Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

ment could determine the surface composition on a centimeter-scale in one laser shot. Regions of high interest could be analyzed with fine spatial resolution. Since the plasma also generates photons and neutral particles, these could also be analyzed, providing additional information. The laser-produced plasma will have sufficient energy to create a shock wave in the lunar surface, which could derive information on the lunar subsurface.

This instrument could provide substantial benefits to planetary surface analysis, allowing smaller spatial resolution and faster analysis than other remote methods.

References: [1] Lubman D. M. (1990) *Lasers and Mass Spectroscopy*, Oxford Univ., New York. [2] Head J. W. (1988) *NASA Mars Conf. Proc., Vol. 71*, Am. Astron. Soc., 215-240.

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AN α-p-x ANALYTICAL INSTRUMENT FOR LUNAR RESOURCE INVESTIGATIONS. T. E. Economou and A. L. Turkevich, Enrico Fermi Institute, University of Chicago, Chicago IL 60637, USA.

An instrument using alpha backscattering, alpha-proton nuclear reactions, and X-ray production by alpha particles and other auxiliary sources can be used on lunar landers to provide detailed
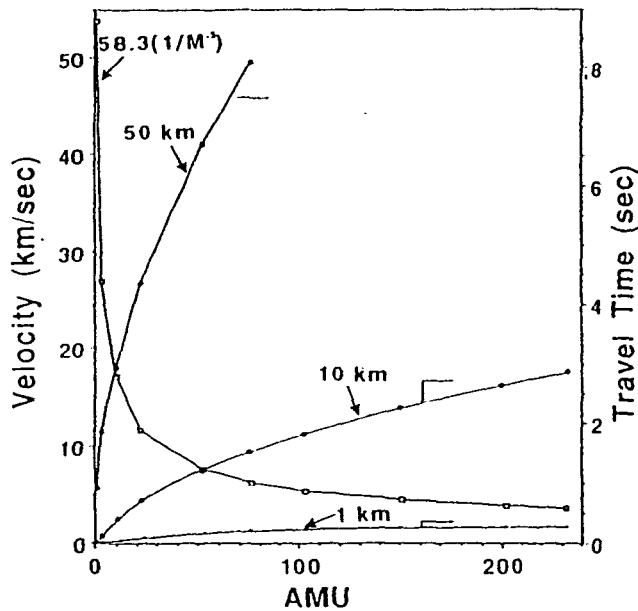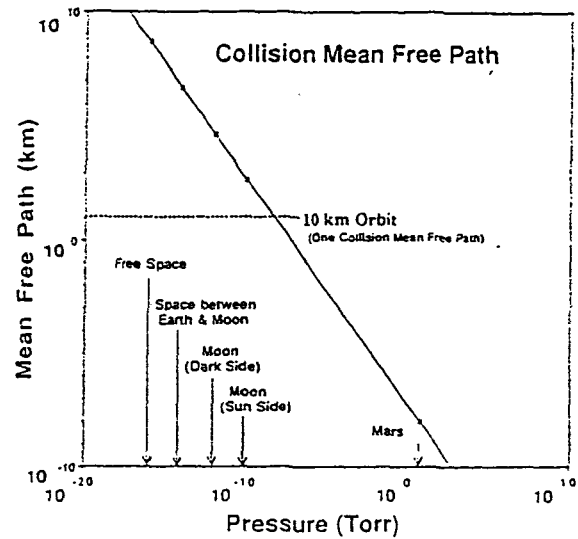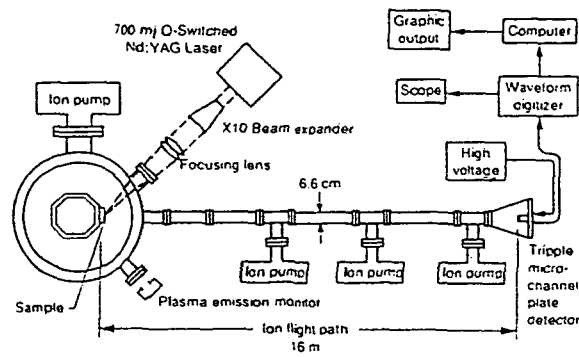
An experiment is now being set up (Fig. 5) to determine the characteristics of such a laser mass spectrometer at long flight distances. This experiment will determine the character of a future flight instrument for lunar resource assessment. Such an instru-

analytical information concerning the lunar surface material. This information is important scientifically and can be the basis for utilizing efficiently lunar resources to build lunar colonies in the future. This alpha particle instrument uses radioactive isotopes, silicon detectors for the alpha and proton modes, and mercuric iodide detectors operating at room temperature for the X-ray mode.

The instrument is highly developed and has significant space heritage. A similar instrument with alpha and proton modes was aboard the Surveyor 5, 6, and 7 and provided the first chemical analyses of the lunar surface in 1967–1968. During the 1970s, it was considered for the Viking missions, and the instrument was significantly miniaturized and its performance improved. An X-ray mode was subsequently added to the alpha and proton modes (α-p-x instrument [1]). Such an instrument was flown on the Soviet missions Phobos 1 and 2 targeted for the martian satellite Phobos in 1988. Unfortunately, both spacecraft missions ended prematurely before reaching Phobos.

Presently, the α-p-x instrument is on the payload of the Russian Mars '94 mission that is scheduled to land on the surface of Mars in 1995. This would provide a chemical analysis of the martian surface much more detailed than that obtained by Viking. A similar instrument is being developed for NASA as part of the straw-

TABLE 1.   Expected accuracies (at 90% confidence limit) for principal chemical elements.

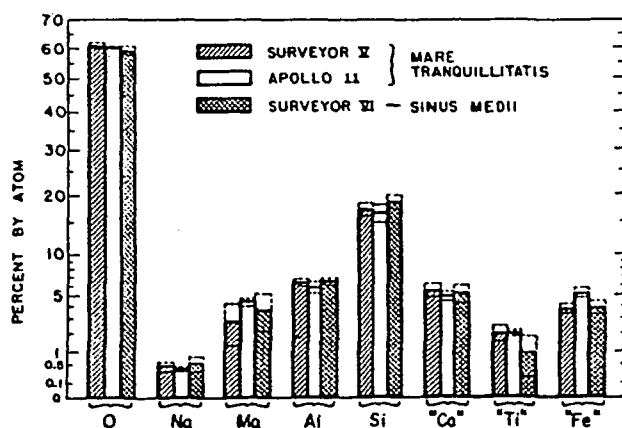| Element	α + p + X-ray modes Weight %	Atom %
C	±0.2	±0.4
O	±0.7	±1.0
Na	±0.2	±0.2
Mg	±0.8	±0.7
Al	±0.4	±0.3
Si	±1.2	±0.9
K	±0.2	±0.1
Ca	±0.2	±0.1
Ti	±0.15	±0.07
Fe	±0.4	±0.2

Fig. 1.   A comparison between the results on samples of lunar mare on Surveyor 5 and 6 with the data obtained later on Earth on samples brought back by the Apollo 11 astronauts from a mare site. It is seen that the Apollo data confirmed the Surveyor results to within the 90% error estimates claimed [2].

TABLE 2.   Examples of expected sensitivies for minor elements evaluated for a basalt matrix using alpha and auxiliary sources.

Element	α + p + X-ray modes Weight %	Atom %
N	0.2	0.3
F	0.05	0.06
P	0.2	0.14
S	0.1	0.07
Cl	0.1	0.06
K*	0.07	0.04
V	0.03	0.013
Cr	0.02	0.008
Mn	0.03	0.012
Ni	0.02	0.008
Cu	0.02	0.007
Zn	0.02	0.007
Rb	0.001	0.0003
Sr	0.001	0.0003
Y	0.0005	0.0001
Zr	0.0005	0.0001
Ba	0.001	0.00017
La	0.001	0.00016
Ce	0.0008	0.00013
Nd	0.0008	0.00012
Sm	0.0005	0.00007
Pb	0.005	0.0005
Th	0.005	0.0005
U	0.005	0.0005

* Sensitivity for K expected in the presence of a few weight percent of Ca.

man payload of the MESUR mission planned for Mars later in this decade.

The alpha and proton modes of the instrument can provide an analysis for all elements (except hydrogen) present in amounts greater than about 1% by atom. These modes have excellent sensitivity and accuracy for the lighter elements, in particular, directly determining the amount of oxygen in the lunar soil. This is an element of paramount significance for the lunar resource missions. The X-ray mode makes possible a determination of Ti, Fe, and other important metals with even greater accuracy. In general, the X-ray mode provides increased sensitivity for heavier elements, in many cases achieving a sensitivity of several hundred ppm.

The α-p-x instrument, due to its small size and low weight, can easily be mounted on a mobile lunar vehicle (rover or microrover), an approach that is highly desirable during the first lunar lander mission in order to increase the range of operations in the search for suitable sites for a permanent lunar base. This instrument does not require the acquisition of a sample on board the vehicle. It can be deployed to the lunar surface either directly or mounted on an arm of the rover and then selectively placed on samples of interest for analysis.

The entire instrument can be made to weigh less than 600 g and to require less than 350 mW of power. It accumulates three different energy spectra with ~15 kbit per sample and therefore imposes a very small burden on the spacecraft resources.

There are several areas where additional work is needed to optimize the instrument for lunar-type missions. A very suitable radioactive alpha source for the lunar missions is ^{242}Cm. This isotope has to be freshly prepared just before the mission. The alternative, ^{244}Cm, is more readily available, but would require

longer times for sample analyses. Early tests with these sources would be very desirable. Additional work with HgI$_2$ detectors and their performance under lunar conditions (e.g., high temperatures) will also have to be investigated.

References: [1] Economou T. E. and Turkevich A. L. (1976) Nucl. Instr. Meth., 134, 391–400. [2] Franzgrote E. J. et al. (1970) Science, 167, 376–379.

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HIGH-RESOLUTION ELEMENTAL MAPPING OF THE LUNAR SURFACE. Bradley C. Edwards, Frank Ameduri, Jeffrey J. Bloch, William C. Priedhorsky, Diane Roussel-Dupré, and Barham W. Smith, Los Alamos National Laboratory, Los Alamos NM 87545, USA.

New instruments and missions are being proposed to study the lunar surface as a result of the resurgence of interest in returning to the Moon. One instrument recently proposed is similar in concept to the X-ray fluorescence detectors flown on Apollo, but utilizes fluorescence from the L- and M-shells rather than the K-shell. This soft X-Ray Fluorescence Imager (XRFI) will be the topic of this presentation.

As was proven by the Apollo missions, the elemental composition of the lunar surface can be mapped using X-ray fluorescence from lunar orbit [1,2]. However, the spatial resolution and precision of the Apollo experiments were limited by both exposure time and flux. Although future missions will have longer lifetimes, the flux for K-shell fluorescence is still a primary limiting factor and imaging keV radiation with a wide field of view is difficult. However, the L- and M-shell fluorescence may provide a solution because the much more intense solar radiation at less than 1 keV will make the lower energy fluorescence flux up to 10^4 times more intense.

The theory behind the XRFI was discussed recently in Edwards et al. [3] and indicates that the fluorescent emission should be intense enough to be observed from lunar and even Earth orbit. Preliminary concepts and designs have been worked out for an XRFI that could be flown in lunar orbit in three years. XRFI is one in the suite of instruments on the Lunar Resource Mapping mission. The proposed instrument will provide maps with high
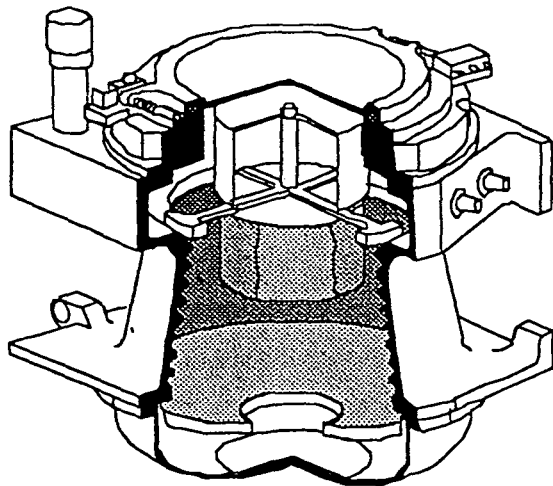

Fig. 1. Diagram of current ALEXIS telescope design. A similar design is to be used for the XRFI instrument on the LRM mission.

spatial resolution (1 km) of the surface distribution of a valuable suite of elements (Al, Mg, Si, Ca, Na, Fe, Ti, etc.).

Although this design is not ideal for the lunar study, optimized instruments with improved capabilities are only in the conceptual stage and may not be feasible for many years.

The XRFI set of soft X-ray telescopes would fly in lunar orbit to observe the fluorescent emission. The telescopes are of the same design to be used on the ALEXIS mission with a normal incidence multilayer mirror, a microchannel plate detector, and thin film filters. The technology, facilities, and software developed and tested for ALEXIS are to be directly applied to the XRFI.

Each telescope would be tuned to an energy that corresponds to an L- or M-shell fluorescent line. The intensity of each line is proportional to the elemental abundance, surface structure, and incident solar flux level. Details of the instrument, its requirements, specifications, and limitations will be presented.

Results from current feasibility studies of the XRFI concept being done at Brookhaven will be discussed and presented along with their implications. Future plans for studies, design, and construction of the XRFI and the lunar community's involvement is also a planned topic for this presentation.

Acknowledgments: We would like to thank D. Vaniman and G. Heiken for helpful discussions concerning the lunar surface. This work was completed under the auspices of DOE.

References: [1] Adler I. et al. (1972) Proc. LSC 3rd, 2157–2178. [2] Adler I. et al. (1975) Space Science Instrumentation, 1, 305–315, Reidel. [3] Edwards B. C. et al. (1991) GRL, 18, 2161–2164.

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LUNAR AND ASTEROID COMPOSITION USING A REMOTE SECONDARY ION MASS SPECTROMETER. R. C. Elphic, H. O. Funsten, B. L. Barraclough, D. J. McComas, and J. E. Nordholt, Space Plasma Physics Group, Los Alamos National Laboratory, Los Alamos NM 87545, USA.

Laboratory experiments simulating solar wind sputtering of lunar surface materials have shown that solar wind protons sputter secondary ions in sufficient numbers to be measured from low-altitude lunar orbit. Secondary ions of Na, Mg, Al, Si, K, Ca, Mn, Ti, and Fe have been observed sputtered from sample simulants of mare and highland soils [1]. While solar wind ions are hundreds of times less efficient than those used in standard secondary ion mass spectrometry, secondary ion fluxes expected at the Moon under normal solar wind conditions range from ~10 to >10^4 ions cm^{-2} s^{-1}, depending on species. These secondary ion fluxes depend both on concentration in the soil and on probability of ionization; yields of easily ionized elements such as K and Na are relatively much greater than those for the more electronegative elements and compounds. Once these ions leave the surface, they are subject to acceleration by local electric and magnetic fields. For typical solar wind conditions, secondary ions can be accelerated to an orbital observing location. The same is true for atmospheric atoms and molecules that are photoionized by solar EUV. Here we discuss the instrumentation to detect, identify, and map secondary ions sputtered from the lunar surface and photoions arising from the tenuous atmosphere.

Solar Wind-sputtered Secondary Ions and Surface Composition: Our laboratory experiments subjected three simulants of Apollo soil samples to ion bombardment, and measured the relative efficiencies of solar wind ions in sputtering secondary ions. The