LBHNC: A LUNAR-BASED HEAVY NUCLEUS DETECTOR

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ABSTRACT

A passive, large-area experiment for the detection of cosmic ray actinides on the lunar surface is discussed. Due to the absence of a geomagnetic cutoff, a 100 $m^2$ array of nuclear-track-detecting glass plates in 5 years will detect ~300-1000 U and Th cosmic ray nuclei of energies > 0.85 GeV/u (compared to the present world's total of 4 actinides). With a charge resolution at uranium of ~0.25e, the U/Th ratio can be accurately determined, thereby dating the r-process component of the cosmic rays; the presence of a fresh r-process component would be corroborated by the likely detection of transuranics as well. In addition, abundances in the Pt/Pb and sub-Pt/Pb regions and abundances of secondary actinides would provide detailed data on the 0-1 $g/cm^2$ region of the cosmic ray path length distribution, hence on the astrophysical site of origin of these cosmic rays. Finally, should a fresh r-process component exist, the detection of postulated superheavy nuclei is conceivable. With an analysis station at the Lunar Base, glass plates could periodically be harvested, analyzed, annealed/remelted, and replaced onto the lunar surface.

INTRODUCTION

Data from the Danish-French instrument[1] and the Heavy Nuclei Experiment[2] on board HEAO-3, and the Ariel 6 satellite[3] show that for Z < 60 the galactic cosmic ray (CR) elemental distribution is very similar to that of the solar system (SS), after the effects of cosmic ray propagation have been taken into account[4]. However, for Z > 60, data from the Heavy Nuclei Experiment and Ariel-6 instruments suggest that there may be a significant enhancement of r-process elements in the ultra-heavy component of the CR's[2], raising the possibility that a fraction of this component may be freshly synthesized nuclei from recent supernovae, accelerated to CR energies by the supernovae shocks.
A high-statistics measurement of the CR actinide abundances would definitively answer this question. Figure 1 (taken from Ref. 5) shows the abundances of the actinide elements from Z=90 to 96 as a function of time after explosive nucleosynthesis. Since the propagation time of CR actinides
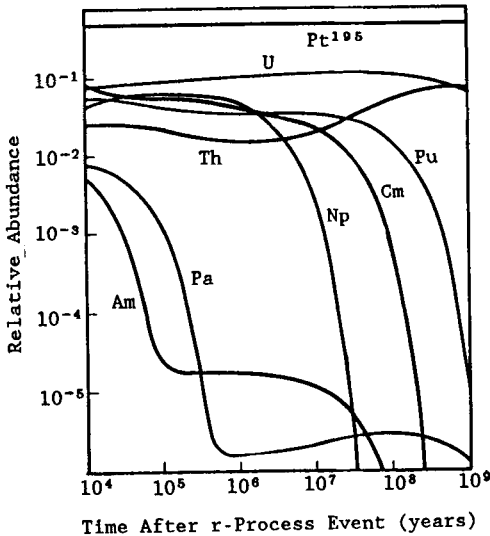
Fig. 1

Time After r-Process Event (years)

should be less than $10^7$ yr (nuclear interactions reduce the lifetime from the CR lifetime of ~$10^7$ yr derived from $^{10}$Be data), the CR U/Th ratio is an excellent indicator of CR age since nucleosynthesis; the measurement of several hundred U + Th CR's would give a U/Th ratio to ~10% accuracy, sufficient to determine the epoch of CR nucleosynthesis. In addition, the observation of short-lived transuranics such as Cm and Pu would be an unambiguous signature of a fresh r-process enhancement of the CR's, and would provide strong evidence for the role of shocks in CR acceleration.

A detector that is also capable of cleanly separating even and odd charges in the (Pt to Pb)/sub(Pt to Pb) region and beyond would dramatically improve our knowledge of the CR path length distribution (PLD) in the critical region of 0-1 g/cm$^2$, thereby yielding information on the astrophysical sites of origin of the CR's. To simultaneously fit CR secondary/primary ratios B/C and sub-Fe/Fe, an energy-dependent deficit in short (0-1 g/cm$^2$) pathlengths in the CR PLD is required[6], supporting the picture of nested leaky box sources, such as OB associations in dense molecular clouds. The secondaries of Pt-Pb and U-Th are ideally suited to study this region of the PLD because their mean nuclear interaction length is of the order of 1 g/cm$^2$ in hydrogen. An extraordinary charge resolution is required for this purpose: < 0.3e at a Z of ~90.

Finally, a high-statistics measurement of the ultraheavy CR's could conceivably result in the first detection of superheavy nuclei (Z > 100). Should an island of nuclear stability exist beyond the transuranics with lifetimes of > $10^7$ yr, then a fresh r-process CR component might carry with itself the only extant superheavy nuclei accessible to us.

At the present time, the total number of observed CR actinides is no more than four, detected with satellite instruments[2,3] of charge resolution > one charge unit at uranium. A lunar base, by comparison, would allow the deployment of an array capable of detecting several hundred actinides with a charge resolution of ~0.25e.

LBHNC

The recent discovery[7] of the extraordinary properties of
certain phosphate glasses as nuclear track detectors has made
possible the construction of an extremely simple and powerful
detector of ultraheavy CR's of Z>60.  Schott's BP-1[8] phosphate
glass has remarkable immunity to many of the problems inherent in
a long-duration space experiment involving nuclear track
detectors.  These include fading of latent tracks over exposure
times of months or years at even fairly low temperatures[9], the
variation of sensitivity with registration temperature[10] and
oxygen pressure[11], and the growth of latent track reactivity with
time[12].  BP-1 glass suffers no fading of latent tracks up to a
test limit of 5 months at 50 °C, ensuring negligible fading over
several years at a lunar base site.  At the design operating
temperature of -20 °C, the dependence of track etch rate on
registration temperature is remarkably weak, with a fractional
shift in etch rate of only ~1 x $10^{-3}$/°C.  Finally, the response
of BP-1 is independent of oxygen pressure, so pressure vessels
with their unavoidable mass overburden are unnecessary; also,
there is no measurable variation of latent track reactivity with
time.
    The charge resolution of BP-1 glass is unequalled in the
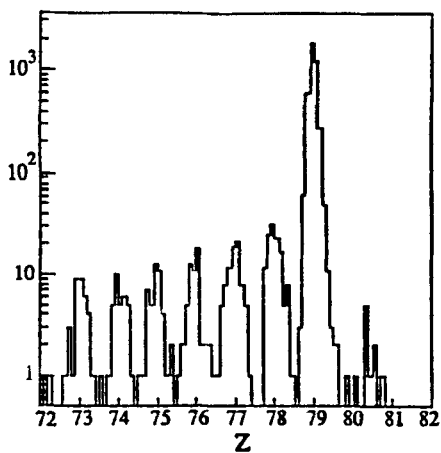high-Z regime.  Figure 2 shows data on the fragmentation of 1
GeV/u Au ions at LBL's Bevalac.
A stack of 5 sheets of glass
(10 surfaces) sufficed to yield
a charge resolution of 0.06e
(note that the ordinate in Fig.
2 is logarithmic)!  With CR
energies initially unknown, the
charge resolution versus energy
also depends upon the ability
to uniquely fit response curves
of individual elements to the
measured track etch rate versus
stack depth.  Figure 3 shows
the results of a Monte Carlo
calculation for a stack of 14
sheets of 0.2 cm-thick BP-1
glass.  It is seen that a
majority of events have their
charge resolved to < 0.3e.



Fig. 2

A Lunar-Based Heavy Nucleus Detector (LBHNC) would
consist of an array of BP-1 glass stacks totalling 100 $m^2$ in area
(and acceptance solid angle of 2.8 sr), deployed for an exposure
period of 5 years, with each stack consisting of 16 0.2 cm-thick
sheets.  A lunar site is arguably the ideal location for such an
experiment.  The absence of a lunar magnetic field implies the
absence of any rigidity cutoff, resulting in substantially higher
CR fluxes on the Moon than in a low-inclination orbit about the

0.4  Z = 79
$\sigma_z$
0.2

0

0.4  Z = 92
$\sigma_z$
0.2

0
  0.5    1    2    4    8

E(GeV)/N)

**Fig. 3**

Earth. The flux of CR U and Th can be estimated from the measured CR Fe flux by scaling with the SS U+Th/Fe ratio, and accounting for propagation effects. The CR Fe flux measured by the Danish-French HEAO-3 experiment[1] has been corrected for the effects of its (variable) geomagnetic cutoff, resulting in a spectrum corresponding to that at 1 AU outside the Earth's magnetosphere[13]. This is then scaled by the SS abundanc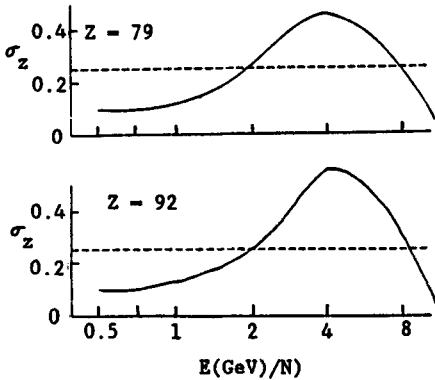e ratio[14] U+Th/Fe = 5.1 × 10-[8]. Propagation effects are taken into account by calculating the survival fraction of both Fe primaries and U+Th primaries after propagation through a truncated exponential PLD using the energy-dependent parameters of Garcia-Munoz et al.[6], and correcting for first-ionization-potential selection effects[4]. Imposing an energy cut of > 0.85 GeV/u to ensure adequate range within a glass stack, we estimate that a total of ~350 U+Th nuclei (this does not include actinide secondaries) will be detected by LBHNC. Should the r-process enhancement suggested by the HEAO-C and Ariel-6 data be real, this number might be as high as ~1000. In either case, these statistics would be sufficient to determine the U/Th ratio to within ~10%, and they imply that LBHNC would be sensitive to transuranics even if the fresh r-process component were to comprise only a few percent of the total ultraheavy CR flux.

The absence of a lunar shielding magnetosphere, while increasing CR flux, raises the question of whether solar flares would generate unacceptable backgrounds in the LBHNC stacks, which are protected only by multilayer insulation. Choosing the June 3, 1982 (1130-1800 UT) Fe-rich solar flare[15] as a test case, we find that LBHNC is not significantly affected. The first few sheets bear the brunt of the exposure: for our test case, the third glass sheet in the stack acquires an Fe-track density of ~25/cm^{2}. LBHNC will be completely insensitive to the larger fluxes of protons and alphas, as these do not even register as tracks in BP-1 glass (as extensive exposure to radioactive $\alpha$ sources has shown). The above Fe-track density will not obscure actinide tracks; it only places a hardship on the track imaging system by increasing the number of tracks requiring analysis. The background density drops off roughly as a power law in stack depth, so several sheets into the stack (corresponding to a small fraction of an actinide's mean interaction length of 11 g/cm^{2} in BP-1) the background becomes insignificant. Thus, at worst, the first few sheets of a stack will be sacrificed, with minimal impact on statistics or charge resolution.

To minimize the effects of accruing background tracks, an etching facility and automated track imaging system could be established at the lunar base. Glass stacks could then be periodically harvested, analyzed, remelted to eliminate all track structures, and placed back onto the lunar surface; in effect, LBHNC could indefinitely be recycled at little additional payload cost.

## ACKNOWLEDGEMENTS

## REFERENCES

[1]  P. Goret et al., Proc. 18th ICRC (Bangalore) 9, 139 (1983), and references therein.
[2]  W.R. Binns et al., Ap. J. 346, 997 (1989).
[3]  P.H. Fowler et al., Ap. J. 314, 739 (1987).
[4]  J.P. Meyer, Ap. J. Suppl. 57, 173 (1985).
[5]  J.B. Blake and D.N. Schramm, Astrophys. and Sp. Sci. 30, 275 (1974).
[6]  M. Garcia-Munoz et al., Ap. J. 280, L13 (1984).
[7]  P.B. Price et al., Nucl. Instr. Meth. B21, 60 (1987).
[8]  Shicheng Wang et al., Nucl. Instr. Meth. (in press, 1989).
[9]  M.H. Salamon et al., Nucl. Instr. Meth. B17, 173 (1986).
[10] A. Thompson et al., Proc. 11th Inter. Conf. on Solid State Nuclear Track Detectors (Bristol, 1981).
[11] J. Drach et al., Nucl. Instr. Meth. B23, 367 (1987).
[12] J. Drach and P.B. Price, Nucl. Instr. Meth. B28, 275 (1987).
[13] E. Juliusson et al., Proc. 18th ICRC (Bangalore) 2, 21 (1985).
[14] A.G.W. Cameron, in Essays in Nuclear Astrophysics, ed. C.A. Barnes et al., Cambridge University Press (1982).
[15] M.A.I. Van Hollebeke et al., Proc. 19th ICRC (La Jolla) 4, 209 (1985).