ENABLING ELEMENTS FOR ARTEMIS SURFACE SCIENCE.

C. R. Neal, University of Notre Dame, IN, USA [neal.1@nd.edu]; S. Dell'Agnello, INFN, Italy; R. Grimm, SwRI, CO; S.P.S. Gulick, UT Austin, TX; J. Head, Brown Univ., RI; P. James, Baylor Univ., TX; P. Lognonné, IPGP Paris, France; C. Nunn, JPL-Caltech; M. Panning, JPL-Caltech; N. Petro, NASA-GSFC; N. Schmerr, Univ. Maryland; T. Watters. Smithsonian Inst., DC; K. Zacny, Honeybee Robotics, CA.

Introduction: The commitment to sending humans to the Moon by 2024 represents a unique opportunity for this science generation to capitalize on the science return of such an endeavor. With lessons from Apollo, the Artemis program of establishing a sustained human presence on the lunar surface will allow science to be woven into the plan and work in tandem with exploration and commercial interests. This is why the lessons from history must be acted on to enable the full potential of such science return.

This short white paper focuses upon elements that will enable science return from the Artemis program and includes infrastructure and technology. Planning an enabling architecture for Artemis that includes specific technology developments will realize an abundant and enduring scientific return from the Moon.

Infrastructure. This category includes power, communications, navigation, and the Artemis Base Camp.

Power: a reliable source of power is critical for allow experiments to survive lunar night & eclipses as there are huge swings between day and night time temperatures on the lunar surface (e.g., [1]). For the Apollo Lunar Surface Experiment Package (ALSEP), radioisotope thermo-electric generator (RTG) power (**Fig. 1**) would have allowed the surface experiments to operate into the 1980s if they had not been manually shutdown on 30 September 1977. Surface experiments set up by human Artemis missions require long-lived power supplies. This also includes more efficient batteries (lower mass, higher power density) if RTGs/RHUs are unavailable so solar-generated electricity can be stored and repeatedly used to enable experiments to survive the lunar night. While this is Technology Development, the power infrastructure for Artemis missions and the Artemis Base Camp can be enduringly enabling for science investigations.

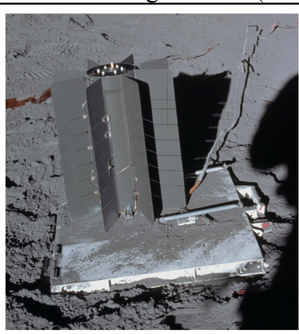

Figure 1: Apollo 14 RTG on the surface of the Moon.

Communications: While it is assumed an orbital communication asset/array will be available, it is unclear what capabilities this asset will have. A definition of these capabilities will undoubtedly enhance the science return. With humans exploring the surface of another world, the video of the Apollo era is unacceptable in the 21st century. High definition video capability is needed for science (and public engagement), as well as high resolution images, for example a gigapan scan of the landing site and nearby investigations. For example, high definition videos could be used to make a "*Structure from Motion*" model of the area highlighting geologic features [2]. HD video will also enable the science backroom to help in real time by clearly seeing the features the astronauts see. If robotic explorers are sent before the humans for reconnaissance, or stay after for follow-up studies, high quality images and video will be crucial and reliable high bandwidth communications assets are vital.

Navigation: Exploration of the Moon will require locations be accurately known and sortie excursions from the Artemis Base Camp can be carefully planned. Starting with a local GPS that could be expanded to regional and global over time enabling both human and robotic missions (e.g., [3]). Spatial referencing would be especially critical for robotic assets undertaking exploratory or follow-up studies before and after human stays. An alternative is laser ranging from orbit to surface retroreflectors [4,5]. It would also enable science by knowing exact sample locations and accurately mapping out geologic structures (e.g., lobate scarps – [6]). This capability would also be critical in evaluating the epicenters of moonquakes detected by astronaut-deployed stations and equating them with lobate scarps [6-8]. Miniaturized retroreflectors also could be deposited at sample locations of interest as geodetic reference marks and/or for future lidar based landing [9] and sample return from those locations. The point is that whatever local system that is set up should be scalable to regional and whole Moon networks.

Artemis Base Camp: Having a long-term base of operations, with a transportation system to visit others areas of the Moon [10], is critical for gaining a deeper understanding of our Moon's origin and evolution by being able to visit many more places than was thought possible during the Apollo program. Such outposts on Earth (e.g., Antarctic) serve as science observatories, laboratories, and logistical centers, all crucial for sustained science activities in harsh, remote environments. An Artemis Base Camp could result in the collection of more samples than could be returned to Earth, so a "lab-in-the-hab" (or close by) may need to be considered for sample analysis and final selection of those for return to Earth. The Base Camp should also be considered a maintenance facility to support surface instrumentation and infrastructure.

Technology Development. Integrating the new datasets from various missions to the Moon since Apollo with the Apollo experience highlights some important technology developments that would greatly enhance the science return from the Artemis program. These broadly fall under power, automation, sampling and sample return, and human-robotic partnerships.

Power: As noted above, battery technology would be enabling for lunar surface science. However, if lunar resources are to be utilized to sustain the human presence on the Moon, multiple kilowatts of power to megawatts of power will be needed [11]. Long-term human occupation of a lunar base, and long-lived observatories will create an ever-increasing demand on power provision capabilities. This will require development of scalable nuclear fission kilowatt power surface units for use on the Moon [12]. Continued development of these power systems will enable the lunar resources to be explored, which will benefit science, exploration, and commercial involvement in human space exploration.

Automation: Experimental packages should, as much as possible, have automated deployment built into their designs (e.g., LGP [7]). This will free the astronauts for geologic exploration of the landing site rather than have them act as laboratory technicians. This would have the benefit of avoiding human error on the lunar surface, such as happened with the Apollo 16, when one of the astronauts tripped on the cable to the already deployed heat flow probes, rendering them inoperable! However, Apollo demonstrated that for investigations of moonquakes more sensitive and complex seismometers are required, with intricate deployments (e.g., a wide sun cover, cable service loops, burial of power cables, etc.), which is most efficiently accomplished by humans [8].

Sampling and Sample Return. The Apollo samples have demonstrated the need for maintaining samples in their pristine form as much as possible to enable them to be studied long after they have been returned to Earth. This is highlighted by the paradigm-shifting discovery of water and other volatiles in Apollo 15 & 17 volcanic glasses unequivocally showing the lunar mantle contains relatively volatile-rich areas [13]. This discovery was made 37 years after the samples were returned to Earth, emphasizing the need for proper curation. However, we now know that areas of the lunar poles contain ice deposits, critical for in situ resource utilization (ISRU) and for science as they could contain pre-biotic materials that seeded the Earth-Moon system prior to the advent of life on Earth. Sampling, caching, returning, curating, and preserving such samples is incredibly challenging and will require investment in cryogenic technology.

Vacuum-sealed sample containers were developed during Apollo, but their use on the lunar surface was compromised by their design, such that wires often got caught in the lid preventing a tight seal. Why is this important? Mature regolith could contain abundant solar wind-implanted protons that, upon heating reduce FeO to metallic Fe and liberate water (e.g., [14,15]). It also contains other important species, such as Helium-3, an isotope of helium that is rare on Earth but relatively abundant in mature regolith on the Moon [16,17]. This represents the ideal fuel for nuclear fusion power on Earth as it results in no toxic by-products. However, Apollo samples represent a minimum abundance for these solar wind implanted species that are loosely bound and agitation during sampling and return to Earth means at least some are lost. <u>Vacuum sampling is the key to understanding the true nature of this component</u>.

Finally, robotic sampling (e.g., deep coring) and return technology is needed to aid in the return of samples either collected robotically or by Artemis astronauts. This is particularly important for sampling in regions inaccessible to astronauts or simply too high risk to send humans. The United States has never robotically returned a sample (as yet) from a planetary surface. Having this technology developed and available would facilitate more science from the Moon and beyond.

Human-Robotic Partnerships: If astronauts had a capable robotic partner as they explore the surface of the Moon, more area would be explored and more samples taken. For instance, areas could be prospected by programmed robotic grid searches. Such partnerships will also enable exploration of locations that would be too risky to astronauts (e.g., teleoperations). However, anecdotal evidence from the Desert RATS astronaut training is that current robotic assistants are too slow to directly aid the human in the field. Technology development is urgently needed in this area.

References: [1] Langseth M.G. et al. (1976) PLSC 7th, 3143-3171. [2] Schönberger J.L. et al. (2016) https://www.cv-foundation.org/openaccess/content_cvpr_2016/papers/Schonberger_Structure-From-Motion_Reviited_CVPR_2016_paper.pdf [3] Hiesinger et al. (2020) This Volume. [4] Porcelli L. et al. (2019) Space Sci. Rev. 215. [5] Dell'Agnello S. et al. (2019) 50th LPSC. [6] Watters T. et al. (2020) This Volume. [7] Panning M. et al. (2020) Artemis This Volume. [8] Schmerr et al. (2020) This Volume. [9] Moebius B. et al. (2010) ICSO Conference. [10] NASA's Aretmis Plan (2020) https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf. [11] Lunar ISRU 2019 Wksp Report (2019) https://www.hou.usra.edu/meetings/lunarisru2019/workshop-report.pdf. [12] Graham K. (2017) Digital Journal http://www.digitaljournal.com/tech-and-science/technology/kilopower-project-nasa-testing-space-rated-fission-power-unit/article/509214. [13] Saal A.E. et al. (2008) Nature 454, 192-195. [14] Haskin L. (1992) *Lunar Bases & Space Activities* **2**, 393-396. [15] McKay D.S. et al. (1991) Lunar Regolith in The Lunar Sourcebook 285-356. [16] Haskin L. & Warren P. (1991) Lunar Chemistry in Lunar Sourcebook, 357-474. [17] Schmitt H.H. (2006) Return to the Moon, Copernicus Books.