longer times for sample analyses. Early tests with these sources would be very desirable. Additional work with HgI2 detectors and their performance under lunar conditions (e.g., high temperatures) will also have to be investigated.


HIGH-RESOLUTION ELEMENTAL MAPPING OF THE LUNAR SURFACE. Bradley C. Edwards, Frank Amoured, 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 104 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 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.

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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 >104 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
and ionization potential of the species, or alternatively its elec-
tronegativity. This dependence of positive secondary ion yield on
nuclear stopping power. However, the 1.5-keV H$^+$ yield is about
an order of magnitude larger than predicted; H is a more efficient
sputterer than one might expect. Yields of the various constituents
simulants were replications of an Apollo 11 high-Ti mare basalt
soil, an Apollo 15 low-Ti mare basalt soil, and an Apollo 16
aluminous highland soil. They were left in rocky, not powdered
form. These simulants were subjected to bombardment by Ar and
Ne ions at 5-keV energies, and the solar-wind-like ions of H and
He at 1.5- and 4-keV energies respectively. The very different
nuclear stopping powers of these ions in the target materials
allowed us to study the relative sputtering efficiencies. Ar$^+$ at
5 keV, with its much larger nuclear stopping power, is about a
factor of 400 more efficient than 1.5-keV H$^+$ in sputtering sec-
dary ions. The major geochemical elements Na, Mg, Al, Si, K,
Ca, Ti, Mn, and Fe are nevertheless detectable.

While we have a first-order understanding of secondary ion
sputtering, it is not immediately obvious that the observed ion
yields can be linked with great accuracy to the simulants' com-
position. The simulants were analyzed by electron microprobe to
establish their detailed composition. The observed secondary ion
fluxes can then be compared with the microprobe results. One
example is shown in Fig. 1, where observed Ti$^+$ fluxes from the
three simulants are plotted vs. the weight percent of TiO$_2$. The
results show that the sputtered Ti$^+$ secondary ions correspond
to the true composition with accuracies better than 10% for
the high-Ti basalt, and about 20% for the low-Ti simulant. The
highland simulants produced a statistically insignificant Ti$^+$ count
rate. Similar but poorer results were obtained for the elements
Al, Fe, Ca, and K. The response of Mg ions did not correlate
well with composition under any circumstances. Sodium content
did not vary enough between samples to do the comparison. We
believe the cause of this poor correlation is that sputtered materials
redeposited on adjacent surfaces (all three simulants were in the
same vacuum chamber). This led to cross contamination between
the samples. In the future we intend to redo the experiment one
sample at a time to prevent this problem.

The relative total secondary ion yields sputtered by Ar, Ne,
and He demonstrate a well-behaved exponential dependence on
nuclear stopping power. However, the 1.5-keV H$^+$ yield is about
an order of magnitude larger than predicted; H is a more efficient
sputterer than one might expect. Yields of the various constituents
of the simulants depend upon both the elemental concentration
and ionization potential of the species, or alternatively its elec-
tronegativity. This dependence of positive secondary ion yield on
ionization potential was suggested first by Anderson and Hinthorne
[2]. In addition, it should be remembered that the secondary ion
yields from regoliths are less than that from solid rocky targets
[3].

Once the secondary ions are ejected from a surface grain, they
are subject to ambient electric and magnetic fields. Sunlit surfaces
emit photoelectrons and, up to about 80° solar zenith angle, are
positively charged; shadowed regions may become negatively
charged to -100 V. In most sunlit regions the secondary ions will
be accelerated away from the surface by the positive surface charge;
the influence of this field extends out one or two Debye lengths,
typically a few meters. Thereafter, the ions are exposed to the
solar wind $\mathbf{V} \times \mathbf{B}$ electric field, which normally points approximately
toward either ecliptic north or south. For typical conditions, this
electric field is so intense it dominates the secondary ion equation
of motion, and the ions simply "fall" along the electric field lines.
Figure 2 shows several characteristic ion trajectories in typical solar
wind conditions. However, in regions of remnant magnetism on
the lunar surface, local magnetic field intensities may (1) deflect
and decelerate the incoming solar wind and (2) may trap the
sputtered secondary ions [4]. Nevertheless, these high surface field
regions are limited to 10-30-km size scales, about the size of an
ion mass spectrometer "pixel" from a 100-km orbit. Moreover,
even secondary ions that are locally trapped may drift to weaker
field regions where they can be picked up by the solar wind electric
field. Quantitative simulations of secondary ions in remnant fields
confirm this escape scenario.

Detection and Mapping of Outgassed Volatiles: In addition
to detecting sputtered secondary ions from the lunar surface, a
high-sensitivity, high-mass-resolution orbital ion mass spectrome-
ter can detect and map atmospheric ions. The ion mass spectrome-
ters placed on the lunar surface during Apollo proved that this
measurement can be made. The known atmospheric constituents
include Ne, Ar, Na, and K; other species are likely. Apollo surface
atmospheric measurements showed a high correlation of global
atmospheric Ar content with deep lunar seismic activity; increases
in the Ar density followed every moonquake. The relationship
between deep seismic and volcanic venting is not understood.
Moreover, arguments based on the Apollo alpha spectrometer
measurements of radon (cf. [5]) suggest that volatile transport from
subsurface reservoirs can occur on occasion be substantial. It is important
to measure episodic lunar volatile venting and establish those
regions that are most active.

Atmospheric constituents that have been photoionized by solar
EUV will be accelerated by the solar wind electric field in the
same way as surface-sputtered ions. These photons travel from
their creation point along the electric field into the instrument.
In this way an ion mass spectrometer can actually sound the
atmospheric structure. More importantly, the instrument can
detect atmospheric transients such as volatile venting episodes
without actually being over the site of activity. The vented volatile
atoms and molecules hop along the surface ballistically, random
walking their way around the Moon; as this diffusive "wave" passes
by the spacecraft, an increase in the flux of photoions produced
nearby will be detected.

The 3-D Linear Electric Field Ion Mass Spectrometer: We
discuss here the design of a secondary ion mass spectrometer
that can be flown in lunar orbit or on an asteroid rendezvous mission.
In order to map elemental composition of the Moon or asteroid,
high sensitivities and high mass resolutions (m/Δm = 50 at FWHM)
are necessary. A new design using a three-dimensional Linear
Electric Field (LEF3D) time-of-flight spectrometer meets these
different locations pass through a 100-km lunar orbit; the two ions are distinct in their arrival directions and their energies.

Fig. 2. Trajectories of sputtered secondary ions for typical solar wind conditions. Two representative paths illustrate how ions originating at different locations pass through a 100-km lunar orbit; the two ions are distinct in their arrival directions and their energies.

Finally, in addition to its orbital reconnaissance role, an LEF3D instrument can also perform surface composition measurements in conjunction with an active sounding technique. For example, ions produced by laser-induced breakdown of lunar materials would facilitate remote assessment of exposed materials not accessible to direct rover sampling, for example. An LEF3D instrument on a stationary landed platform would also provide synoptic monitoring of the atmosphere and volatile environment in conjunction with a geophysical station.


LUNAR RESOURCE ASSESSMENT: AN INDUSTRY PERSPECTIVE. S. C. Feldman, B. H. Altenberg, and H. A. Franklin, Bechtel Corporation, P.O. Box 193965, San Francisco CA 94119, USA.

Introduction: The goals of the U.S. space program are to return to the Moon, establish a base, and continue onward to Mars. To accomplish this in a relatively short time frame and to avoid the high costs of transporting materials from the Earth, we will need to mine resources on the Moon. Oxygen will be one of the most important resources, to be used as a rocket propellant and for life support. Ilmenite and lunar regolith have both been considered as ores for the production of oxygen.

Resource production on the Moon will be a very important part of the U.S. space program. To produce resources we must explore to identify the location of ore or feedstock and calculate the surface and underground reserves. Preliminary resource production tests will provide the information that can be used in final plant design. Bechtel Corporation’s experience in terrestrial engineering and construction has led to an interest in lunar resource assessment leading to the construction of production facilities on the Moon.

There is an intimate link between adequate resource assessment to define feedstock quantity and quality, material processing requirements, and the successful production of lunar oxygen. Although lunar resource assessment is often viewed as a research process, the engineering and production aspects are very important to consider. Resource production often requires the acquisition of different types, scales, or resolutions of data than that needed for research, and it is needed early in the exploration process. An adequate assessment of the grade, areal extent, and depth distribution of the resources is a prerequisite to mining. This paper emphasizes the need for a satisfactory resource exploration program using remote sensing techniques, field sampling, and chemical and physical analysis. These data can be used to define the ore for oxygen production and the mining, processing facilities, and equipment required.

Background: The lunar environment is harsh and the placement of production facilities and mining will not be simple. Adequate data gathered now will prevent costly errors later. There are special problems associated with the lunar environment and mining operations. Temperature fluctuations will cause materials to become brittle. Reduced gravity will affect material handling