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Space systems – Lunar Simulants

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

ISO CD 10788 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operation,* Working Group 4*, Space Environments*.

Introduction

This International Standard provides lunar systems developers and operators with a specific quantitative measure for lunar regolith simulants in comparison to other simulants and with relation to sampled lunar materials from Apollo and Lunakhod missions. Developers of lunar systems will use simulants as test materials. This International Standard is a reference for quantitative measures of lunar simulants finer than 10cm. The quantitative measures of lunar dust simulants are based on the quantitative measures of lunar regolith samples collected at multiple lunar landing sites of the Apollo missions.

This standard provides communication of the geological quality of the simulant between developing organizations and systems operations organizations.

Space systems – Lunar Simulants

1 Scope

This International Standard is a reference for quantitative measures of lunar simulants. The quantitative measures of lunar simulants are based on the quantitative measures of lunar samples collected at multiple lunar landing sites of the Apollo missions.

2 References

2.1 Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 10788 dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 10788 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO WD 10905 Space Environment (Natural and Artificial) — Lunar Dust Creation, Suspension and Transport

2.2 Informative References

NASA/TM-2008-215261, NASA Technical Memorandum: The Need for High Fidelity Lunar Regolith Simulants

Carrier, W. David, III, 1973, Lunar Grain Size Distribution: The Moon, v. 6, p. 250-263.

Heiken, G., D. Vaniman, et al. (1991). Lunar sourcebook : a user's guide to the moon. Cambridge [England] ; New York, Cambridge University Press.

Jolliff, B. L., M. A. Wieczorek, et al. (2006). New views of the Moon. Chantilly, Va., Mineralogical Society of America.

Papike, J. J. (1998). Planetary materials. Washington, D. C., Mineralogical Society of America.Terms, definitions and abbreviated terms

2.3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

Regolith -
All particulate surface material including rocks, soils and dust.

Dust -
A component of regolith which has dominant forces in addition to or other than gravity. This may include electrostatic forces

Note – the current definition used in NASA is 20 micrometers. This was done based on analog with pulmonary considerations behind US Environmental Protection Agency and US Occupational Safety and Health Administration rules related to lower gravity. As stated in the Introduction, this standard is limited in scope to particles 10cm and smaller.

Re-Use-
After a simulant volume is used (any sequence of events in which a simulant volume is removed from a storage container) then placed back into storage, any future use constitutes re-use.

2.4 Abbreviated terms

TBD for this document. Complete in DIS/FDIS stage.

3 General Characteristics of Lunar Regolith

3.1 Primary Properties

3.1.1 Minerologies

The lunar surface mineralogy is variable across major terrain. These properties are qualitative. A listing of the primary minerologies is:

Anorthite, Olivine (Fo_{80}), Clinoenstatite, Pigeonite, Hedenbergite, Augite, Enstatite, Spinel, Hercynite, Ulvospinel, Chromite, Troilite, Whitlockite, Apatite, Ilmenite, + native iron

3.1.2 Other Properties

The Lunar Sourcebook© provided a compilation of properties from Apollo and Lunakhod lunar samples of use to the scientific community. These properties are listed since a large amount of data exists for lunar regolith characterization. These properties are qualitative and quantitative.

3.1.2.1 Physical Properties

3.1.2.1.1 Geotechnical Properties

Size

Shape

Specific Gravity

Bulk Density

Porosity

Relative Density

Compressibility

Shear Strength

Permeability and Diffusivity

Bearing Capability

Slope Stability

Trafficability

3.1.2.1.2 Electrical and Electromagnetic Properties

Electrical conductivity

Photoconductivity

Electrostatic Charging

Dielectric Permittivity

3.1.2.2 Chemical Properties

Major Elements

Incompatible Trace Elements

Miscellaneous Minor Elements

Siderophile Elements

Vapor-Mobilized Elements

Solar Wind Implanted Elements

4 Quantitative Measurement Properties of Lunar Simulants

The proper qualification of lunar simulants is tied to lunar minerologies and is expressed most concisely in four figures of merit: Composition, Size, Shape and Density. The figures of merit for lunar simulants range from zero to one. A zero figure of merit indicates no useful correlation to a comparative sample. A one figure of merit indicates exact correlation as defined by the standard measurements to a comparative sample. Data from existing lunar samples is necessary to use these figures of merit.

4.1 Comparative Baseline

Comparative (quantitative) measures shall be stated for lunar simulants. Figures of merit for a simulant shall be stated against a single baseline. If multiple baselines are referenced for a simulant a complete set of figures of merit shall be calculated for each reference.

4.2 Impurities and Contamination

Simulants will not be completely defined by these Figures of Merit for reasons of mineralogical impurity and contamination of the simulant by organic/inorganic materials.

Impurity of the sample/simulant measured shall be stated in percent of the sample mass.

Contamination of the sample/simulant shall be stated in percentage of the sample volume. Characterization of the sample contamination and the nature of that contamination shall be stated if an analysis is performed.

4.3 Validation of Figures of Merit

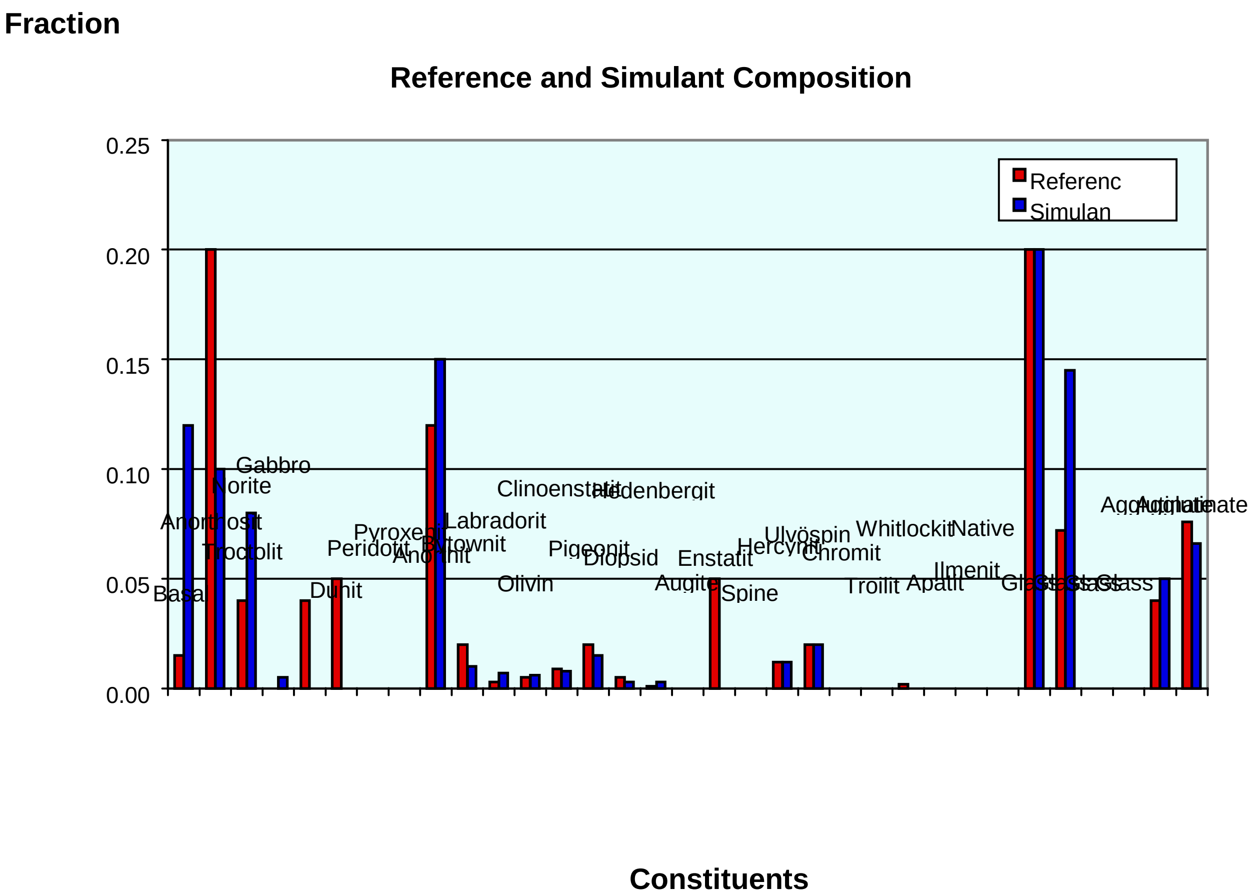
Calculation of figures of merit for a simulant shall be performed and recorded for each use. In the event a volume of simulant is re-used, the figures of merit shall be recalculated in accordance with this standard.

4.4 Composition Figure of Merit

4.4.1 Composition Figure of Merit (FoM) Equation

$$FoM = 1 - \frac{\left\| w_{adjusted} \left(c_{adjusted-reference} - c_{adjusted-simulant} \right) \right\|_1}{\left\| \left[\max_1 \left(w_{adjusted} \right) \max_2 \left(w_{adjusted} \right) \right] \right\|_1}$$

where $\max_i(w)$ is the i^{th} largest element of *w.*



than mineralogy for lithic fragments. Texture describes the grain to grain connectivity boundary. Lunar textures cannot be replicated on Earth. Lunar terrains are mare and highlands.

4.4.3.2 Glasses

Glasses shall be made from the rest of the material in the simulant

Glasses shall have a normative mineralogy within the range of the moon.

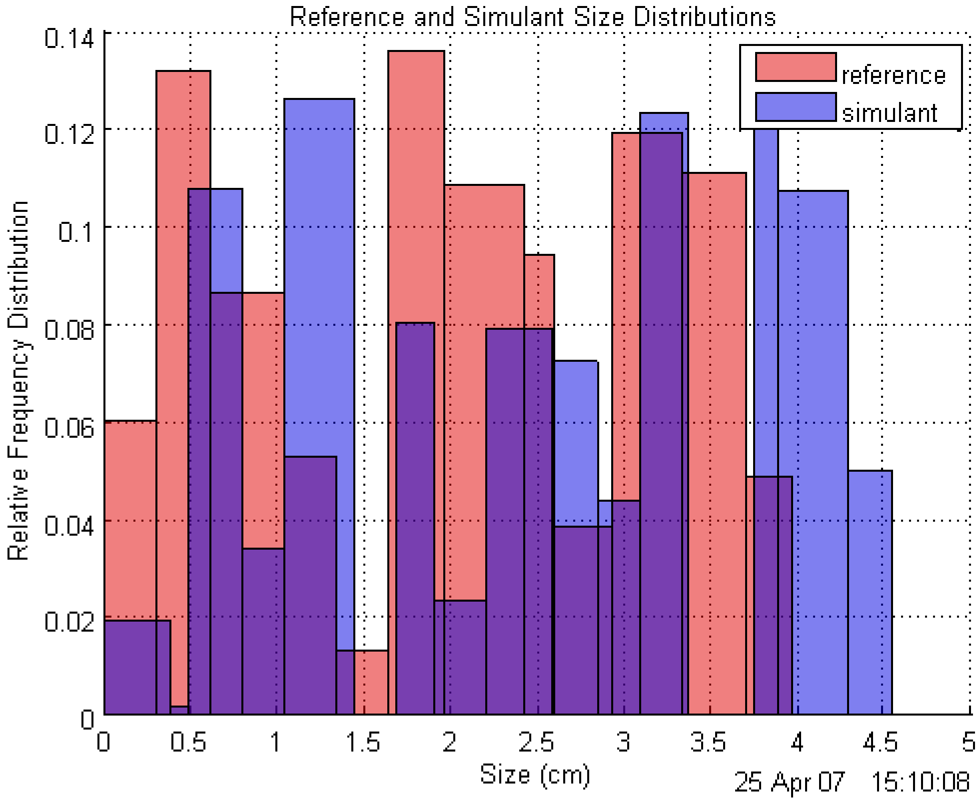
4.5 Size Distribution Figure of Merit

4.5.1 Size Distribution FOM Equation

$$FoM_{before-constraints} = 1 - \frac{\int \left(w \left(RFD_{reference} - RFD_{simulant} \right) \right)^2}{\int wRFD^2_{reference} \int wRFD^2_{simulant}}$$

with the further constraint

$$FoM = \begin{cases} FoM_{before-coonstraints} & if \ |RFD_{reference} - RFD_{simulant}| \le \max RFDdifference \\ 0 & otherwise \end{cases}$$



Example

4.5.2 Particles from 4 cm to 75 microns

Particles from 4 cm to 75 microns shall be measured by sieving.

(Specifications for the Apollo materials will be drafted by JSC/Sue Wentworth and by UC/Susan Batiste for the simulants.)

4.5.3 Particles from 100 microns to 1 micron

Particles of Apollo and simulant materials between 100 microns and 1 micron shall be analyzed using optical imaging.

(This will be drafted by Allen Wilkinson of GRC.)

4.5.4 Particles finer than 2 microns

Particle finer than 2 microns shall be analyzed using aerosol dispersion.

(This will be documented by Paul Greenberg of GRC.)

(Alan Rawle of Malvern and Paul Greenberg will make a recommendation about production of a physical standard to test various manufacturer's instrumentation for cross comparison and validation.)

4.6 Shape Figure of Merit

4.6.1 Shape FoM Equation

$$FoM_{before-constraints} = 1 - \frac{\int w \left(RFD_{reference} - RFD_{simulant} \right)^2}{\int wRFD^2_{reference} + \int wRFD^2_{simulant}}$$

with the further constraint

$$FoM = \begin{cases} FoM_{before-coonstraints} & if \ \left| RFD_{reference} - RFD_{simulant} \right| \leq \max RFDdifference \\ 0 & otherwise \end{cases}$$

4.6.2 Aspect Ratio

Aspect ratio shall be determined to define particle shape.

4.6.3 Angularity

Angularity shall be determined to define particle shape.

4.7 Density Figure of Merit

4.7.1 Density FoM Equation

$$FoM = \begin{cases} \frac{1}{density_{quotient\_}\lim it} \left(\frac{simulant_{density}}{reference_{density}} \right) - \frac{density\_\lim it - 1}{density_{quotient\_}\lim it} \\ for \ 1 - density_{quotient\_}\lim it \leq \frac{simulant_{density}}{reference_{density}} \leq 1 \\ \frac{-1}{density_{quotient\_}\lim it} \left(\frac{simulant_{density}}{reference_{density}} \right) - \frac{density\_\lim it + 1}{density_{quotient\_}\lim it} \\ for \ 1 \leq \frac{simulant_{density}}{reference_{density}} \leq 1 + density_{quotient\_}\lim it \\ 0_{otherwise} \end{cases}$$

4.7.2 Measurement

Density shall be measured by taking a sufficiently large enough sample so that the sample follows the particle size distribution of the material as defined in the slides on Size Distribution.

5 Quantitative Properties of Lunar Simulants

Lunar simulants may be measured as lunar samples were measured and published (reference paragraph 4.1.2.). However, the quality of lunar simulants measured in this way cannot be readily compared to lunar source material nor communicated across development and operational communities. Comparison of these measures for simulants for other than scientific purposes is not recommended.

5.1 Physical Properties

5.1.1 Geotechnical Properties

Size

Shape

Specific Gravity

Bulk Density

Porosity

Relative Density

Compressibility

Shear Strength

Permeability and Diffusivity

Bearing Capability

Slope Stability

Trafficability

5.1.2 Electrical and Electromagnetic Properties

Electrical conductivity

Photoconductivity

Electrostatic Charging

Dielectric Permittivity

5.2 Chemical Properties

Major Elements

Incompatible Trace Elements

Miscellaneous Minor Elements

Siderophile Elements

Vapor-Mobilized Elements

Solar Wind Implanted Elements