Inner Radiation Belt Generation of Light Nuclei Isotope

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Abstract

Nuclear interactions between inner zone protons and atoms in the upper atmosphere provide the essential source of H and He isotopes nuclei in radiation belt. This paper reports the calculations of these isotopes intensities from the inner zone proton intensity model AP-8, the atmosphere drift-averaged composition and densities model MSIS-90, and cross sections for the various interaction processes. To calculate drift-averaged densities and energy losses of secondaries the particles are traced in geomagnetic field according IGRF-95 model by numerical solution of motion equation. The calculations account for nuclear interactions kinematic along the whole trapped protons trajectories. The results of calculations are compared with experimental data from SAMPEX, CRRES, RESURS-04 and MITA satellites taken during different solar activity phases. The comparison with observational data shows that the atmosphere is sufficient source for inner zone ^{4}He, ^{3}He,^{2}H and ^{3}H for L-shell less than 1.3.

1. Introduction

As it is well known protons present the main inner radiation belt component. Trapped protons nuclear interactions with the upper atmosphere atoms form the secondary nuclei of H and He isotopes. If pitch angle of generated particle lies outside the loss cone on the given geomagnetic shell this particle becomes trapped. This paper reports the calculations of directional intensities of secondary light nuclei isotope from the inner zone proton intensity obtained out of empirical model AP-8, the atmosphere drift-averaged composition and densities received out of dynamic atmosphere model MSIS-90, and double differential cross sections for the various interaction processes.

2. Method of Calculations

For L-shell less than 1.3 the atmospheric production of energetic secondary nuclei is balanced only by ionization energy loss in the atmosphere, as since radial diffusion is inessential at this region [4]. The intensity j of generated particles satisfies a continuity equation [3]:

pp. 4257–4260

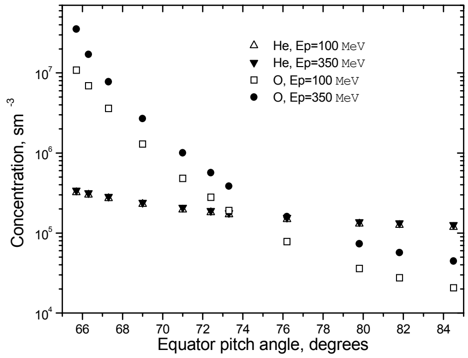

Fig. 1. The density.

$$\frac{1}{\nu}\frac{\partial j}{\partial t} = S + \frac{\partial}{\partial E}(j\times \mid \frac{dE}{dx} \mid) \tag{1}$$

where ν -is the nonrelativistic particle speed at time t and kinetic energy E; the production rate is S. If is interpreted as the solar cycle average value or if the particle lifetimes are short compared to the 11-year solar cycle the solution is [5]:

$$j = \frac{1}{\mid \frac{dE}{dx} \mid} \times \int_{E}^{\infty} SdE \tag{2}$$

During the longitude drift trapped proton performs great number of oscillations or bounces between mirror points. Therefore, if the drift averaged atmospheric density n_i of given type target atoms is known as function of trapped particle guide center location along field line, then the expression for production rate of secondary nuclei can be writing in the following way:

$$S(E,\alpha,L) = \int dt \sum_i \int dE_p \int d\Omega_p(x(t)) n_i(x(t)) \times j_p \times \frac{d^2\sigma_i}{d\Omega dE} / \int dt \tag{3}$$

The first integral covers the time interval $[t_m, t'_m]$ over which the guide center of trapped proton performs one oscillation between mirror points x_m and x'_m . The summation extends over all interactions that lead to a given type of secondary particle and the following integrals cover the range of proton energies E_p and solid angle $d\Omega_p$ that kinematically can produce secondaries with energy E , equatorial pitch angle α in a solid angle $d\Omega_{eq}$ and at given $L - shell$. The proton intensity is j_p , and the cross section for interaction i is σ_i. As since there are essential longitude variation of the trapped particle oscillation period and oscillation amplitude it is more convenient to define the position of trapped proton guide center along the magnetic field line using the value of local pitch

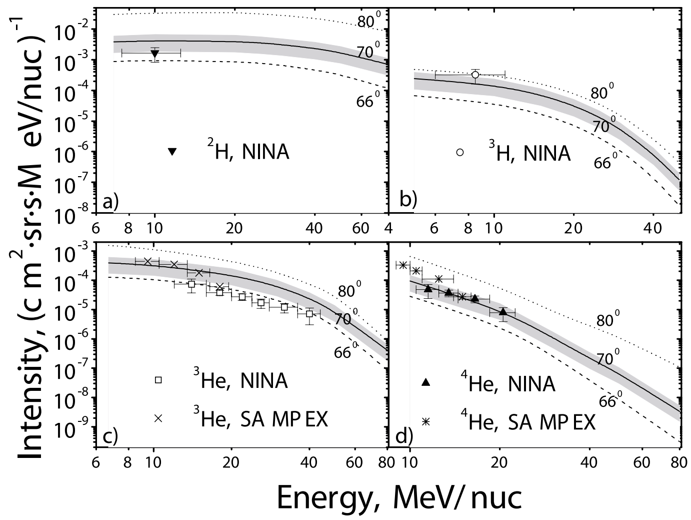

Fig. 2. The differential energy spectra of H,He isotopes.

angle. Then the expression for secondary particles production rate becomes:

$$S(E, \alpha, L) = \sum_k \sum_i \int dE_p \int d\Omega_p^k < n_i >_k \times j_p \times (d^2\sigma_i/d\Omega dE) \quad (4)$$

. The first sum covers various intervals k of guide center trajectory between the mirror points. Each interval is defined by range of local proton pitch angles a'_p corresponding to fixed proton equatorial pitch angle a_p. By this the calculations account for nuclear interaction kinematics along the whole trajectory of trapped proton guide centre between the mirror points. This allows correctly take into account the generation of secondary particles nearby the mirror points where the atmosphere density is more larger. Drift-averaged density of atmosphere component i at given trajectory region k is:

$$< n_i >_k = \int_{t_k} n_i(\alpha'_p(t))dt / \int_{t_{dr}} dt \quad (5)$$

where t_k - drift time at given proton trajectory region k; t_{dr} - time of total longitude proton drift.

To calculate drift-averaged densities of different atmosphere components the protons were traced in geomagnetic field according IGRF-95 model by numerical solution of motion equation. Atmospheric densities were defined from dynamic atmosphere model MSIS-90. Similarly, to define the average energy losses of secondary nuclei they trajectories in the geomagnetic field were modelled.

3. Results

For $L - shell$ less than 1.3 atmosphere hydrogen, helium and oxygen give main contribution to drift-averaged densities. Fig.1 shows the dependence of the

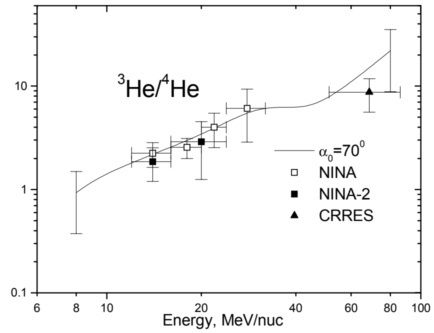

Fig. 3. The ratio of He isotopes calculated for He atmospheric target at $L-shell$ 1.2.

atmospheric helium and oxygen densities averaged over the drift path of protons with energies 100 and 350 MeV and over the local time versus equator proton pitch angle at L=1.2. Drift-averaged densities were calculated for value of solar 10.7-cm flux F10.7=137.5 and for the magnetic index Ap=4. Calculated intensities for trapped nuclei: ^{2}H (a), ^{3}H (b), ^{3}He (c), ^{4}He (d) generated on atmospheric helium and oxygen targets are shown in Fig.2 together with experimental data [1, 5] for different pith angles. The middle curve complies with the measured average pitch angle of NINA experiment [1]. Grey area shows the accuracy of calculation for this curve, which mainly defined by uncertainties in double differential cross-sections of proton interaction with oxygen target. Calculated helium isotope ratios from atmospheric helium target are presented in Fig. 3. Experimental data are taken from works [1,2,5]. Vertical bars mark the calculation accuracy.

4. Conclusion

The results of calculations and comparisons with experiments shows that the atmosphere is sufficient source for inner zone energetic light isotopes ^{4}He, ^{3}He, ^{3}H and ^{2}H.

5. References

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