APOLLO 17 LUNAR SURFACE COSMIC RAY EXPERIMENT - MEASUREMENT OF HEAVY SOLAR WIND PARTICLES, J. Borg and M. Maurette, Laboratoire René Bernas, Orsay, France, and R. M. Walker and E. Zinner, Laboratory for Space Physics, Washington University, St. Louis, Mo. 63130

The Apollo 17 Lunar Surface Cosmic Ray Experiment (LSCRE) consisted of a series of metal foils and nuclear track detectors designed to measure light and heavy solar wind particles as well as more energetic solar and galactic nuclei (Fig. 1). One half of the experiment was mounted in the sun and the other half in the shade for a total of 45.5 hours on the moon. During this time the flux of protons of energies > 3 MeV did not exceed that of quiet sun conditions. However, proton and He fluxes in the range of 0.3 to 1 MeV/nuc as measured on Vela (1), Pioneer 10 (2), and Imp 7 (2) were about a factor of 10 higher than normal quiet time levels during the second half of the period of deployment. We report here fluxes of solar wind particles based on an analysis of the mica detectors. Results for more energetic particles have previously been reported by us and the G. E. and Berkeley groups (3-7). The abundances given by the Berkeley group for particles with energies from 0.2 to 40 MeV/nuc indicate a mixture of solar and galactic particles.

Calibration Experiments: Heavy ions of solar wind energy (∿1 keV/nuc) produce shallow pits in etched mica (8). We used two different etching times and two methods of observation to study particles in different mass ranges. Samples etched for 10 min in a 40% HF solution at 30°C were studied using Pt-C replicas and a transmission electron microscope. Samples etched for 2 hrs were silvered and studied with an optical microscope using interference contrast in reflected light (Nomarski method for Zeiss microscopes). The shorter etching was used for the abundant lighter elements (CNO to Fe), the second for less abundant heavier masses. Calibration irradiations were made with 0.9 keV/nuc ions of O, Ne, Ar, and Fe at fluxes between $5 \times 10^8/cm^2$ and $5 \times 10^{11}/cm^2$. Pit size distributions and registration efficiencies were measured as a function of temperature to account for annealing on the moon and to separate charge groups by differential annealing. Pit sizes for all ions range from zero to a maximum of 0.8 microns after a 10 min etch. The pits produced by Fe ions are deeper than those produced by O and the former can clearly be separated from the latter. Fig. 2 shows the registration efficiencies applying two different acceptance criteria for pits. No difference in pit morphologies was found for Fe^+, Fe^{++}, and Fe^{+++} calibration ions. After 2 hrs etching, Kr, Xe, and Pb give pits that increase in average size with increasing mass (see Fig. 3). Calibration experiments show that the pit distributions for these heavier elements are modified by the presence of large numbers of lighter Fe ions. The lunar environment was simulated by studying the registration and annealing of heavy particles in samples that also contained 1.5×10^9 Fe ions/cm^2. As a function of annealing temperature, there is a flat maximum for the efficiency of detecting large pits at the presence of Fe background

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between 150°C and 200°C. Measurement of the registration of Mn, Kr, and Xe as a function of bombarding angle showed only small effects.

Abundance of Fe-Group Elements: The mica samples exposed in the sun had fifty times as many small pits as those exposed in the shade. Applying both scanning criteria (Fig. 2), we derive a flux of Fe group particles of $3.1 \pm 0.8 \times 10^4$/sec cm^2. Unfortunately, no satellite data of the proton solar wind are available for the same period. Assuming the average proton flux of 2.4×10^8/sec cm^2 (9), we obtain a Fe/H ratio of 1.28×10^{-4}. This value is subject to changes awaiting the still outstanding measurements of the light rare gas abundances from the metal foils. For the moment it exceeds the only other direct observation from a satellite of 3.45×10^{-5} (10) and the solar system abundances of 2.85×10^{-5} (11) by a factor of four. Taking into account our errors, we can rule out an overabundance of Fe in the solar wind by more than a factor of 5. Because of the extreme shallowness of oxygen pits and the large errors on the registration efficiencies, only a crude upper limit estimate can be made on the CNO abundance. We obtain a value of 1.2×10^6/sec cm^2 which is a factor of 4.3 above the solar system abundance (again assuming a proton flux of 2.4×10^8/sec cm^2).

Experimental Results on Large Pits: We previously reported a puzzling lack of large pits (3). We now understand that this is due to a combination of the suppression of large pits by the background of small ones and annealing effects on the moon. Our conclusions on the abundance of extremely heavy ions is limited by a background of pits produced by the more energetic particles that were present in the interplanetary medium during the mission. Calibration irradiations with Na, Ar, and Fe ions with energies up to 30 keV/nuc have shown that pits from such particles are very shallow and cannot in many cases be distinguished from solar wind pits. Fig. 4 shows the results of the analysis of sun and shade micas after a preannealing at 175°C. The background observed in the shade mica sets an upper limit on the heavy element abundances in the solar wind. We can rule out an overabundance of $Z > 45$ elements relative to Fe by more than a factor of ~ 7 and of $Z > 60$ of ~ 2.

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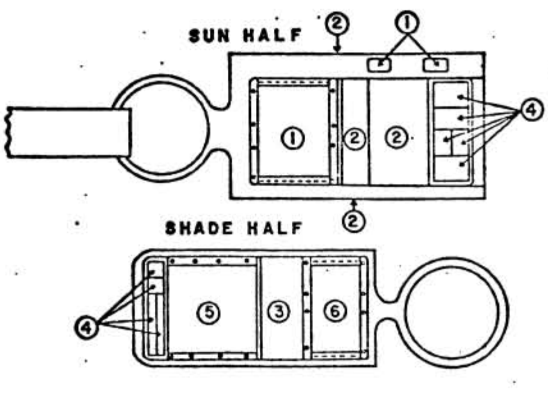

Fig. 1 Detectors of the Lunar Surface Cosmic Ray Experiment. #1 sun mica (heavy solar wind), #2 and #3 metal foils (#2 light solar wind, #3 for control), #4 glass detectors and #5 Lexan stack (more energetic particles of solar and galactic origin), #6 shade mica

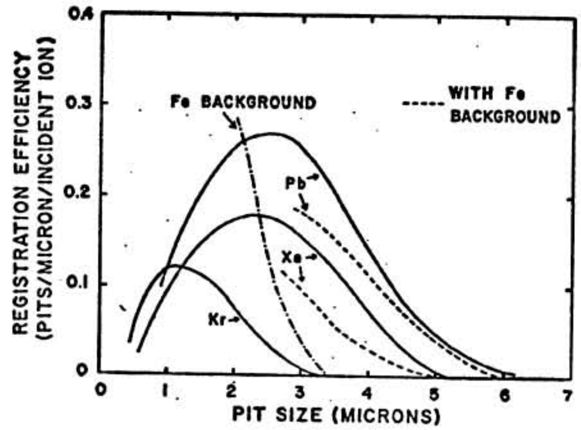

Fig. 3 Pit size distribution for Kr, Xe and Pb ions after annealing at 175°C for 72 hrs and etching for 2 hrs. The area under the curves gives the total registration efficiency. Increasing annealing temperatures result in decreasing average pit sizes and a reduction of registration efficiencies affecting lighter elements first (eg. annealing at 175°C reduces the total registration efficiency of Kr from 48% to 16% but that of Pb only from 90% to 80%). Also shown are the efficiencies for Xe and Pb registration in the presence of an Fe background of 1.5×10^9 ions/cm^2.

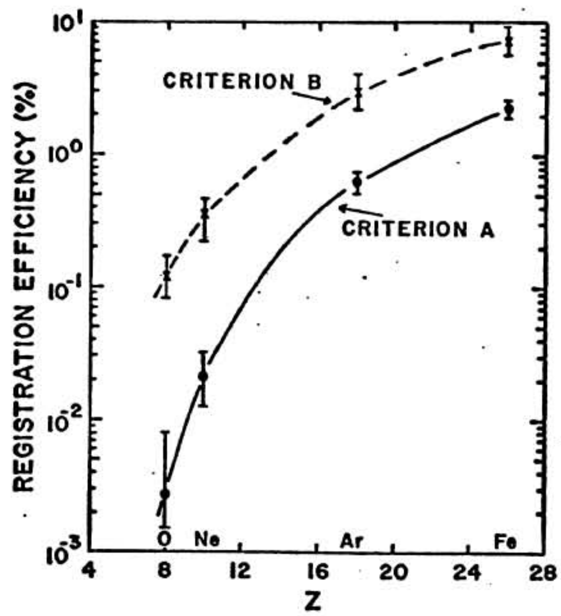

Fig. 2 Registration efficiencies of various ions of 0.9 keV/nuc energy after annealing at 120°C and etching for 10 min. Two different (arbitrary) criteria have been applied for the acceptance of pits, criterion A accepting pits beyond a certain apparent depth, criterion B accepting also shallower pits.

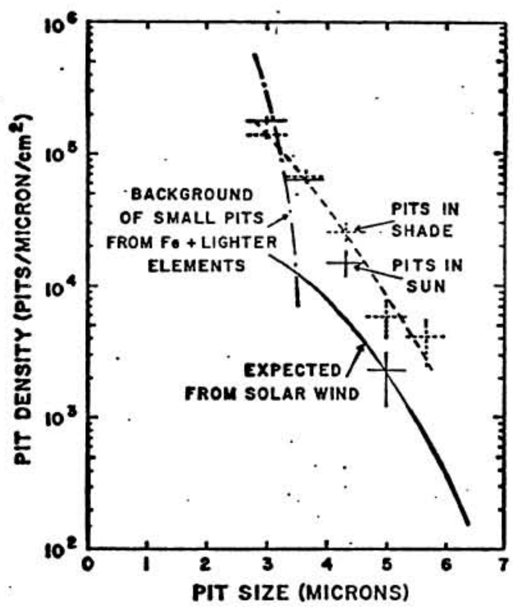

Fig. 4 Pit size distribution of large pits in sun and shade after annealing at 175°C and etching for 2 hrs. Plotted are pit sizes larger than those of the Fe group background. Shown also is the pit size distribution expected from heavy solar wind particles based on our Fe group flux and assuming solar system abundances (11).