1995LPI....26..103B

THE USE OF LUNAR SOIL FOR NON-CRITICAL RADIATION DOSIMETRY FOR ROBOTIC ROVERS. P.H. Benoit and D.W.G. Sears, Cosmochemistry Group, Dept. Chemistry and Biochemistry, University of Arkansas, Fayetteville AR, 72701 USA. Internet: COSMO@uafsysb.uark.edu.

Radiation is arguably one of the most critical hazards in planning and management of long-term space missions and missions to essentially airless worlds like the Moon. Long-term radiation exposure not only presents well-known hazards to living organisms but also poses threats to the longevity and routine operation of equipment, especially to devices which rely heavily on solid-state electronics [1]. Clearly any long-term mission to airless worlds will require extensive environmental radiation monitoring. Such monitoring to protect equipment, however, will be difficult, especially for robotic explorers in areas far from human bases. We here suggest that, in the case of the Moon and possibly other bodies, it is possible to use samples of unprocessed soil as dosimeters and measure the absorbed dose using thermoluminescence dosimetry. In addition to the utility of these measurements for mission planning, the data can be used to address other questions important from an exploration standpoint, such as the on site determination of the degree of maturity of the soil and its approximate composition.

Luminescence measurements, especially of thermoluminescence (TL) and cathodoluminescence (CL), have been made on lunar materials since the earliest Apollo missions [2,3]. Cathodoluminescence and TL are related phenomena. The level of TL in a given sample reflects the length of time it has been exposed to radiation, the radiation dose rate, and the thermal history of the sample. Cathodoluminescence can be considered the shorter term response of the sample to radiation (an electron beam); in general CL and TL are produced by the same minerals and the CL spectra is similar to that of TL emission from the same mineral [4].

Thermoluminescence measurements can be divided into those involving *natural* TL, which is the TL of a "pristine" rock or mineral sample, and those involving *induced* TL, which is the TL of a sample which has had its natural TL removed and is then given a known dose of radiation in the laboratory [5]. Natural TL measurements enable the study of radiation exposure and thermal history and induced TL parameters depend on the petrography/crystallography of the TL phosphors in the sample. We have previously reported new measurements of the natural and induced TL properties of lunar soils and rock samples [6-8] and have recently obtained new observations on the response of lunar soils to radiation. Several groups have previously suggested that the TL of lunar soils may be used for radiation dosimetry [*e.g.*, 1,2], but we suggest using lunar soil for radiation monitoring, in analogy to the synthetic TL dosimeters commonly used for personnel radiation monitoring [9]. Although we suggest using bulk soil samples for this purpose, the major TL phosphor in these samples is feldspar, which makes up 60 - 95 % by volume of lunar soils [10].

Proposed Method. A schematic of the system needed for TL measurements is shown in Fig. 1. The proposed application would entail the following steps. (1) A robotic sampler obtains a small (<100 mg) sample from the soil and pours it onto a heating strip. (2) The strip heats to sample to approximately 500°C in order to remove pre-existing "natural" TL. (3) The sample is poured into a storage container. (4) After some desired interval (weeks to months), the "dosimeter" sample is poured from the storage container onto the heating strip and is then heated to approximately 500°C at a set rate (between about 5 to 20° C/sec). During this heating, the intensity of light emitted by the sample is measured by a photomultiplier tube or diode array as a function of temperature (5) While still on the heating strip, the sample is exposed to an on-board radiation source, such as a ^{90}Sr beta source. (6) The irradiated sample is then heated again to obtain the "induced" TL glow curve. (7) The sample is either poured into a storage container for re-use or is disposed of. (8) During data reduction (either by downloading the data to a central base or by on-board computers) the intensity of the "dosimeter" glow curve is divided by the intensity of the "induced" glow curve. The resulting "equivalent dose" curve then, subject to some modifications mentioned below, gives the radiation dose received by the sample during its storage as a "dosimeter".

Caveats/Potential Limitations. The proposed system has a number of advantageous properties for dosimetry. Perhaps the most useful property of soil dosimetry is the extreme hardiness of the dosimeters. The soil used will virtually always have been exposed to galactic radiation for millions of years prior to being used and thus there is little danger of the dosimeters being further compromised by radiation damage. They are also obviously quite resistant to physical damage or other environmental effects (although extreme heating will obviously cause the loss of dosimetry data); any event which is strong enough to effect the dosimeters will probably be more than sufficient to destroy the object being monitored. Lunar surface regolith is generally very fine-grained (<100 μm) and can thus be used without further processing. Soil dosimeters can be used repeatedly without affecting their dosimetry properties and, if and when it is desired to replace a given dosimeter with a new sample, the old sample is, by definition, "environmentally friendly" for disposal purposes. Feldspar also has a fairly high saturation dose (it takes about 10^5 years to reach saturation under "typical" cosmic ray doses in space [11].

On the negative side, lunar feldspar exhibits a TL sensitivity (response to a known radiation dose) about 1000 times less than typical commercial dosimetry materials, such as LiF, as measured by response to ^{90}Sr beta radiation. Obviously lunar soil is inappropriate for personnel dosimetry and will be of minimal use in monitoring relatively small changes in the radiation environment. In addition to being less responsive to radiation than typical dosimetry materials, lunar feldspar also exhibits "anomalous fading" [12,13], which is essentially the loss of stored TL by electron-tunnelling. Anomalous fading is a common (but not universal) feature of the TL of feldspar and is related to the degree of ordering in the feldspar structure. Disordered feldspar is common in many meteorite classes and exhibits little or no anomalous fading, while ordered feldspar, common in planetary samples, usually exhibits anomalous fading [14]. While the presence of anomalous fading poses problems in the present application, it can largely be taken into account during the dosimetry calculation using a power law decay term as a modifier. We have found that lunar feldspars in general exhibit very similar anomalous fading decay constants in laboratory studies.

A third problem for TL dosimetry is the thermal senstivity of the TL signal. While TL properties of lunar feldspar are not changed by fairly extreme thermal events (unlike many commercial TL dosimeters), heating much above 100°C or so will remove some or all of the stored TL signal, thus producing a false low dose estimate. This should not prove to be a problem for lunar applications, since surface temperatures even at lunar noon do not generally exceed 120°C degrees [15].

Other Applications. One key advantage to carrying a TL dosimetry system on board robotic rovers is that the equipment has other scientific and exploration applications in addition to just radiation dosimetry. In brief, the equipment can also be used as a to determine the degree of soil maturity and the amount of highland/mare mixing of a given soil sample using its induced thermoluminescence properties [8]. In particular, the relative intensity of TL from soil samples is indicative of the highland component in these soils and the peak TL temperature is determined by the bulk average degree of disorder of feldspar, which, in turn, is indicative of the degree of regolith reworking. Such data, which would be obtained by the rover without need of sample return, would be of great interest in mapping and prospecting and allow changes in exploration programs in real time. The setup could also be modified by adding a "calibrated" light source to allow determination of additional soil parameters of interest from the prospecting standpoint and from the standpoint of comparison with remote sensing maps, such as sample albedo or, using a system of interchangable filters, spectral reflectance.

In closing, we propose that thermoluminescence apparatus be considered as a component for future lunar rovers (or for rovers on other airless worlds). Using lunar soil, such apparatus could be used for radiation dosimetry, allowing monitoring over extended periods of time without human intervention. These data would be of primary use in determining maintenance schedules or estimating equipment longevity. The same equipment could also be used for *in situ* sample analysis of soil, permitting assessment of soil maturity, approximate composition, and possibly parameters such as spectral reflectivity. The apparatus is relatively simple, but would allow a rover to operate much more in the mode of a human geologist, rather than as a simple sample retrieval device.

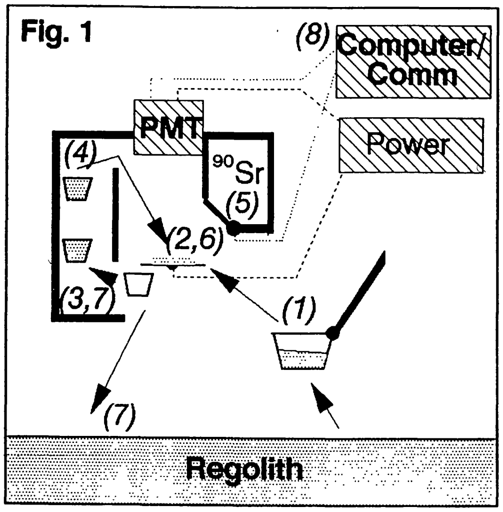

FIG. 1. Schematic of a robotic thermoluminenscence apparatus. Numbers in parentheses refer to steps in the proposed procedure (see text) and arrows show general sample flow paths. The photomultiplier tube (PMT) shown here could be replaced by other light detection devices and the ^{90}Sr beta source could be replaced by some other radiation source.

Acknowledgements. We wish to thank CAPTEM for providing the lunar samples used in this study and Steve Symes for helpful discussions. This study funded by NASA grants NAGW 3479 and NAGW 3519

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