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New Results on the Relative Abundance of Actinides in the Cosmic Radiation

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ABSTRACT

The DIAS-ESTEC Ultra Heavy Cosmic Ray Experiment (UHCRE) on the Long Duration Exposure Facility (LDEF), collected approximately 3000 cosmic ray nuclei with Z>65 in the energy region E>1.5 GeV/nucleon during a six year exposure period in Earth orbit. Most (97%) of the accessible collecting area of the solid state nuclear track detector array has now been scanned, yielding a sample of 30 actinides (from an exposure of ≈ 150 m^2 sr yr). The charge frequency distribution for Z>70 is presented. The current best value for the cosmic ray actinide relative abundance (Z≥88)/(74≤Z≤87) is reported and discussed in relation to current theories of cosmic ray origin.

INTRODUCTION

The Ultra Heavy Cosmic Ray Experiment (UHCRE) was exposed in earth orbit aboard the NASA Long Duration Exposure Facility (LDEF) for approximately 69 months to investigate the charge spectrum of cosmic ray nuclei with Z>70. This region of the charge spectrum is relatively unexplored due to the poor statistics available (e.g. Drury and Keane, 1995). The experiment employed an array of thick (≈5.6g cm^{-2}) solid state nuclear track detector stacks, mainly polycarbonate, with a collecting area of $10m^2$. Details of experiment design, detector composition and processing may be found elsewhere (Thompson *et al*, 1993; Keane *et al*, 1997). The objective of the experiment is to gain insight into the origin and propagation of the ultra-heavy cosmic rays by searching for signals of nucleosynthesis processes in the relative abundance of elements within various charge groups (Thompson *et al*, 1993; O'Sullivan *et al*, 1995; Drury and Keane, 1995). Notably, the ratio of osmium, iridium and platinum (77≤Z≤79) to lead (Z=82) (predominantly r- and s-process elements respectively) and actinides to subactinides (Z>88)/(74≤Z≤87). Comparisons can then be made with a number of theoretical models and with the results of earlier experiments (Binns *et al*, 1989; Fowler *et al*, 1987). The UHCRE succeeded in collecting ≈ 3,000 nuclei with Z>65, including 30 actinides (Z≥88).

EXPERIMENTAL STATUS

A total of 919 ultra-heavy cosmic rays (Z>65) scanned from 36% of the accessible detector area (randomly selected) of UHCRE have been completely measured and analysed. Of these events, 760 - including 13 actinides - satisfied various selection criteria (including complete traversal of a detector stack, zenith angle <60° and Z>70). The scanned events from most of the remainder of the accessible detector area (up to 97%) were subjected to a further selection process (involving ionisation thresholds) designed to extract the upper end of the ultra-heavy charge spectrum. These events (≈80) were then fully measured and analysed bringing the total number of actinides up to 30 (derived from an exposure of ≈ 150 m^2 sr yr). The analysis for all events employed the REL ionisation model with ω_0 set to 1 KeV. In order to produce a unified charge frequency distribution, the subactinide events in the first 36% of the accessible detector collecting area were normalised to the remainder.

Figure 1 shows a charge frequency distribution of the Z>70 events, with an inset showing an enlargement of the histogram in the actinide region. This distribution has been corrected for the UHCRE geometry factor which increases with Z. The main point of interest in the present context is the high abundance around Thorium (Z=90) and Uranium (Z=92).

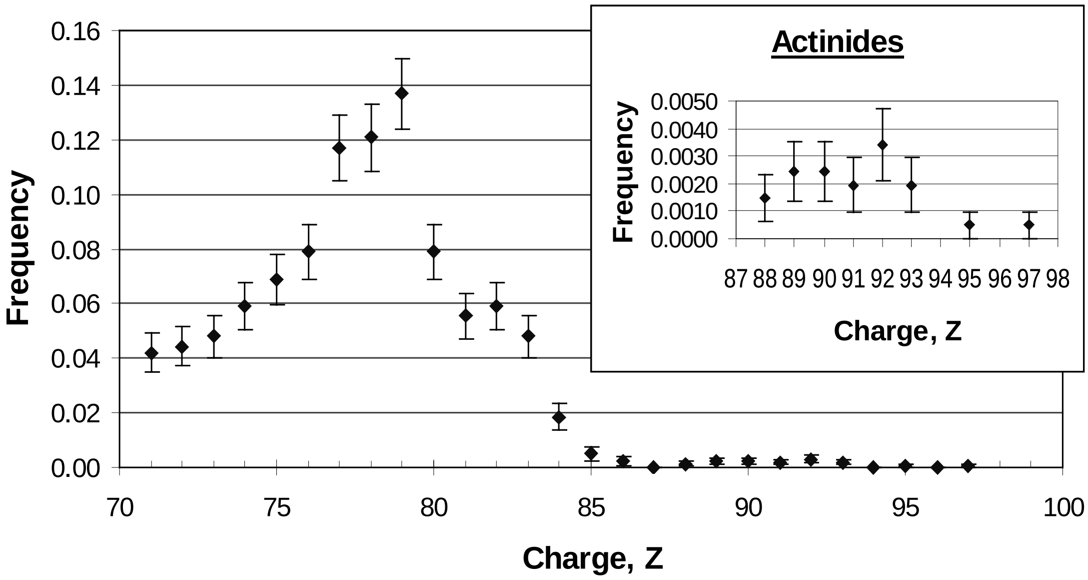

Figure 1 *Frequency distribution charge spectrum of Z>70 cosmic rays with an inset providing detail in the actinide region.*

DISCUSSION

Having applied the selection criteria and corrected for the variation in geometry factor, the actinide relative abundance [i.e. the actinide/subactinide ratio, (Z≥88)/(74≤Z≤87)] was found to be 0.0147 ± 0.0032/0.0027. As can be seen in figure 2, this value appears significantly greater than that of propagated present day solar system material (0.0077). However, it is fully consistent within statistical error with propagated primordial solar system material (0.013), as given by Brewster *et al* (1983).

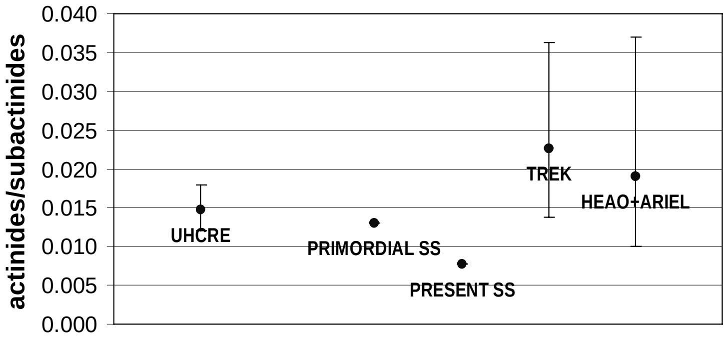

Figure 2 *Observed and derived actinide relative abundances (Z≥88)/(74≤Z≤87). The propagated primordial and propagated present day solar system (SS) values are from Brewster* et al *(1983). Statistical error bars on UHCRE and TREK correspond to 84% confidence limits (Gehrels, 1986).*

The agreement within statistical error of the actinide/subactinide ratio from TREK (Westphal *et al*, 1998) with that of UHCRE is also of interest, particularly since the former uses significantly different detector stacks. TREK, aboard the space station Mir, employed 150 stacks of BP-1 glass track-etch detectors, with a total collecting area of ≈1.2 m^2 array. One third of this array was exposed for 2.5 years and the remainder for 4.2 years. HEAO+ARIEL represents the combined result from two satellites (HEAO-3 and ARIEL-6) launched by NASA in 1979 (Binns *et al*, 1989 and Fowler *et al*, 1987 respectively).

The charge assignment error for the UHCRE events in the actinide region is estimated to vary from ±1.5e to ±2.5e approximately. The overall charge resolution of the actinides is expected to improve with the processing of further calibration ultra-heavy nuclei beams of known charge and energy in the detector plates containing actinide events in order to reduce systematic errors. It is anticipated that this will allow normalisation to the reference beam with a commensurate increase in charge resolution, sufficient to investigate the thorium/uranium ratio.

The fact that the UHCRE value for the actinide to subactinide ratio is fully consistent with standard primordial solar system abundances supports the view (Meyer *et al*, 1997; Ellison *et al*, 1997; Meyer *et al*, 1998; Drury *et al*, 1999) that the origin of the cosmic ray material is predominantly normal interstellar gas and dust. It is mildly inconsistent with an origin in dwarf star coronae (Shapiro, 1997) where one would expect significant decay of the actinides to have occurred (as in the sun) although if young flare stars are invoked as the injectors it may be possible to avoid this problem. It is not entirely clear what the alternative view, that the origin is to be sought in freshly synthesised supernova ejecta (Ramaty et al, 1997; Lingenfelter *et al* 1998), would imply for the actinide to subactinide ratio in view of the uncertainties in locating the site(s) of the r-process. However one can argue that, as the ratio is basically a ratio of r-process abundances (with the exception of lead), averaged over supernovae it must reproduce essentially the primordial solar system value. The more significant observation here would be the absolute flux of actinides and other r-process elements relative to the lighter elements, but this requires a careful consideration of propagation effects and goes beyond the scope of this paper. The main point to be made here is that, as at lower charges, the ultra-heavy composition appears essentially "normal" with no striking anomalies. The apparent lack of significant actinide decay constrains the source material to be relatively young in Galactic terms thereby providing an interesting complement to the K-capture bounds on the time between nucleosynthesis and acceleration.

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