WHEN DID THE AVERAGE COSMIC RAY FLUX INCREASE?

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Abstract

We developed a new ^{129}I-^{129}Xe method to obtain cosmic ray exposure ages and to study the average cosmic ray flux on a 10^7-10^8 year time-scale. The method is based on secondary neutron reactions on Te in troilite and the subsequent decay of ^{129}I, the reaction product to stable ^{129}Xe. We report the first measurements of ^{129}I and ^{129}Xe in aliquot samples of a Cape York troilite sample.

Introduction

Several investigations were carried out regarding possible variations of cosmic ray intensity in the past. Cosmic ray produced ^{14}C in trees provides one of the most reliable records for the cosmic ray intensity in the past 10^4 years in spite of some uncertainties in the carbon cycle and/or past geomagnetic field variation [eg. 1]. For longer periods ^{10}Be ($t_{1/2}$ = 1.6x10^6 years) and/or ^{36}Cl (3.0x10^5 years) concentrations in ice cores or deep sea sediment cores may provide additional information on the cosmic ray flux in the past. However, there are many uncertainties in past climates, in precipitation and sedimentation rates, in geomagnetic fields, because the terrestrial environment is rather complex. On the other hand, the study of cosmogenic radionuclides in extraterrestrial matter provides key information for the history of cosmic rays. Kohl et al (1978) found that the average solar cosmic ray (SCR) flux changed relatively little over the last 1-10 million years, based on a study of cosmogenic ^{53}Mn ($t_{1/2}$ = 3.7x10^6 years) and ^{26}Al (7.05x10^5 years) in several lunar rocks [2]. The average SCR flux during the last few million years was similar to that measured during the last few decades by detectors on satellites. However, ^{14}C ($t_{1/2}$ = 5740 years) [3] and ^{81}Kr (2.1x10^5 years) [4] activities in lunar samples indicate that the average SCR flux during the last 10^4 - 10^5 years was somewhat higher than the recent average flux. Very useful records on the galactic cosmic ray (GCR) flux were observed in meteoritic detectors. Nishiizumi et al (1980) carried out systematic studies on cosmogenic nuclides of various half-lives such as ^{22}Na ($t_{1/2}$ = 2.6 years), ^{81}Kr, ^{26}Al, and ^{53}Mn in chondrites as a test for possible variation of the GCR flux during the last ~10 million years [5]. All sets of nuclides, with the possible exception of ^{26}Al indicate that the averaged GCR flux was constant within ~15%, at least during the last 5 million years. More recently, Moniot et al (1983) confirmed this result using ^{10}Be as the monitor [6]. On the other hand, the records of spallation K and Ar observed in iron meteorites reflect ~33% smaller average GCR fluxes on the 10^8-10^9 year timescale [7, 8]. This suggests a cosmic ray flux increase $\lesssim$2x10^8 years ago.

^{129}I-^{129}Xe Method:

An investigation for possible intensity changes of GCR flux between 10^7 and 10^8 years is required. The half-life of ^{129}I (1.57×10^7 years) makes this an appropriate nuclide for such a study. The ^{129}I in extraterrestrial materials is produced by cosmic ray secondary neutron reactions on Te, $^{130}Te\ (n,2n,\beta)\ ^{129}I$ and $^{128}Te\ (n,\gamma\ \beta)^{129}I$, and by high energy spallation reactions on Ba and the Rare Earth elements. Troilite inclusions in iron meteorites are ideal monitors among extraterrestrial materials because of their long cosmic ray exposure ages (10^8 to 10^9 years) their relatively high Te contents (~ ppm) and their low abundances of Ba and Rare Earth elements. The ^{129}I decays to stable ^{129}Xe. ^{129}Xe is not directly produced by cosmic ray secondary neutrons, yielding a fractional isobaric production ratio $P(^{129}I)/P(^{129}I + ^{129}Xe) \sim 1$ [9]. The simultaneous determination of cosmogenic ^{129}I and ^{129}Xe in the same troilite phase is the basic concept of the new method of determining ^{129}I-^{129}Xe exposure ages. This exposure age can be obtained without any shielding and target element corrections for a constant exposure geometry. The exposure age T can be calculated from the equation:

$$\frac{\lambda_{129}T - 1 + e^{-\lambda_{129}T}}{1 - e^{-\lambda_{129}T}} = \frac{^{129}Xe_{Te}}{^{129}I_{Te}}$$

where λ^{129} is decay constant of ^{129}I, $^{129}I_{Te}$ is ^{129}I content (atom/sample), and $^{129}Xe_{Te}$ is cosmogenic ^{129}Xe content (atom/sample) produced from Te after subtraction of other components. The comparison of ^{129}I-^{129}Xe exposure ages and with those obtained by methods such as ^{40}K-^{41}K [7], ^{26}Al-^{21}Ne, and ^{36}Cl-^{36}Ar could indicate either a complex exposure history of the meteorite or a change in cosmic ray flux intensity. We developed the experimental techniques and measured both ^{129}I and ^{129}Xe in the same troilite sample of the large Cape York iron meteorite. The ^{129}I measurement was carried out by accelerator mass spectrometry using the University of Rochester MP tandem van de Graaff accelerator [see 10], while the ^{129}Xe measurement was performed by static mass spectrometry.

Discussion:

The Cape York iron meteorite contains $(8.3 \pm 1.3) \times 10^6$ atoms ^{129}I/g troilite and $(2.6 \pm 0.3) \times 10^7$ atoms $^{129}Xe_{Te}$/g troilite. The ^{129}I-^{129}Xe exposure age of Cape York is calculated from the above equation as T = 93 ± 18 million years. This is the first determination of a cosmic ray exposure age of Cape York. The inferred Ar production rate $P(^{38}Ar) \sim 200$ atoms/g Fe x year [11] is one order of magnitude smaller than that corresponding to the most shielded location for which $P(^{38}Ar)$ data are available. This result documents (a) the extremely heavily shielded location of our sample and (b) that secondary cosmic ray neutrons are very useful in unravelling exposure histories and geometries. The Cape York results, however, do not allow an evaluation of the average cosmic ray flux over the 93 million year exposure period, since no other information on the exposure age is available. Therefore, we are now applying the $^{129}I-^{129}Xe$ dating method to meteorites for which independent exposure age information is either available, or can be obtained.

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