LUNAR REGOLITH ALBEDOS USING MONTE CARLOS. T. L. Wilson[1], V. Andersen[2], and L. S. Pinsky[2], [1]NASA, Johnson Space Center, Houston, Texas 77058 USA. [2]University of Houston, Houston, Texas 77204 USA.

Introduction: The analysis of planetary regoliths for their backscatter albedos produced by cosmic rays (CRs) is important for space exploration and its potential contributions to science investigations in fundamental physics and astrophysics [1-2]. Albedos affect all such experiments and the personnel that operate them. Groups have analyzed the production rates of various particles and elemental species by planetary surfaces when bombarded with Galactic CR fluxes, both theoretically [3-5] and by means of various transport codes [6-8], some of which have emphasized neutrons [9-11]. Here we report on the preliminary results of our current Monte Carlo investigation into the production of charged particles, neutrons, and neutrinos by the lunar surface using FLUKA [12]. In contrast to previous work [3-4], the effects of charm [13] are now included.

Method: Developments in high-energy physics (HEP) and astrophysics have been intimately involved with the science of CRs since the onset of all three disciplines. It is therefore natural that the advanced HEP technology used in designing the world's particle accelerators should find its way into space investigations by means of CR astrophysics.

In addition to fundamental physics experiments themselves, this includes hardware instrumentation and detectors as well as computer software design-and-analysis tools. The latter utilize transport codes for the propagation of particle scattering and nuclear fragmentation events. One such code is the Monte Carlo technique, the method of choice adopted here.

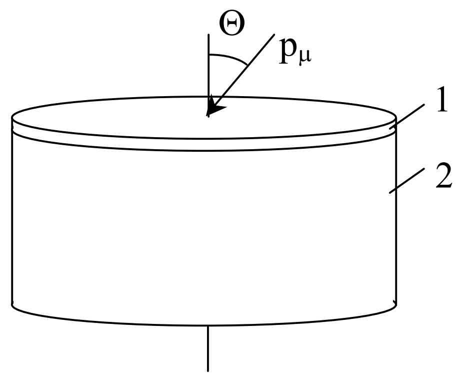

Fig. 1. Tracking Volume

Monte Carlos: The radiation transport code chosen for the study is FLUKA (an acronym from the German, for "Fluctuating Cascade") modified with an advanced 3-D graphics geometry package [12]. This is used in conjunction with an object-oriented (OO) physics analysis infra-structure that is currently evolving at CERN known as ROOT [14]. The FLUKA/ROOT simulation packages are launched on a multi-processor Linux-based architecture.

Table 1. Lunar Surface Model

Element	Atomic Weight	Z	Percent Weight
Si	28.09	14	20.86
O	16.00	8	43.47
Ti	47.88	22	1.46
Al	26.98	13	9.63
Cr	52.00	24	0.22
Fe	55.85	26	9.08
Mn	54.94	25	0.16
Mg	24.31	12	5.54
Ca	40.08	20	8.93
Na	22.99	11	0.32
K	39.10	19	0.15
P	30.97	15	0.09
S	32.07	16	0.09

Model: The model of the lunar surface is taken to be the chemical composition of soils found at various landing sites during the Apollo and Luna programs [15], and then averaging over all such sites to define a generic regolith for the present analysis. This is the same model as used in [3-4]. The resulting weight percentages by element have been calculated and are given in Table 1. Neglecting biogenic elements (H, C, and N), these are the 13 elemental abundances measured to be present on the Moon with more than a trace, having atomic mass A and charge Z. The lunar surface model is assumed to have a mean density of 2.85 g cm^{-3} [16] and a negligible magnetic field.

The collisional tracking volume is depicted in Figure 1, illustrating a cylindrical tube comprised of a thin wafer of vacuum (tracking medium 1) followed by a homogeneous mixture of the lunar surface material in Table 1 (tracking medium 2). The differential CR flux is taken from Simpson [17] to be protons (H, hydrogen) and α–particles (He, helium) obeying a power-law spectrum dN ~ $E^{-\gamma}$ dE with γ = 2.7. The incident flux (having 4-momenum p_μ whose energy is E) impacts the regolith at an angle Θ with respect to the zenith.

Results: A CR-induced particle cascade (lines goind down) and albedo backscatter (lines going up) are given in Figure 2, viewing the cylindrical volume (radius and height = 170 cm) of pie-shaped sectors of regolith from its side. A primary H nucleus (proton) incident from the zenith at $\Theta = 0$ with energy $E = 100$ GeV is shown producing prompt neutrinos (red), protons (blue), and other particles (yellow).

Conclusions: Earlier Monte Carlo investigations [3,4] were unable to give rigorous results because the prompt neutrino production from charmed meson decay [13] was not simulated. Using the latest available enhancements in FLUKA, the simulation now produces expected results and additional study is being carried out.

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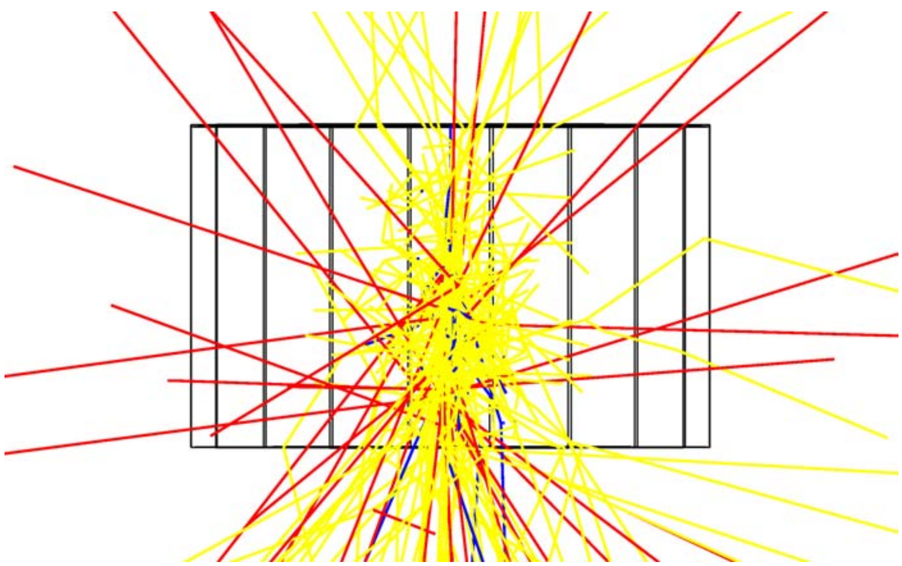

Figure 2. Shower Cascade and Albedo Backscatter in Lunar Regolith.