Lunar Natural Environment for Use by the Constellation Program

by
Dale C. Ferguson
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The Lunar Environments used by the Constellation Program are embodied in two documents, the NEDD (Natural Environments Definition for Design) and the DSNE (Design Specification for Natural Environments). Recently, the lunar environments for the NEDD have been defined and incorporated in the document, as the result of contributions from experts in all areas of lunar environments. The purpose of the NEDD is to provide a uniform description of the natural environment to serve as a basic framework for both the crewed and robotic missions of the Exploration Systems Mission Directorate (ESMD). It is intended to support engineering and analysis, requirements development, and verification involved in the development of exploration concepts and architectures, flight hardware, and new technologies. (It does not support the operational phases of the Program since models and data with different properties are needed for those applications.) By presenting a single benchmark definition of natural environment parameters it provides an easily accessible and uniform baseline for competitive studies, independent analyses, and concept studies. This document is a requirement in the sense that its use is directed by the Program, but it does not contain any requirement "shall" language. It provides a single description of each environment that requirements may be written against, thereby enabling clear definition of contract scope and control. By providing a complete and single source for environment data, the document also reduces system development cost by providing a ready source of required technical data and minimizing the environment related efforts required of the contractor community. Since the definitions specified herein are, for the most part, definitions developed and used on prior programs, they are well understood by NASA and significant portions of the contractor community. Thus, use of this book enables a better understanding of Program technical risk than would be possible without a baselined definition document.

The scope of the NEDD lunar sections is described below:

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> a. Terrestrial Environments (Sections 2 through 4)
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Cis-Lunar and Lunar Environments focus on the lunar orbital and surface environments.

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Overall Lunar NEDD Editor – Dale Ferguson, MSFC
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Lunar NEDD Writing Team Leads:

Plasma Interactions, Vehicle Charging
Dale Ferguson, MSFC

Radiation Environment, Secondary Radiation
Joe Minow, MSFC

Contamination
Joey Norwood, MSFC

Lunar Regolith Mechanical Properties
Paul Greenberg, GRC
Lunar Regolith Electrical Properties, Dust Charging
Jason Vaughn, MSFC
Lunar Regolith Chemical and Magnetic Properties
Jim Gaier, GRC
Meteoroids
Bill Cooke, MSFC

In this paper, we give examples of some of the lunar sections of the NEDD, showing the type of content that is present, with particular emphasis on the lunar dust, plasma and charging environments.

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NASA Marshall Space Flight Center, Huntsville, AL, 35812

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Nomenclature

ALSEP	=	Apollo Lunar Surface Experiment Package
CxP	=	Constellation Program
DSNE	=	Design Specification for Natural Environments
ESD	=	electrostatic discharge
ESMD	=	Exploration Systems Mission Directorate
eV	=	electron volts
LEAM	=	Lunar Ejecta and Meteorite experiment
NASA	=	National Aeronautics and Space Administration
NEDD	=	Natural Environments Definition for Design Introduction
nm	=	nanometers
R_e	=	Earth radii
SIG	=	Systems Integration Group
S/m	=	Sieverts per meter
SRR	=	Systems Requirements Review
UV	=	Ultraviolet

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[1] CxP Test and Verification Lead, Environments and Constraints SIG, MSFC EM50, AIAA Senior Member.

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I. Scope

The scope of the NEDD lunar sections is described below:

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II. Table of Contents

In order to describe the types of environments covered in the NEDD, the Table of Contents for the NEDD Lunar Sections follows:

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13.8.4 Speed
13.8.5 Meteor Showers
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III. Lunar NEDD Editors

Writing of the Lunar NEDD Sections was assigned to teams of authors, each team being led by a topical editor. The editors are listed here:

Overall Lunar NEDD Editor – Dale Ferguson, MSFC

NEDD Book Manager – Leigh Smith, MSFC

Lunar NEDD Writing Team Leads:

Plasma Interactions, Vehicle Charging - Dale Ferguson, MSFC

Radiation Environment, Secondary Radiation - Joe Minow, MSFC

Contamination - Joey Norwood, MSFC

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Lunar Regolith Electrical Properties, Dust Charging - Jason Vaughn, MSFC

Lunar Regolith Chemical and Magnetic Properties - Jim Gaier, GRC

Meteoroids - Bill Cooke, MSFC

IV. Examples of Lunar NEDD Sections

Below are some Lunar NEDD sections, lifted verbatim from the 09/24/08 version of the NEDD. References are given in the NEDD reference sections.

Lunar Regolith Electrical Properties

Introduction

Theoretical considerations and observational evidence acquired from Apollo, as well as subsequent lunar missions, indicates that the lunar surface and dust grains are electrostatically charged by the incident solar UV radiation and the solar wind plasma.[172,173] On the lunar dayside of the Moon, the dust is believed to be charged positively by photoelectric emissions with the incident solar UV radiation, and predominantly negatively by the incident solar wind electrons on the nightside. There is considerable evidence to indicate that the charged fine lunar dust grains, smaller than a few microns in size, are levitated and transported to high altitudes and transported over long distances across the lunar terminator.[174, 175, 176, 177] The lunar dust, with its toxic nature and high adhesive characteristics, constitutes a major source of hazard for humans and the mechanical systems in human and robotic exploration of the Moon.

Although the basic principles and the underlying sources of the observed lunar dust phenomena are recognized, the extent and the details of the lunar dust charging, levitation, and transportation process remain poorly understood. The current theoretical models do not satisfactorily explain the observed lunar dust phenomena. A more definitive knowledge of the lunar dust phenomena with acquisition of the basic data is needed for engineering solutions and development of mitigating strategies.

Lunar Dust Charging Processes

The charging of the lunar regolith is a complex process and can be accomplished by many different means. The lunar regolith is typically a non-conductive material suggesting that it can be charged readily by many different means. Electrostatic charging of the lunar regolith and dust can be done by photoelectric emissions produced by UV radiation at wavelengths near 200 nm on the dayside, leading to positively charged grains, with substantial electrostatic charging taking place when the dust is bombarded by soft X-rays with a wavelength <100 nm. Electron or ion collisions on the nightside of the lunar surface produce negatively charged dust grains due to low-energy electrons (<100 eV) impact, and positively charged dust grains due to high-energy electron impact. These different charge states are typically driven by variations in the secondary electron yield of the dust grains.

Triboelectric charging is the other charging process that must be considered. Triboelectric charging of dust grains by contact charging is a process in which electrons are transferred from a solid material with high work function to one with a lower work function, and occurs during landing of a lunar vehicle or movement of an astronaut over the regolith. Triboelectric charging can be exacerbated by trying to remove the dust through brushing, dusting, or blowing. Triboelectric charges can build up rapidly because there is no atmosphere to discharge through, and the regolith is electrically insulating (i.e., there is no common "ground" for electrical equipment). The dust forms unique morphologies, is loosely packed, and is electrically and thermally insulating. The experience of the Apollo astronauts was that the dust is very adherent and abrasive, and hindered the effectiveness of even those very short missions. Mitigation of the effects of charge and dust must be a priority for any mission planned for a long stay on the lunar surface. The source of the problem is twofold: induced charging through triboelectric effects and interactions with naturally occurring background charge.

Effects on Landed Operations: Roving, Power Systems, and Dust

The surface potential and its fluctuations in solar storms can affect landed systems in three ways: roving and charge dissipation, Constellation Program (CxP) Power System, and lunar dust.

a. Roving and charge dissipation: As astronauts rove, they will accumulate triboelectric charge (frictional or contact electricity) with the regolith. In sunlit regions, the photoelectric and ambient plasma currents can dissipate astronaut charge on time scales of < 0.01 seconds. However, in unlit regions where solar wind flow is obstructed (by a large mountain or inside a crater such as Shackleton or Shoemaker), there are little natural environmental currents to remediate any tribocharge build-up. Within the cold craters, the conductivity of the regolith can become as low as 10^{-14} S/m, rendering them insulators (unable to deliver the needed currents). Recent studies indicate that the dissipation time in unlit craters could be as large as 10-100 seconds. Hence, a rover (continuous charging) or astronaut (charging with each step with a cadence of a second) will charge faster than can be dissipated. As a consequence, roving systems in unlit regions can become Electrostatic Discharge (ESD) hazards.

b. CxP Power System: Any polar base will spend some fraction of time in darkness and away from the photoelectric sheath. As a consequence, the region is susceptible to solar-storm-induced variations in surface potential. Given the poor conductivity of the lunar regolith (making it a poor electrical "ground"), a potential difference can develop between the surface and objects located on the unlit surface during storms. To date, there are no direct measurements of this effect and modeling is just beginning to address this issue. In essence, an object in the unlit region is sitting on an insulator. Consequently, it is recommended that there are clear ground paths for all landed system components to reduce the effect of differential charging, especially during solar storms when the ground and landed components will develop potential differences relative to each other.

   Any system venturing into a polar crater should also be aware that the surface in the unlit region is strongly negative relative to any voltage referenced at the crater rim (in daylight). Thus, the use of a tether for power will have a ground reference to the sunlit region where the power source is located, but the surface surrounding the exploration system could be many hundreds of volts negative relative to the system ground (referenced to a topside location). Some consideration should be given to mitigating this ESD risk.

c. Lunar dust: At terminator/polar regions, where electric fields are expected to be large (see Figure 13.3.3.4.1-2), the dust environment becomes active. The Lunar Ejecta and Meteorite (LEAM) experiment, an Apollo 17 ALSEP package, detected incidence of highly energetic lifted dust grains with speeds >100 m/s at both terminator crossings Berg et al.[145] The dust was detected in all directions but was primarily moving in nightside directions. The activity peaked at the terminators but extended well into the nightside. Figure 13.3.3.4.4-1 shows the incidence of naturally-lifted grains as detected by LEAM with detection of these energized grains at one every couple of minutes. Since LEAM was relativity insensitive to low-energy dust, it is anticipated that there is a progressively larger flux of natural dust at progressively lower speeds (a distribution of dust that increases with density at decreasing velocities) and that LEAM is detecting only the most energetic lofted grains at the "tail" of the distribution. However, landed instrumentation is required to confirm this possibility. The naturally-lifted lunar dust is an indicator of locations where near-surface electric fields may become large.

V. Conclusions

The Constellation Program Natural Environments Definition for Design has been supplemented with Sections on Lunar Environments. These sections of this document will serve as the basis for writing the lunar sections of the Design Specification for Natural Environments (DSNE), an official specification document for the Constellation Program. Along with the DSNE, the NEDD will allow confident and reliable design of Constellation Program missions to the moon.

VII. Acknowledgments

This paper could not have been written without the contributions to the NEDD of all the lunar writers, including Kai Hwang, Bill Farrell, Linda Parker, Joe Minow, Albert Whittlesey, Jim Howard, Marge Bruce, Joey Norwood, Jonathan Campbell, Keith Albyn, Paul Greenberg, Ram Ramachandran, Barbara Cohen, Doug Rickman, Jeff Plescia, Jason Vaughn, Todd Schneider, Mian Abbas, Carlos Calle, Barry Hillard, Jim Gaier, Bob Richmond, John Lindsey, Steve Wilson, Sara Majetic, Bill Cooke, and Ron Suggs. Our very special thanks to the Constellation Program Chief Lunar Scientist, Wendell Mendell.

Lunar Natural Environment for Use by the Constellation Program

Dale Ferguson, Technical Lead for Lunar Environments Definition,
Constellation Environments & Constraints SIG

47th AIAA ASM, Jan. 6, 2009

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  - 13.8.5 Meteor Showers
  - 13.8.6 Lunar Secondaries

Examples of NEDD Lunar Sections

- **13.3.3.2 Lunar Dust Charging Processes**
- **The charging of the lunar regolith is a complex process and can be accomplished by many different means. The lunar regolith is a typically a non-conductive material suggesting that it can be charged readily by many different means.**
- **Electrostatic charging of the lunar regolith and dust can be done by photoelectric emissions produced by UV radiation at wavelengths near 200 nm on the day side, leading to positively charged grains. With substantial electrostatic changing taking place when the dust is bombarded by soft x-rays with a wavelength < 100 nm. Electron or ion collisions on the night side of the lunar surface produce negatively charged dust grains due to low energy electrons (< 100 eV) impact, and positively charged dust grains due to high energy electron impact. These different charge states are typically driven by variations in the secondary electron yield of the dust grains.**

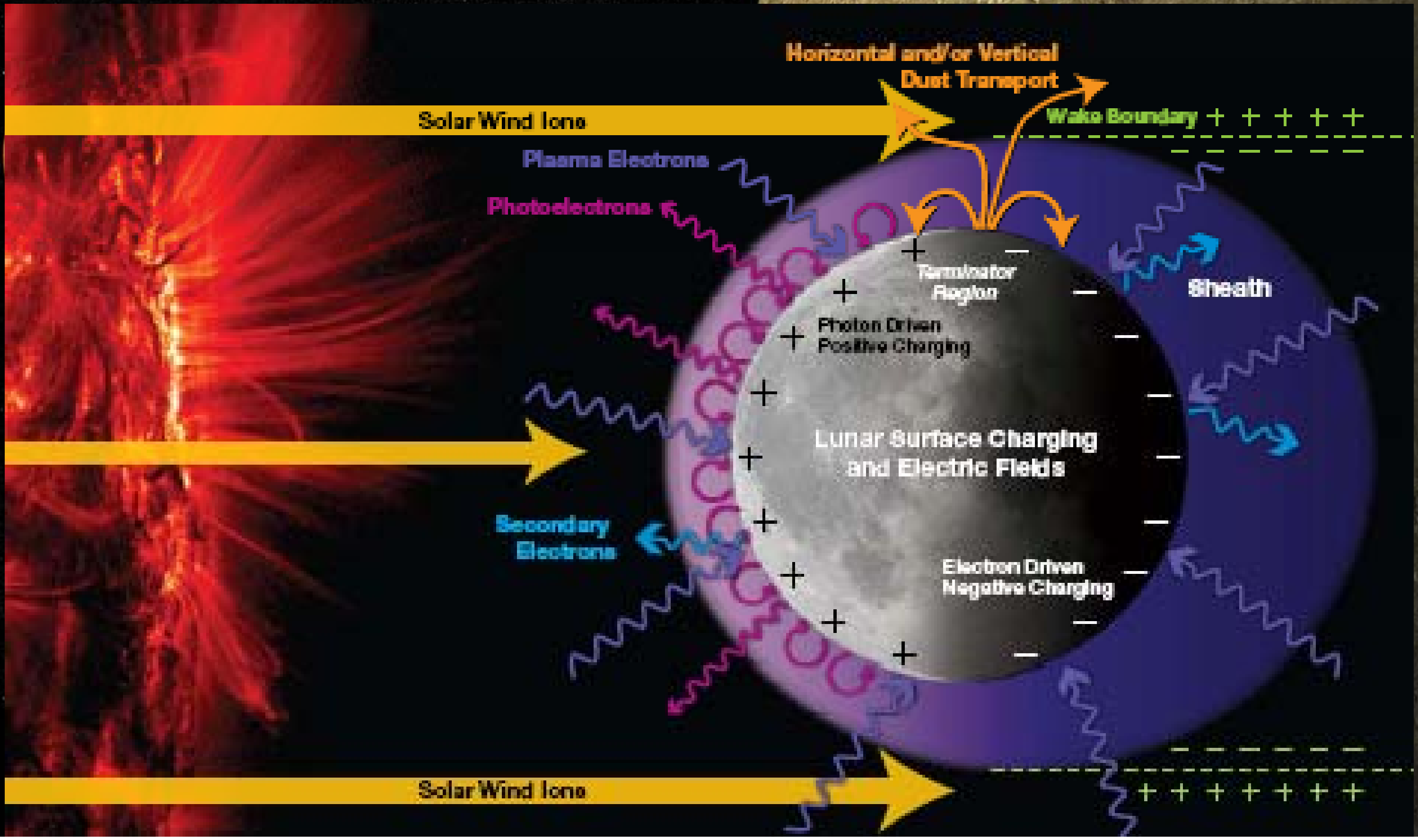
Examples of NEDD Lunar Sections

- The other charging process that must be considered is that of triboelectric charging. Triboelectric charging of dust grains by contact charging process in which electrons are transferred from a solid material with high work function to one with a lower work function will occur during landing of a lunar vehicle or movement of an astronaut over the regolith. Triboelectric charging can be exacerbated by trying to remove the dust through brushing, dusting or blowing. Triboelectric charges can build up rapidly because there is no atmosphere to discharge through, and the regolith is electrically insulating (i.e., there is no common “ground” for electrical equipment). The dust forms unique morphologies, is loosely packed, and is electrically and thermally insulating. The experience of the Apollo astronauts was that the dust is very adherent and abrasive, and hindered the effectiveness of even those very short missions. Mitigation of the effects of charge and dust must be a priority for any mission planned for a long stay on the lunar surface. The source of the problem is twofold: induced charging through triboelectric effects and interactions with naturally-occurring background charge.

Examples of NEDD Lunar Sections

- **13.3.3.4.1 A description of the surface and near surface electrical environment**

  Figure 13.3.3.4.1-1 shows the near-surface electrical environment, characterized by three major regions: a) Dayside region … b) Nightside region...c) Terminator/polar region.



Examples of NEDD Lunar Sections

- 13.3.3.4.4 Effects on Landed Operations: Roving, Power Systems, and Dust
- The surface potential and its fluctuations in solar storms can affect landed systems in three ways:

1) Roving and charge dissipation – As astronauts rove, they will accumulate triboelectric charge (frictional or contact electricity) with the regolith. In sunlit regions, the photoelectric and ambient plasma currents can dissipate astronaut charge on time scales of < 0.01 seconds. However, in unlit regions where solar wind flow is obstructed (by a large mountain or inside a crater like Shackleton or Shoemaker), there are little natural environmental currents to remediate any tribocharge build-up. Within the cold craters, the conductivity of the regolith can become as low as 10^{-14} S/m, rendering them insulators (unable to deliver the needed currents). Recent studies indicate that the dissipation time in unlit craters could be as large as 10-100 seconds. Hence, a rover (continuous charging) or astronaut (charging with each step with a cadence of a second) will charge faster than can be dissipated. As a consequence, roving systems in unlit regions can become ESD hazards.

Examples of NEDD Lunar Sections

♦ **13.3.3.4.4 Effects on Landed Operations: Roving, Power Systems, and Dust (cont.)**

2) CxP Power System – Any polar base will spend some fraction of time in darkness and away from the photoelectric sheath. As a consequence, the region is susceptible to solar-storm-induced variations in surface potential. Given the poor conductivity of the lunar regolith (making it a poor electrical "ground"), a potential difference can develop between the surface and objects located on the unlit surface during storms. To date, there are not direct measurements of this effect and modeling is just beginning to address this issue. In essence, an object in the unlit region is sitting on an insulator.

Consequently, it is recommended that there are clear ground paths for all landed system components to reduce the effect of differential charging, especially during solar storms when the ground and landed components will develop potential differences relative to each other.

Examples of NEDD Lunar Sections

- **13.3.3.4.4 Effects on Landed Operations: Roving, Power Systems, and Dust (cont.)**

Any system venturing into a polar crater should also be aware that the surface in the unlit region is strongly negative relative to any voltage referenced at the crater rim (in daylight). Thus, the use of a tether for power will have a ground references to the sunlit region where the power source is located, but the surface surrounding the exploration system could be many hundreds of volts negative relative to the system ground (referenced to a topside location). Some consideration should be given to mitigating this ESD risk.

3) Lunar dust – At terminator/polar regions where electric fields are expected to be large (see Figure 13.3.3.4.1-2), the dust environment becomes active. The Lunar Ejecta and Meteorite (LEAM) experiment, an Apollo 17 ALSEP package, detected incidence of highly energetic lifted dust grains with speeds > 100 m/s at both terminator crossings [Berg et al., 1973]. The dust was detected in all directions but primarily moving in nightside directions. The activity peaked at the terminators, but extended well into the nightside.

Examples of NEDD Lunar Sections

- **13.3.3.4.4 Effects on Landed Operations: Roving, Power Systems, and Dust (cont.)**

Figure 13.3.3.4.4-2 shows the incidence of naturally-lifted grains as detected by LEAM with detection of these energized grains at one aver couple minutes. Since LEAM was relativity insensitive to low energy dust, it is anticipated that there is a progressively larger flux of natural dust at progressively lower speeds (a distribution of dust that increases with density at decreasing velocities) and that LEAM is detecting only the most energetic lofted grains at the "tail" of the distribution. However, landed instrumentation is required to confirm this possibility. The naturally-lifted lunar dust is an indicator of locations where near surface electric fields may become large. Figure 13.3.3.4.1-2 indicates that driving E fields may indeed peak where LEAM dust is most active at the terminator. Such an electrical environment would also have an impact on any anthropogenically-lofted dust since there is an induced potential on both the roving astronaut and the dust that may further increase their electrostatic attraction.

Examples of NEDD Lunar Sections

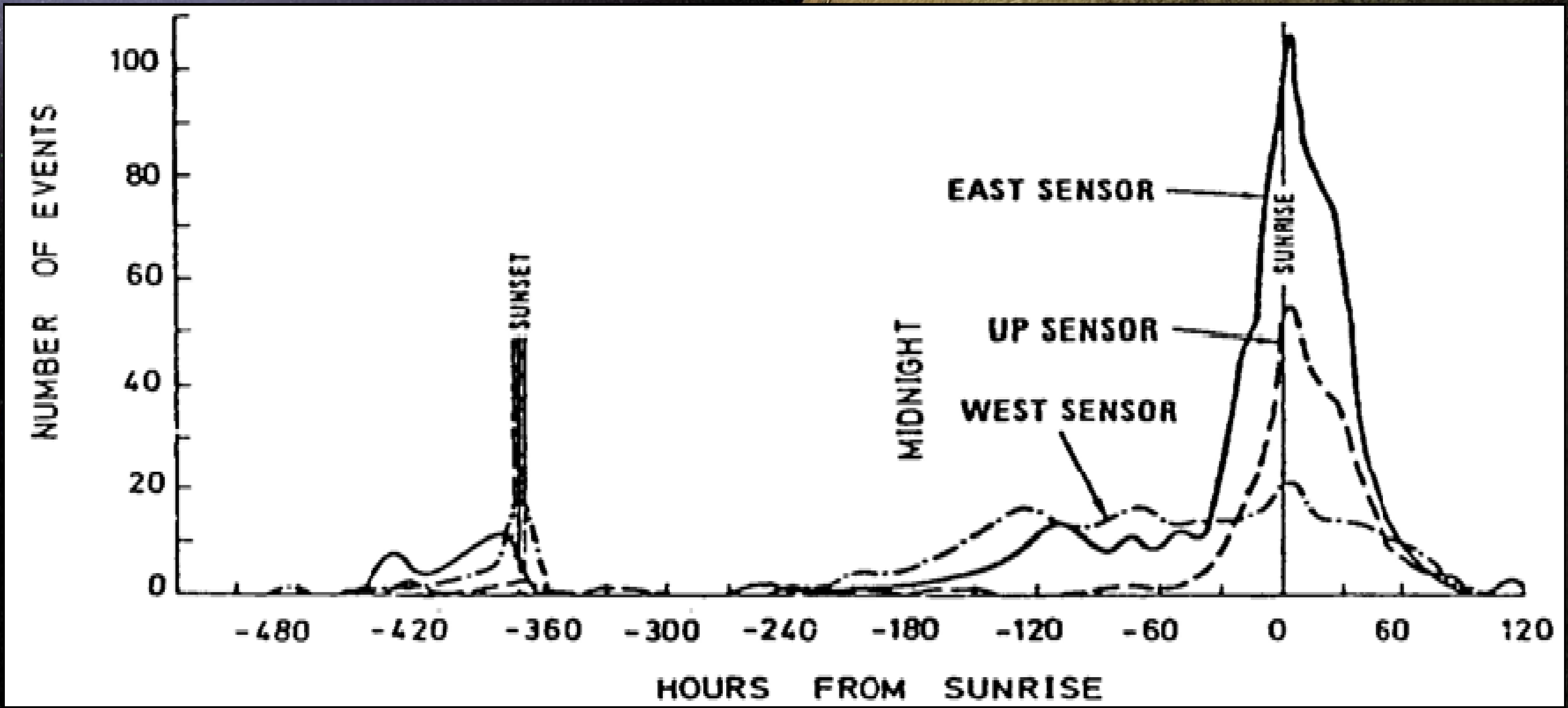


FIGURE 13.3.3.4.4-2: ACCELERATED DUST IMPACTS DETECTED BY APOLLO 17 LEAM SURFACE PACKAGE

Conclusions

The Constellation Program Natural Environments Definition for Design has been supplemented with Sections on Lunar Environments. These sections of this document will serve as the basis for writing the lunar sections of the Design Specification for Natural Environments (DSNE), an official specification document for the Constellation Program. Along with the DSNE, the NEDD will allow confident and reliable design of Constellation Program missions to the moon.

Acknowledgments

This paper could not have been written without the contributions to the NEDD of all the lunar writers, including Kai Hwang, Bill Farrell, Linda Parker, Joe Minow, Albert Whittlesey, Jim Howard, Marge Bruce, Joey Norwood, Jonathan Campbell, Keith Albyn, Paul Greenberg, Ram Ramachandran, Barbara Cohen, Doug Rickman, Jeff Plescia, Jason Vaughn, Todd Schneider, Mian Abbas, Carlos Calle, Barry Hillard, Jim Gaier, Bob Richmond, John Lindsey, Steve Wilson, Sara Majetic, Bill Cooke, and Ron Suggs. Our very special thanks to the Constellation Program Chief Lunar Scientist, Wendell Mendell.