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PROGRESS REPORT ON THE ULTRA HEAVY COSMIC RAY EXPERIMENT (A0178)

A. Thompson, D. O'Sullivan, J.Bosch and R. Keegan
Dublin Institute for Advanced Studies (DIAS), Ireland
Phone: +353-1-774321, Fax: +353-1-682003

K.-P. Wenzel and F. Jansen
Space Science Dept of ESA, ESTEC, Noordwijk, The Netherlands
Phone:+31-1719-83573, Fax: +31-1719-84698

C. Domingo
Universitat Autònoma de Barcelona, Spain
Phone:+34-3-581-1530, Fax: +34-3-581-2155

ABSTRACT

The Ultra Heavy Cosmic Ray Experiment (UHCRE) is based on a modular array of 192 side-viewing solid state nuclear track detector stacks. These stacks were mounted in sets of four in 48 pressure vessels employing sixteen peripheral LDEF trays. The extended duration of the LDEF mission has resulted in a greatly enhanced scientific yield from the UHCRE. The geometry factor for high energy cosmic ray nuclei, allowing for Earth shadowing, was 30 m^2-sr, giving a total exposure factor of 170 m^2-sr-y at an orbital inclination of 28.4 degrees. Scanning results indicate that about 3000 cosmic ray nuclei in the charge region with $Z>65$ have been collected. This sample is more than ten times the current world data in the field (taken to be the data set from the HEAO-3 mission plus that from the Ariel-6 mission) and is sufficient to provide the world's first statistically significant sample of actinide ($Z>88$) cosmic rays.

Results to date are presented including details of a sample of ultra-heavy cosmic ray nuclei, analysis of pre-flight and post-flight calibration events and details of track response in the context of detector temperature history. The integrated effect of all temperature and age related latent track variations cause a maximum charge shift of ± 0.8e for uranium and $\pm$ 0.6e for the platinum-lead group. The precision of charge assignment as a function of energy is derived and evidence for remarkably good charge resolution achieved in the UHCRE is considered. Astrophysical implications of the UHCRE charge spectrum are discussed.

INTRODUCTION

Prior to LDEF there were only two spacecraft which carried experiments dedicated to the investigation of ultra-heavy nuclei. HEAO-3 (Binns et al., 1989) and Ariel 6 (Fowler et al., 1987) were launched in 1979 and employed electronic detectors of geometric factors 5 m^2-sr and 2 m^2-sr respectively. The combined sample from both missions with $Z \geq 65$ comprises approximately 300 events, and the entire sample of actinides ($Z \geq 88$) is only 3.

The experiment on LDEF (Thompson et al., 1990) which was dedicated to the study of ultra-heavy (UH) nuclei consists of an extensive array of primarily lexan polycarbonate solid state nuclear track detectors, of geometric factor 30 m^2-sr, which were mounted within cylindrical aluminium pressure vessels in 16 LDEF experiment trays.

DESCRIPTION OF UHCRE

Since the primary objective of the UHCRE experiment was to study ultra-heavy cosmic ray nuclei of $Z > 65$ and the geomagnetic cut-off was $\sim$ 1 GeV/N, the main detector material chosen was lexan polycarbonate.

Each stack consists of a sandwich of many layers of lexan (approx 70 plates) together with several sheets of lead interleaved. The lead sheets act both as electron strippers and velocity degraders and were chosen because of their low cross section for nuclear interactions.

The stacks are 20.5 cm × 26.0 cm in area and are approximately 5 g/cm^2 thick. All 192 stacks were mounted in sets of four within cylindrical Eccofoam moulds which were then inserted into aluminium pressure vessels (48 in total).

All cylinders, except one, were pressurised to 1.0 bar with a dry oxygen-nitrogen-helium mixture in the ratio of 20:70:10. Three pressurised vessels were mounted on each experiment tray which in turn was mounted on the LDEF framework.

PRESENT UHCRE STATUS

Following an initial scan using wide field Nikon zoom scanning microscopes, it was decided to employ the ammonia scanning technique for event location. This technique, which involves long term etching (of up to 21 days) in 6.25N NaOH at 40°C was undertaken on 2 plates situated approximately at $\frac{1}{3}$ and $\frac{2}{3}$ of a stack depth and correlations between the etched cylinders were sought.

Current scanning gives approximately 15 cosmic ray events per stack bringing the expected number of cosmic ray nuclei recorded to approximately 2800 nuclei.

Having located the UH candidates alternate plates from a set of 20 plates at the top of each stack and a similar set from the bottom of each stack were etched for 5 days at 40°C. The remaining plates in each set were kept for further analysis if required.

Etch cone measurements are carried out on Leitz Ortholux microscopes which have 10x and 12.5x eyepieces and 100x oil-immersion objectives. From these cone measurements, both track etch rate (V_t) and bulk etch rate (V_g) are calculated and the reduced etch rate $\left(S = \frac{V_t}{V_g}\right)$ is then determined. Shown in figures 1,2,3 and 4 are plots of S versus Path Length (lexan equivalent) for various recorded UHCRE events. The small change in etch rate in traversing the stack is typical of relativistic ultra heavy cosmic ray nuclei. Fig. 4 shows an UH nucleus (Z $\approx$ 90) which has interacted after passing through almost 9.5g/cm^2 of matter, losing approximately 10 charge units in the process.

To date approximately 65 cosmic ray events have been measured and processed. Charge identification is based upon the determination of the fractional etch rate gradient (Fowler et al., 1976), defined as

$$G = \frac{1}{S}\frac{dS}{dx}$$

where S is the reduced etch rate and x is the path length, and on the effective reduced etch rate (S_{eff}). The relevant data for a given event is reduced to one point which may be plotted on an $S_{eff} - G$ plot as shown in Fig. 5. All cosmic ray events to date are shown in Fig. 5, together with the location of the Z =80, 72, and 62 preliminary calibration curves which are based on the assumed relation

$$S = g(REL)^h$$

where REL is the restricted energy loss rate and g and h are determined from calibration data. The preliminary UHCRE status report (O'Sullivan et al., 1991) was based on calibration using U nuclei. The present work includes calibration with 1150 MeV/N Au nuclei also. Calibration studies will be extended over the next few months.

CONCLUSIONS AND DISCUSSION

A post flight thermal analysis on the UHCRE was published in March 1992 by Lockheed Engineering and Sciences Co. (Sampair and Berrios, 1992). The results of the thermal analysis showed that the tray located at position C6 had the widest temperature cycle of 28.8°C with a maximum of −2.3°C and a minimum of −31.1°C. The tray position E10 had the smallest temperature cycle of 11.9°C with a temperature range of -26.0°C to - 14.2°C. The analysis also showed that the maximum detector stack thermal gradient was 0.15°C per stack. Hence we expect virtually no difference in sensitivity between the top and bottom of a given stack.

Results of the comparison of the pre-flight and post-flight uranium calibration events in the UHCRE stacks (Thompson et al., 1991) indicate that there is no difference between the two, within the limits of experimental error. This work, when taken into consideration with the long term ageing work (Domingo et al., 1990) and the short term ageing (Thompson et al., 1991) indicate that there should be no appreciable loss in charge resolution under LDEF exposure conditions.

Uranium calibration work indicates that the UHCRE detectors have undergone virtually no change in sensitivity or loss of charge resolution over the 5.8 year exposure period. The initial observations (see Fig.(5)) show a dramatic decrease in flux at approximately charge 83 with most of the events falling into the region $70 \leq Z \leq 83$. The distribution of points indicates a concentration of events in the platinum–lead region. It is also apparent that two actinide cosmic ray nuclei have been located at this stage of the analysis.

C-4

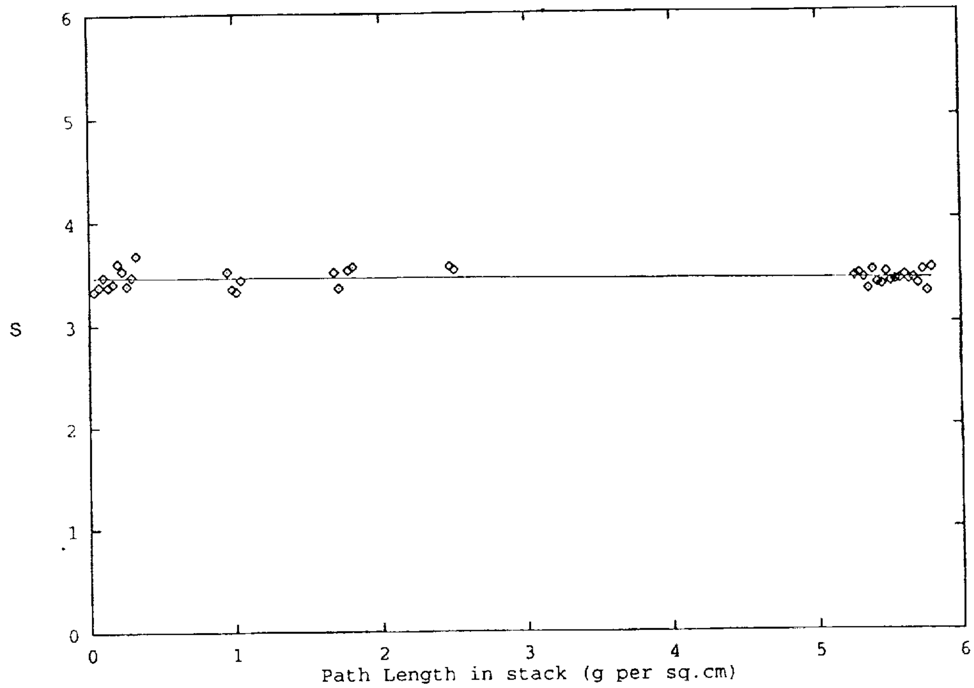

Fig.1 An S versus Path Length plot for Event No. 1 in Stack 86.

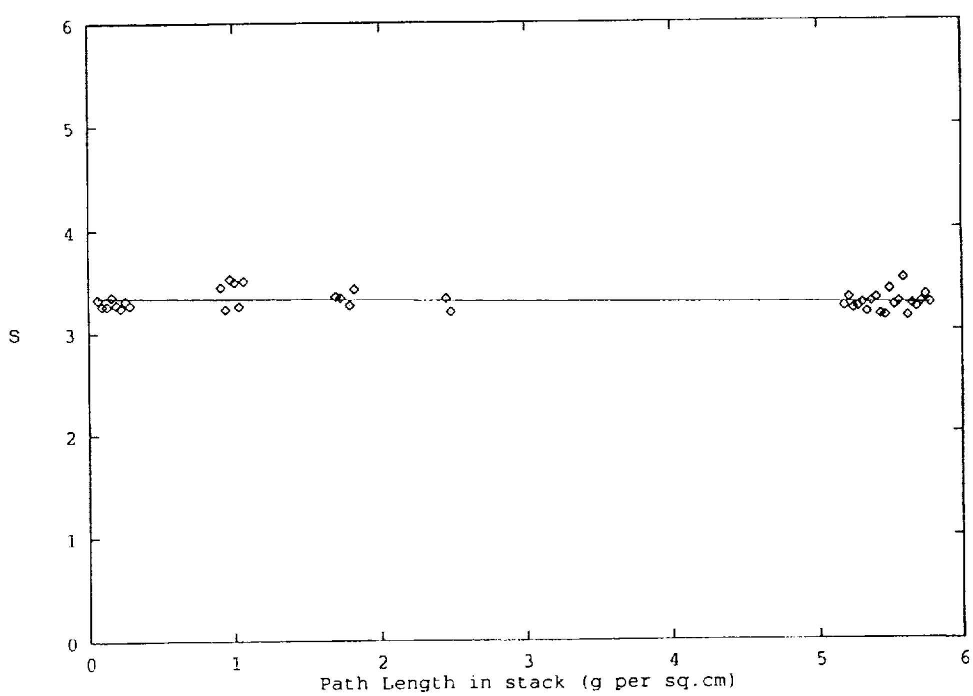

Fig.2 An S versus Path Length plot for Event No. 2 in Stack 40.

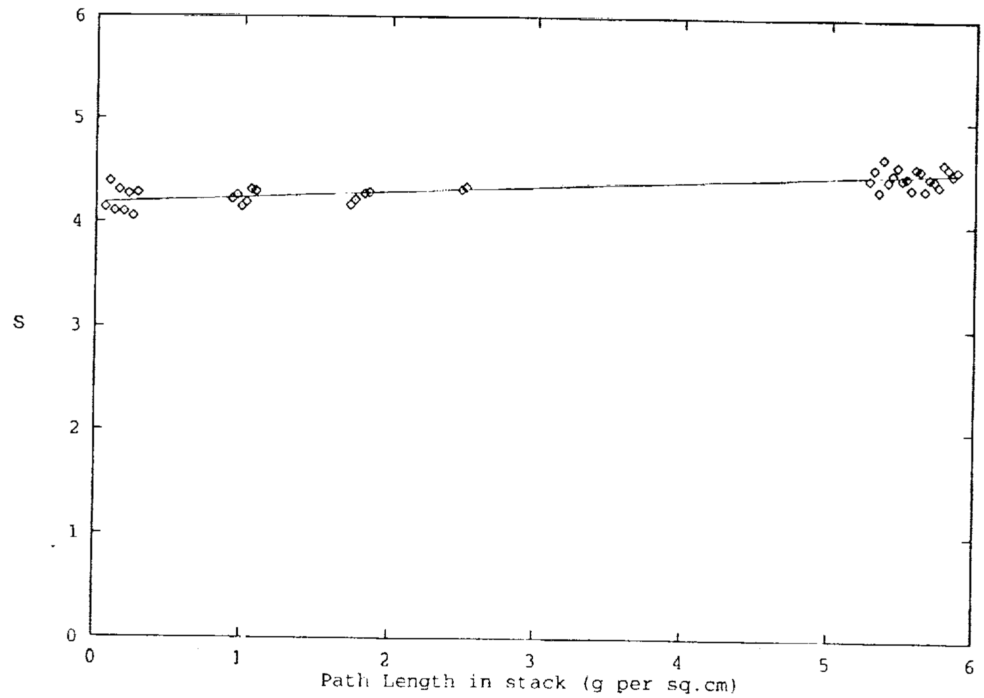

Fig.3 An S versus Path Length plot for Event No. 6 in Stack 40.

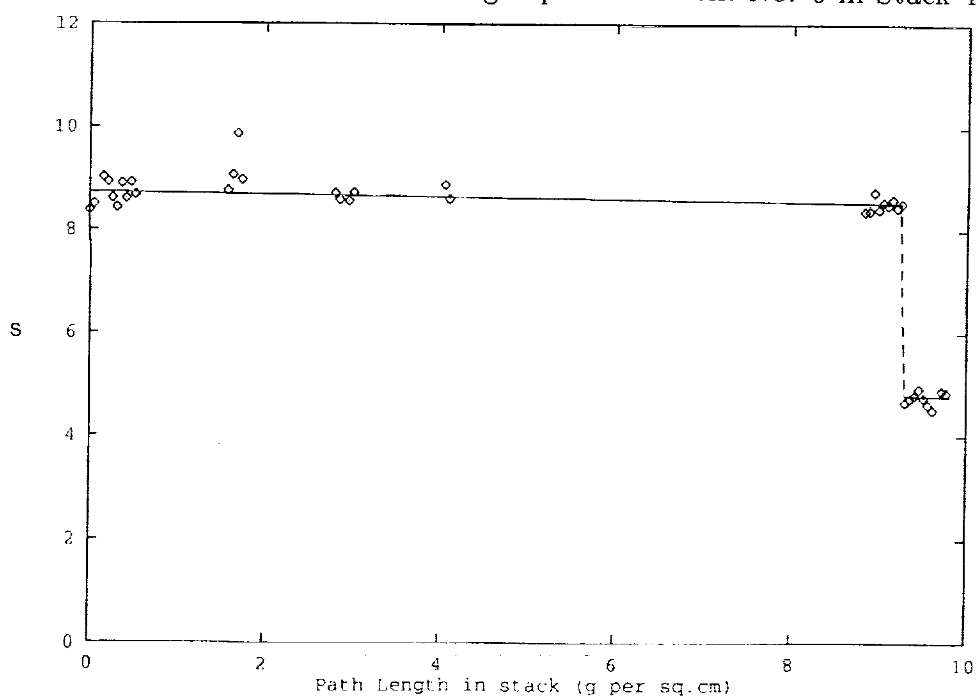

Fig.4 An S versus Path Length plot for Event No. 14 in Stack 123 (Actinide Candidate). Note interaction following path length of $\sim 9.5 g\ cm^{-2}$ in the stack.

Further measuring and analysis is continuing and it is hoped that a set of data equivalent in size to the present world sample will be available for the next LDEF symposium.

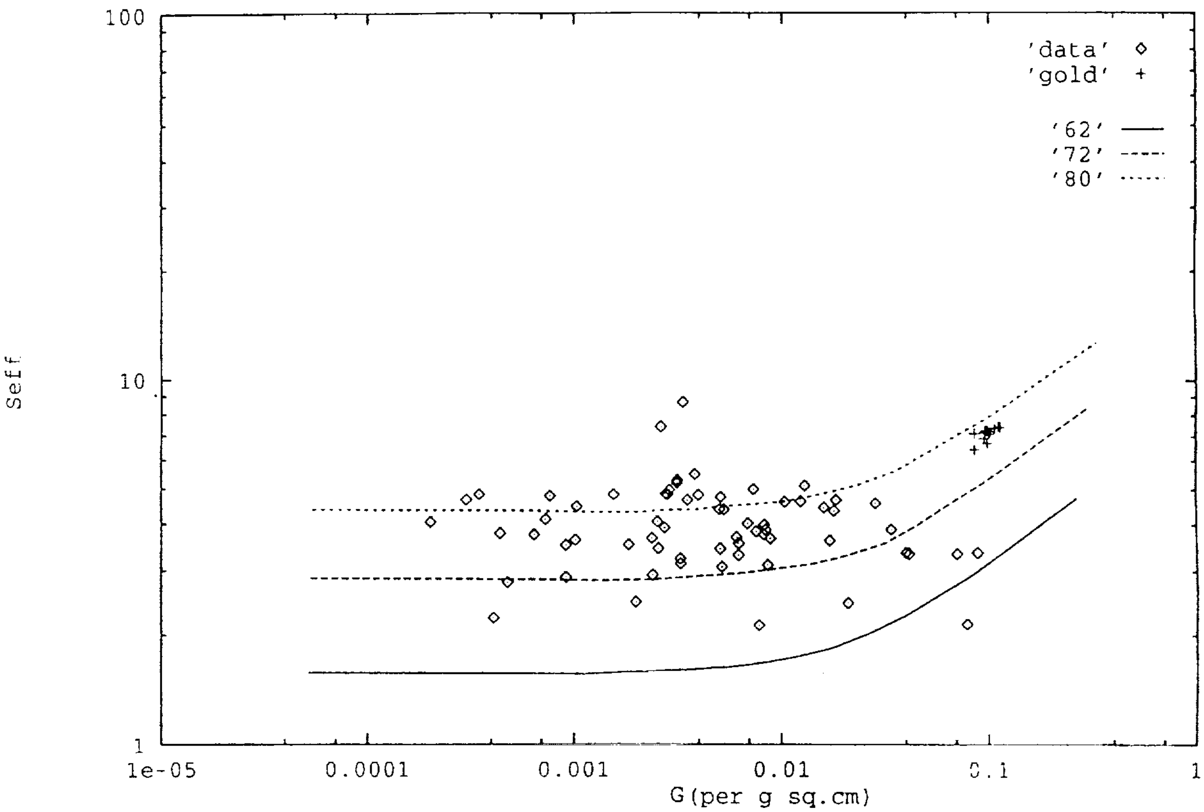

Fig.5 An S_{eff} versus G plot showing all cosmic ray events to date together with some gold calibration events. The preliminary locations of the calibration curves are shown for charges $Z = 80$, 72 and 62.

In view of the excellent quality of the UHCRE data it is hoped that we will be able to distinguish between different cosmic ray source and propagation models when a sufficient sample of nuclei has been analysed. For instance, attempts to describe the abundances of actinides and anti-protons in the cosmic radiation by means of the Leaky Box model have not been satisfactory. Eventually, results from the Dublin–ESTEC experiment will be compared with the predictions of a diffusion model which will be developed to examine the propagation of these particles.

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