Heavy Charged Particle Transport and Dose Reduction in Lunar Regolith and Regolith Simulant

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Introduction: The Moon is void of an effective atmosphere (10^{-10} to 10^{-12} torr) such that the effects of space radiation can have deadly effects upon human life. With the renewed interest in establishing a human-occupied lunar outbase in the near future, it is imperative that every precaution be made to insure that the astronauts will be adequately protected from such radiation. Studies of the type outlined here will aid mission planners determine the efficacy of lunar regolith as shielding against galactic/cosmic ray (GCR) heavy ions for astronauts on future lunar missions.

Samples of lunar mare and highland regolith, returned by the Apollo missions, as well as several different types of lunar regolith simulants, were exposed to high energy heavy ions at the NIRS HIMAC (Heavy Ion Medical Accelerator in Chiba), Japan. The average energy deposited by charged particles before and after passing through the samples was used to estimate radiation dose reduction as a function of regolith thickness.

Methodology: Sixteen (16) different samples of Apollo regolith and simulant at depths between 6 and 13 gm/cm^2 were exposed to 400 MeV/u ^{10}B nuclei, as shown schematically in Figure 1. The percent dose reduction per unit areal density (in gm/cm^2) varied between 0.7% and 1.0%, comparable to aluminum and approximately half that of polyethylene (Figure 1).

METHODS

Heavy ion beams were directed onto a stack of charged particle detectors. A trigger detector recorded the presence of a beam particle.

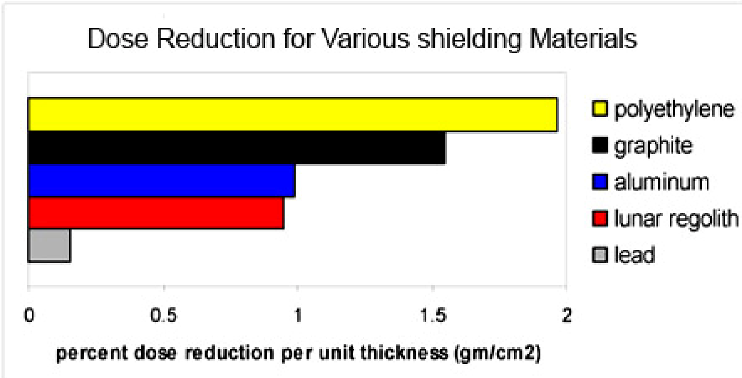
The average summed energy deposition in silicon (at HIMAC) or scintillator (at NSRL) downstream of the target materials was used to estimate the shielding-induced change in the dose per particle, δD, according to

$$\delta D = (1 - \Delta E_{avg\text{-}in} / \Delta E_{avg\text{-}out})$$

The results are expressed in a depth-independent form by dividing out the sample thickness. This yields a δD_n, the normalized dose reduction, in units of $(g/cm^2)^{-1}$.

Figure 1. Schematic relationship of the high-energy beam, the sample as the target, and the particle detectors.

Results: The experiments at HIMAC indicate that ***lunar regolith simulant is an adequate substitute for lunar samples for purposes of radiation protection studies.*** The results suggest that use of *in situ* resources on the lunar surface holds promise for radiation protection, with modest lunar soil quantities providing substantial protection against GCR heavy ions.



- Percent decrease in dose per unit "areal density" (defined as thickness × density, which takes into account the weight penalty of importing shielding — 1 cm lead reduces dose by almost the same percentage as 1 cm polyethylene, but is much heavier)
- Regolith is only about half as effective as polyethylene at reducing dose, but has the great advantage of being available *in situ*

Figure 2. Dose reduction for various shielding materials

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Sample	*percent* dose reduction (per gm/cm^2)
A-62241	0.9
A-64501	0.7
A-67461	0.9
A-61501	0.9
A-10084	0.8
A-70051	1.0
S-15041	0.8
S-61141	0.8
S-10084	0.8
S-70051	0.9

Sample	*percent* dose reduction (per gm/cm^2)
JSC-1A	0.9
JSC-1AF	0.9
MLS-1	0.9
MLS-2	1.0
HAKP	0.9
"Claudia"	1.0

polyethylene (CH_2)	1.7
graphite	1.4
aluminum	0.8
lead	0.2

A= Apollo soil Samples

S= Synthetic Apollo Soils

Others= Lunar Soil Simulants

Table 1. Results from HIMAC radiation experiments with lunar soil and various lunar soil stimulants.