LONG DURATION SURFACE EXPERIMENTS ON AIRLESS BODIES: THE NEED FOR EXTENDED *IN SITU* MEASUREMENTS AND LESSONS FROM ALSEP.

N. E. Petro[1], J. Richardson[1], J. Bleacher[1], D. Hollibaugh-Baker[1], W. Farrell[1], D. Williams[1], N. Schwadron[2], M. Siegler[3], N. Schmerr[4], L. Carter[5], and B.Cohen[6], [1]NASA Goddard Space Flight Center, [2]UNH, [3]PSI, [4]UMD, College Park, [5]U.ofA., [6]NASA MSFC.

Introduction: Future exploration of planetary bodies, especially airless bodies such as the Moon and asteroids, will be science driven endeavors with the goal of sample return or human and/or rover-based exploration. The detailed sampling of a planetary surface, as was done during the Apollo exploration of the Moon, will drive the selection of sampling sites and the technical capabilities will drive the duration of surface stays. A critical aspect of any future exploration should be the deployment of experiments that are left behind and continue to operate long after humans leave the surface or the landed robotic or rover missions are concluded. Such long duration measurements enable additional science not possible during short duration surface explorations and afford the opportunity to measure periodic or temporally controlled phenomena.

During the Apollo program the Apollo Lunar Surface Experiments Package (ALSEP) was a multi-year geophysical and environmental monitoring station [1] that established a long baseline of measurements, which have proven to be a treasure trove of data for modern interpretation [2-11]. However, ALSEP was terminated prematurely on September 30, 1977 due to budgetary and logistical interferences, cutting short the anticipated 20-30 year lifetime [12] (with a power source of Plutonium-238, half-life of 89.6 years). Granted, the design life of the stations was 1-2 years [1], but at the time of their termination viable data were being transmitted.

Here we discuss the lessons from the ALSEP program and their implications for future long duration surface measurement packages. In addition, we discuss new approaches to such long duration experiments, an approach outside NASA's Planetary Science Division's current mode of operations.

The Need For Long Duration Surface Measurements: One of the most valuable lessons from ALSEP was that extended duration surface measurements provide critical insight into the internal (*e.g.,* seismic and heat flow), surficial (*e.g.,* dust environment), and exospheric (*e.g.,* atmospheric constituents) variability at the Moon over several years. Indeed, some experiments showed long term temporal drifts [13] that could be natural phenomena or unidentified instrument error, demanding long new term data to provide answers. The long baseline data were useful at the time in identifying, for example, variations in crustal structure as data were being collected [14, 15] but also provided, after termination of the program, a large number of events so that such data could be re-evaluated using modern techniques [6, 7].

Long baseline measurements, especially when part of a widely distributed network, provide unique opportunities to gain insight into a distinctly new dimension of the processes that act on a planetary body. An example of this is illustrated in Figure 1, where the impact of increasing spatial and temporal baselines for seismic measurements is plotted. In the case of ALSEP, the stations were distributed across the nearside and operated for multiple years. However, had the stations been left on for 10 years or more, more insight into the deep interior could have been gained.

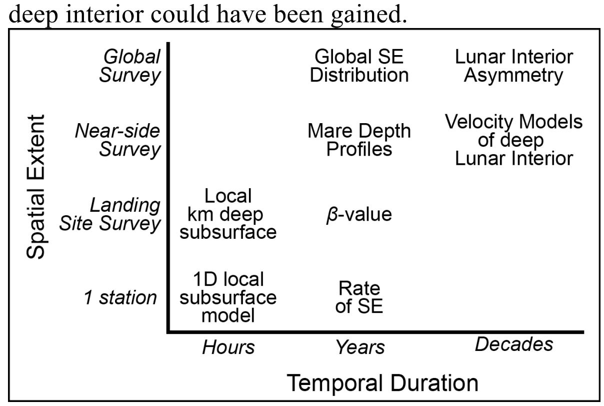

Figure 1. Diagram showing an example of the benefits of extended spatial and temporal measurements from a network of seismometers. Any other measurement on a network (heat flow, radiation environment, dust environment, etc.) would show similar improvements as a function of distribution and duration. SE= Seismic Events.

Example Measurements: While a modernized version of each of the ALSEP experiments at the Moon would be beneficial, here we identify a distinct suite of measurements. Clearly these would be dependent on the target (Moon vs. asteroid), but in general are broadly applicable. If broadly deployed to airless objects throughout the Solar System (the Moon, Ceres and other main belt asteroids, outer solar system icy moons) these packages would provide a detailed geophysical characterization of very different objects that could revolutionize how we think about interiors and surface space weathering throughout the Solar System.

In addition, future measurements should be made over as much of the lunar day as feasible, not just during lunar night as was done by several of the ALSEP experiments.

Radiation Monitoring: The CRaTER instrument on LRO has clearly demonstrated the value of extended measurements of the radiation environment at the

Moon, as a direct result of both solar and Galactic Cosmic Ray (GCR) activity [e.g., 16, 17]. A broadly distributed network of surface measurements not only would measure the entire sky for GCR radiation, but also would measure how the flux of solar radiation varies over time, interacts with the regolith to modify chemical properties, and produce secondary radiation products. The measured chemical modifications of the regolith will affect how we interpret the long-term history of space weathering and energetic particle interactions at the Moon.

Solar Wind, the Plasma Environment, and the Exosphere: Long baseline measurements of the solar wind, its interactions with the surface, and variations in the compositions of exospheric constituents [18-21] would provide important constraints on, for example, how volatiles migrate across the surface, if at all. Such measurements, especially when coupled with orbital observations [22], would provide important constraints on the influence of the solar wind and its interactions with the surface.

A long baseline system could examine the plasma-surface-volatile interaction, like that associated with solar wind hydroxylation, over a range of space plasma conditions from solar min to solar max. A local space weather station along with a local IR spectrometer could examine the dynamic effect that a strong solar storm or CME might have on surface hydroxylation. We suspect that the hydroxylation level will reach a different equilibrium during a solar storm - but given enhancements in both source protons and sputtering losses, it remains unclear if that overall level grows or shrinks. Having a space weather station with IR augmentation would also allow an examination of hydroxylation associated with meteors and meteor streams - which LADEE found to be a dominant process for driving the exosphere.

Geophysical Measurements: The seismic measurements from ALSEP have proven to be extremely useful in characterizing not only the interior of the Moon, but also for monitoring the surface and the number of impacts. The accompanying heat flow measurements show that the interior and crustal composition vary dramatically on spatial scales. This suite of measurements has yet to be improved upon on any other planetary body, and still provide for valuable data for the interpretation of the early history of the Moon. A long baseline of seismic observations, coupled with a broadly distributed array, would provide not only insight into the structure of the Moon, but also the variability in heat production from the crust and interior. When expanded to different sized asteroids and perhaps icy outer Moons, this geophysical package would revolutionize our understanding of interiors and be an incredible comparative planetology dataset.

Lessons from ALSEP: At the premature conclusion of the ALSEP program, five recommendations were made [1] that should be heeded in similar future experiments. **1**. Personnel changes should be minimized during the duration of the experiments. **2.** Ground hardware and software changes should be minimized. **3.** Data should be collected at regular intervals across the entire lifetime of the experiment. **4**. All data downlinked should be stored in as modern a method as possible, and all data need to be both time-tagged and registered to each other. **5.** During deployment, the experiments should be located as far as possible from interfering sources (launches, cabin outgassing).

We expand those lessons here, given the nearly 40 years since the termination of ALSEP. Issue 1 is perhaps the most in conflict with the current model for how planetary missions are operated. NASA should treat these experiments as facilities, with consistent funding and support over decades. In addition, where experiments are too long to accommodate a single science lead, a succession plan should be implemented so new personnel will have a seamless transition. The surface experiments must also be easily and quickly deployable. Also, where possible, surface measurements should be coupled with long-term orbital observations as well (akin to surface weather stations on Earth and orbital weather monitoring). The data from these stations should also be made available in near-real time, following an initial validation period. As such the impact to the community would be felt immediately and over a long period of time.

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