DEVELOPMENT OF STANDARDIZED LUNAR REGOLITH SIMULANT MATERIALS. P. Carpenter[1], L. Sibille[1], and S. Wilson[2], [1]XD42/BAE Systems, Marshall Space Flight Center, AL 35812, paul.carpenter@msfc.nasa.gov, [2]United States Geological Survey, MS964, Lakewood CO 80025.

Introduction: Lunar exploration activities require scientific and engineering studies that use standardized testing procedures and ultimately support flight certification of hardware and the development of technologies for their use on the lunar surface. It is necessary to anticipate the full range of source materials and environmental constraints that are expected on the Moon and Mars, and to evaluate in-situ resource utilization (ISRU) coupled with testing and development. Historical use of lunar simulants has focused on physical aspects of the lunar regolith for landing and transportation activities. Lunar mare simulants MLS-1 and JSC-1 have been developed, but supplies have been exhausted. Renewed emphasis on exploration and ISRU activities requires development of standardized simulant reference materials that are traceable interlaboratory standards for testing and simulate the lunar regolith in terms of physical, chemical, and mineralogical properties. This new generation of lunar regolith simulants must therefore support both technological development and testing methods. These issues were extensively discussed at the 2005 Lunar Regolith Simulant Materials Workshop [1].

Root and Derivative Lunar Simulants: A lunar simulant is manufactured from terrestrial components for the purpose of simulating one or more physical and chemical properties of the lunar regolith. A *root* simulant represents an end-member in terms of simulant properties, and a *derivative* simulant is formed from a root by modification or addition of material [2]. The degree of duplication of soil characteristics in the simulant is the simulant *fidelity*. The 2005 Workshop recommended production of two root simulants corresponding to a low-Ti mare basalt and a high-Ca highland anorthosite. These roots represent compositional end-members of mare and highland materials, and can in principle be physically mixed to target the range of soil compositions in the Apollo inventory. Specific lunar regolith properties can be addressed by addition of ilmenite, glassy agglutinates, nanophase iron, and other materials [3]. The fidelity of root simulants is thus increased by addition to form derivative simulants. Lunar dust simulants are also needed for studies on human toxicology and mechanical abrasion. The workshop recommended redeployment of JSC-1, as it can serve as a preliminary general purpose testing material for immediate needs while root simulants are developed.

Standardized Simulant Reference Materials: An ideal standard reference material is homogeneous, widely available, and inexpensive to produce and purchase. Homogeneity is most important, on the scale of material supplied to the end user, and on the scale of a production run. Geochemical standards are finely-ground rock powders that reduce chemical variability by reducing the grain size. Small aliquots of the standard are representative of the master distribution because each aliquot contains a large number of grains. Conversely, lunar simulants have a grain size variation and distinct modal mineralogy at each size fraction that must be retained in order to match the target lunar regolith. As the sample size is reduced, at some point it is no longer representative. The deviation in properties is typically monitored by chemical analysis using major, minor, and trace element analytical data of progressively smaller sample sizes, and comparing these data with replicate analyses performed on bulk material. This problem is illustrated for MLS-1, where a ~10% variation in SiO_2 is observed, compared to a 160% variation for Cr. This is a chemical contrast effect, illustrating small differences in the major element Si for silicates, but large differences for the trace element Cr. Similarly, geotechnical properties may be dominated by a large difference in mineral hardness, and rogue grains would stand out in tests using too small a quantity of material. The variability of simulant material thus is an inherent property but must be taken into account for both quality control and for simulant use by the scientific community.

Simulant Production and Quality Control: Simulant production requires selection of the appropriate terrestrial source material, milling to produce the required grain size distribution, characterization of chemistry, mineralogy, and geotechnical properties, and monitoring of adherence to simulant requirements and homogeneity during production. Simulant must be characterized during critical stages of production and packaging. This quality control establishes a traceability and a chain of calibration to a master set of reference standards. A supplied certificate documents the placement of the simulant material within the production sequence, and includes compositional data and other information specific to the reference material.

References: [1] Sibille L. and Carpenter P. (2005) *Lunar Regolith Simulant Materials Workshop Final Report and Subsequent Findings*. NASA Technical Memorandum (*In preparation*). [2] Carter J., et al. (2004) Space Resources Roundtable VI, 15. [3] Taylor L. et al. (2004) Space Resources Roundtable VI, 46.