(E)$. The volume, V, between $L = 1$ and $L = 2$ is 3.1×10^{27} cm^3 (9). Solution of equation (5) gives $n = 6.6 \times 10^{-4}$ cm^{-3} so that $N = 2.0 \times 10^{24}$ protons for the total proton population of the inner radiation belt. The total number of protons precipitated per second is given in equation (3) as p and can be expressed as

$$p = F_T A \text{ second}^{-1} \tag{6}$$

The total flux $F_T = F_o E_o \text{cm}^{-2}\text{sec}^{-1}$ and the area into which protons are precipitated is $A = 8 \times 10^{17}$ cm^2 representing 16% of the global surface area. Therefore, p is 2.0×10^{24} protons sec^{-1}. Substitution of these values for p and N into equation (3) gives the time T required to empty the inner radiation belt of protons as about 1 second.

In comparison with the hundreds of years required to replenish the belt through neutron decay the time to precipitate is very small indeed. Hence ion propulsion operations will empty the inner radiation belt in a short time producing an amount of NO which is much less than the normal production per day due to cosmic rays and nitrous oxide as demonstrated in Fig. 1. Once empty the radiation belts will be unable to refill fast enough to maintain the initial proton precipitation rate. As far as NO production in the middle atmosphere and its possible consequences for ozone are concerned, proton precipitation by ion propulsion does not pose any hazard.

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REFERENCES

1. G. Hanley and C.H. Guttman, *Satellite Power Systems Concept Definition Study: Final Report Executive Summary*, Vol. I, Rockwell International, April 1978.
2. S.A. Curtis and J.M. Grebowsky, Changes in the terrestrial atmosphere-ionosphere-magnetosphere system due to ion propulsion for solar power satellite placement, submitted to *Space Solar Power Review*.
3. P.J. Crutzen, I.S.A. Isaksen and G.C. Reid, Solar proton events: Stratospheric sources of nitric oxide, *Science*, **189**, 457, 1975.
4. J.E. Frederick, Solar corpuscular emission and natural chemistry in the earth's middle atmosphere, *J. Geophys. Res.*, **81**, 3179, 1976.
5. J.I. Vette, Trapped radiation population, in *The Trapped Radiation Handbook*, J.B. Cladis, G.T. Davidson and L.L. Newkirk, Eds. Lockheed Palo Alto Research Laboratory, Palo Alto, CA, January 1977.
6. C.H. Jackman, J.E. Frederick and R.S. Stolarski, Production of odd nitrogen in the middle atmosphere: an intercomparison of source strengths, submitted to *J. Geophys. Res.*, 1980.
7. P. Warneck, Cosmic radiation as a source of odd nitrogen in the stratosphere, *J. Geophys. Res.*, **77**, 6589, 1972.
8. M. Nicolet, On the production of nitric oxide by cosmic rays in the mesosphere and stratosphere, *Planet. Space Sci.*, **23**, 637, 1975.
9. W.N. Hess, *The Radiation Belt and Magnetosphere*, Blaisdell Publishing Company, Waltham, MA, 1968.