THE IMPORTANCE OF INCORPORATING FIELD PORTABLE INSTRUMENTATION IN LUNAR SURFACE EXPLORATION – AND THE IMPLICATIONS OF DOING SO. K. E. Young[1], J. E. Bleacher[1], T. G. Graff[2,3], T. D. Glotch[4], A. D. Rogers[4], A. McAdam[1], P. L. Whelley[5,1], J. Richardson[5,1], C. Achilles[6,1], C. Knudson[5,1], W. B. Garry[1], B. Feist[2,3], S. P. Scheidt[7,1], C. Honniball[6,1], Z. Morse[7,1], A. Naids[3], D. Coan[8,1], E. B. Rampe[3], C. Evans[3], E. Bell[5], and N. Schmerr[5], [1]NASA Goddard Space Flight Center, Greenbelt, MD, 20771; [2]Jacobs at NASA Johnson Space Center, Houston, TX, 77058; [3]NASA Johnson Space Center, Houston, TX, 77058; [4]Stony Brook University, Stony Brook, NY, 11794; [5]University of Maryland, College Park, College Park, MD, 20771; [6]Universities Space Research Association at NASA GSFC, Greenbelt, MD, 20771; [7]Howard University, Washington, DC, 20059; [8]The Aerospace Corporation, Houston, TX, 20771; corresponding author email: Kelsey.E.Young@nasa.gov

Introduction: With NASA's plans for lunar surface exploration under the Artemis program comes a need to reconcile any necessary changes from our Apollo lunar surface exploration experience with the many decades of technological advancements that have occurred in the interim. Laboratory-based technologies that have served to advance our base of knowledge in critical areas (e.g. laboratory x-ray fluorescence which has been a critical resource in analyzing both lunar and terrestrial materials) have since been miniaturized to allow for field-based use. Many studies have been done to evaluate how best to use these handheld and field portable technologies in the field as an analog for astronauts deploying them during future planetary surface exploration. This submission explores many of these tests in the context of lessons learned about designing hardware, software, and operational strategies for incorporating field portable instruments into future Artemis missions. The science and instrument community should take these lessons into consideration as we continue the push toward instrument advancement in preparation for lunar and martian crewed exploration.

Background: *Instrumentation:* Many different techniques have been used in terrestrial field geology to evaluate scientific regions of interest from an outcrop to orbit scale. This includes, but is not limited to, remotely sensed data, data obtained using aircraft (both crewed and with Uncrewed Aerial Vehicles, or UAVs), outcrop-scale data (using tripod-mounted or other standoff techniques), and data obtained on or using rocks and other geologic materials (including *in situ* analysis and follow-up sample analyses). We already have detailed remotely sensed data of the entire lunar surface thanks to the Lunar Reconnaissance Orbiter (LRO) and future Artemis remote sensing work will likely not impact crew extravehicular activity (EVA) timelines as that work will take place prior to crew arrival. However, the use of outcrop scale instruments, handheld instruments, and payloads that will be astronaut-deployable will definitely impact crew activities and time due to the need for crews to operate them real-time. This submission details lessons learned from interacting with these payloads in analog studies, and what Artemis missions need to consider when designing EVAs incorporating instruments.

Analog Testing Environments: No testing location is a perfect analog for the lunar or martian surface, but by combining lessons learned from multiple analog tests, we can robustly prepare for Artemis. One such testing environment is through the Remote In Situ and Synchrotron Studies for Science and Exploration (RIS^{4}E and RISE2) team led out of Stony Brook University (PI Tim Glotch) and funded by the Solar System Exploration Research Virtual Institute (SSERVI). RIS^{4}E and RISE2 work focuses on the incorporation of field portable instruments into planetary surface exploration. RIS^{4}E work focused specifically on timeline implications of using instruments in science-driven EVAs as well as the trade space between the science value added of real-time instrument data and the operational hit of using those tools. RISE2 work now focuses on the informatics support necessary to operate science EVAs incorporating instruments (what the crew on EVA and the science support teams back on Earth) need access to in order to track and facilitate EVA progress.

Other testing environments include NASA Extreme Environment Mission Operations (NEEMO) work, numerous geologic field campaigns in analog environments including lava tubes in California and volcanic fields in both Iceland and Flagstaff, Arizona.

Handheld Instruments: Certain advanced technologies and payloads may be set up by a crewmember, initialized, and left for longer durations of data acquisition (e.g. tripod-mounted techniques like Light Detection and Ranging (LiDAR)). However, other technologies require constant interaction with a crewmember in order to obtain valuable data. For example, handheld instruments such as a handheld x-ray fluorescence spectrometer (hXRF) or a handheld laser induced breakdown spectroscopy tool (LIBS) function by, following the critical step of the crewmember selecting the analysis spot, an astronaut holding the instrument up to a rock, soil, or outcrop of interest, initializing the data collection by depressing a button or trigger, and holding the instrument to the sample for the entire duration of analysis (ranging from seconds to up to a minute). Many commercial companies have developed these tools for purposes such as industry, mining, and even field science, and field testing (i.e. RIS^{4}E and RISE2) has deployed these in a variety of analog environments to evaluate how best to use these in a future Artemis EVA.

Astronaut Deployable Payloads: Beyond handheld technologies are instruments that require a variety of astronaut interaction but not constant contact between the instrument and the astronaut during data acquisition. For example, a geophysics package similar to the Apollo Lunar Seismic Experiment Package (ALSEP) that an astronaut must set up, initialize, and then leave to collect data has different operational implications than a handheld tool. These differences must be field tested to fully understand how to design EVAs that include these instruments.

Hardware Constraints: Regardless of the mode of deployment, instruments that require interaction with a suited EVA crewmember must be carefully designed. Based on more than a decade of field-testing instruments both commercially available and those in development in-house, there are many concerns that must be taken into account when designing hardware for inclusion in Artemis. Sharp and pinch hazards are a real concern, and must meet all requirements outlined by NASA's EVA Office. The physical rigors of working in a pressurized suit preclude instruments that require complex body positions or a sustained trigger pull or button push for operations. Mass and volume must be considered, both because of down mass restrictions and for ease of handling by the crew. Minimizing time on instrument is critical because time is the most precious resource during planetary exploration. An instrument that requires hours of set-up or maintenance time is likely not worth the science data it will provide.

Software Constraints: Beyond the hardware constraints are those concerns associated with viewing and manipulating data and instrument operations, both real-time and post data collection (required when you want to assimilate data either within an EVA or in between EVAs). A perfectly designed instrument package is useless real-time with software that drastically slows down operations or renders data assimilation impossible. Nominal and trouble-shooting procedures must be accessible, whether it be onboard the instrument (accessible by the EVA crewmember deploying it), accessed by a supporting intravehicular (IV) crewmember, or accessible from an Earth-based Mission Control team. Advanced informatics (i.e. a touchscreen on a cuff or a heads-up display mounted directly into the helmet) have the ability to present EVA crews with instrument data real-time from that EVA or prior EVAs, perhaps even annotated by IVA crew or by Earth-based science teams. Field testing how these informatics will be incorporated is absolutely critical, as we have no experience with this kind of advanced platform in spaceflight up until now. Field tests such as RIS^{4}E, RISE2, and NEEMO present several options for viewing and manipulating instrument data, but the critical factor is providing the crew with data without overwhelming them with it, as an EVA's primary science objective should always be exploration.

Concepts of Operations: Determining what science instruments and payloads should be included in Artemis missions and how best to design EVAs to incorporate them is no easy feat. RIS^{4}E work focused on the integration of datasets collected by UAVs (to provide aerial context for each EVA), by tripod-mounted or outcrop scanning instruments (to provide outcrop-scale context for all collected samples and handheld instrument data collection), and by handheld instruments like the hXRF and the LIBS. By combining data from all types of instruments, RIS^{4}E crews and science teams were able to form a complete view of the provenance of each site as well as place all collected samples into a greater geologic context. RIS^{4}E work also highlighted the ability of instruments to high grade for each other. For example, the hXRF takes approximately two minutes to collect one data point, giving the chemistry of an analyzed spot. The portable x-ray diffractometer (XRD) takes upwards of an hour to analyze, but provides a more detailed look of a sample's mineralogy. By using the hXRF to select which samples should be analyzed using the XRD, RIS^{4}E crews maximized the amount of highly valuable scientific data, while minimizing the amount of their critical EVA time to work hands-on each instrument. Field testing has been critical in driving out these lessons learned.

Conclusions: Field portable instruments, regardless of their deployment mode, have the potential to dramatically increase the science return of crewed planetary surface exploration. However, more than a decade of field testing has shown that hardware and software constraints must be rigorously tested and controlled, and understood for mission implementation. This effort outlines lessons learned from multiple operational field tests in an effort to determine how best to design and implement field portable technologies into future Artemis EVAs.

Acknowledgments: Thanks to NASA's SSERVI and Planetary Science Through Analog Research programs for funding this research. We would also like to acknowledge the broader RIS^{4}E, RISE2, NEEMO, and Goddard Instrument Field Team (GIFT) teams for their hard work and dedication to safe and productive field deployments.