High performance particle detection system for trans iron isotopes in galactic cosmic rays

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Abstract. The isotope identification with the solid-state track detector (SSTD) newly developed for the observation of heavy cosmic ray particles was performed using $^{56}\text{Fe}$ and $^{55}\text{Fe}$ ions with 460 MeV/nucleon. Mass resolution for iron isotope was thus improved to $\sim 0.20$ amu in rms. The high speed automatic system of microscope analyzer was also developed to scan and analyze tracks formed by heavy ions in SSTD. The combination of isotope telescope consisting of SSTD with the high speed scanning system enables us to realize a large-scaled observation for trans-iron galactic cosmic rays (GCRs).

1. Introduction
Observation of nuclear components consisting of stable and radioactive isotopes with various half-lives in ultra-heavy (UH) cosmic rays gives crucial constraints on the source of GCRs, the stellar nucleosynthesis, the chemical history of Galactic material, and offers new possibilities for the study of the acceleration and propagation mechanisms of charged particles in space [1]. Although UH elemental composition has been observed by previous experiments [2, 3, 4] and recent TIGER experiment [5], their isotopes have not been observed yet because of the difficulty of identification and the extremely low flux in GCRs. Thus SSTD with high mass resolution was newly developed to meet the requirement for UH isotopes observation of GCRs.

2. Development of heavy ion detection system
SSTD such as CR-39 plastic detector is very promising for the large-scale observation of UH-GCRs in space, because it is easy to realize a low-cost large detector array. In the case of SSTD,
we use the relation of $L$ values and $R$ values to identify the mass of an ion, where $L$ denotes the cone-length of the etch-pit which is a function of $dE/dx$, and $R$ is the residual range of an ion. The mass identification of an ion can be achieved by using the so-called "$L$-$R$ pairs" [6] by tracing its trajectory. Using heavy ion beam from NIRS-HIMAC, we have already verified the capability of a CR-39 plastic detector for isotope identification. As a result, we obtained a good mass resolution for iron nuclei in CR-39 of 0.28 amu in rms and found that the mass resolution is expected to be improved to $\sim 0.20$ amu by eliminating some errors as much as possible [7]. CR-39 plastic detector allows us to identify adjacent isotopes for $Z \geq 30$.

The handling of SSTD has been historically required for a long period and many human powers to scan and analyze etch-pits produced on the detector. Moreover, since a large area greater than a few m$^2$ for GCR detector is required to observe UH isotopes in GCRs, a high speed scanning system is practically important to realize the observation. For this reason, we have developed the fast automated digital imaging optical microscope (HSP-1000) to scan and analyze the etch-pit produced on the detector, whose image acquisition speed is 50-100 times faster than conventional microscope system [8]. Furthermore, new technique to measure the cone-length of etch-pit with high accuracy as well as the diameter of etch-pit mouth, which is essential to clearly separate the adjacent isotopes, is now under development in the new three-dimensional scanning system for measuring the cone-length with high accuracy.

3. Concluding remarks

The study of UH-GCR isotopic composition is thought as the most important theme as next step after the ACE measurement of light isotopes, since no data of isotopic abundances in the UH regions are now available. Isotopic abundance is less biased as for the chemical fractionation, which leads us to bring a preferred probe to study the origin. Trans-iron nuclei are produced by the process different from thees below iron-group. Pure $s$, $r$, $p$-process isotopes such as $^{96}$Mo, $^{100}$Mo, $^{92}$Mo will thus be useful for understanding of the origin of GCRs. In particular, the separation between pure $r$ and $p$-process isotopes for $Z \geq 30$ are relatively easy because abundant isotopes are separated by two atomic mass units.

Definitive measurements will be obtained from super-pressure balloon experiments over Antarctica, whose advantages are the long duration flight of $\sim$ a few months or more, a relatively small variation of residual air thickness and a stability of high altitude without ballast. The statistics of $\sim 15,000$ for even-$Z$ nuclei with the energy below 1 GeV/n at the top of atmosphere is expected in a 60-day of a 4 m$^2$ detector. A large-scaled telescope with the new SSTDs for the Antarctica balloon allows us to make first measurement of the isotopic abundances of UH-GCRs with a good mass resolution for $Z \geq 30$ with the energy above 100 MeV/n, which will determine the contribution of $r$-process material in GCRs.

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