NASA Technical Memorandum 4271

Lighting Constraints on Lunar Surface Operations

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MAY 1991

NASA

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National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division

1991

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ABSTRACT

An investigation into the levels of ambient lighting on the lunar surface indicates that for most nearside locations, illumination will be adequate throughout most of the lunar night to conduct extravehicular activities (EVAs) with only minor artificial illumination. The maximum lighting available during the lunar night from Earthshine will be similar to the light level on a July evening at approximately 8:00 p.m. in the southern United States (approximately 15 minutes after sunset). Because of the captured rotation of the Moon about the Earth, the location of the Earth will remain approximately constant throughout the lunar night, with consequent constant shadow length and angle. Variations in the level of Earthshine illumination will be solely a function of Earth phase angle. Experience during the Apollo Program suggests that EVA activities conducted during the period around the lunar noon may be difficult due to lack of surface definition caused by elimination of shadows.

INTRODUCTION

During the Apollo Program, operational, design, and safety constraints limited lunar surface operations to the portions of the lunar day between early lunar morning, the nominal landing time, and late lunar morning from 24 to 96 hours after landing. Due to vehicle design constraints on consumables, no Apollo missions were planned or executed that would have extended beyond the ≈328-hour lunar day into the lunar night. Consequently, no significant planning took place for lunar surface operations conducted outside the lunar module using ambient night lighting.

The Space Exploration Initiative (SEI), proposed in 1989 by President George Bush, plans to extend our capability for stay times on the lunar surface beyond the 72- to 96-hour Apollo limit to eventual permanent habitation of the Moon. Consequently, it becomes necessary to consider, and to plan for, the operational constraints that would be faced during surface operations conducted during the lunar day. Considerations in developing these operational constraints include the lighting conditions on the lunar surface throughout the ≈655-hour lunar day, and the effect these conditions will have on planning and execution of crew and robotic operations. These constraints affect not only planning for routine surface operations in the vicinity of an outpost or lander, but planning for science operations away from the outpost/lander as well. Issues that are of significant concern to mission development in SEI are as follows.

- Can arrival and departure from the lunar surface be executed at any time during the lunar day?
- Can geologic field work and other surface activities be carried out using only light reflected off the Earth (Earthshine) during the lunar night, or will artificial lighting be required?

- Are there any lighting constraints to lunar surface operations conducted during the high Sun angles of late lunar morning to early lunar afternoon?

For simplicity, this study considered two basic conditions: (1) the amount of illumination on the lunar surface due to Earthshine, and (2) lighting on the lunar surface during high-Sun-angle illumination. An important part of the study was to interpret any conclusions about the amount of illumination available on the lunar surface from Earthshine to "real world" values providing the reader with information that might be tested if so desired. To do this, it was necessary to relate the engineering data on illumination found in various sources to a comparable illumination that would be experienced on Earth. The approach to this task has followed several lines. The first approach was to collect information from crew observations and recollections on the amount of surface topography and geography visible on the lunar surface from orbit using Earthshine as the sole source of illumination, and also to collect information on the constraints involved in working on the lunar surface in varying Sun angles. The second approach was a literature search to find existing values for full-Earth illumination. To complement this, it was necessary to relate the value of Earthshine illumination on the lunar surface to full-Moon illumination on Earth, and to understand how the value of Earthshine illumination changes with differing Earth-Moon geometries. Finally, existing lunar surface photos were scrutinized to determine what lighting constraints might exist under conditions of varying Sun angle.

STUDY ASSUMPTIONS

A number of assumptions were used as a baseline for this study. The first assumption is that the study will not consider heat rejection or cooling questions in its assessment of EVA operations, assuming that future generation life support equipment will be adequate to maintain an appropriate thermal environment inside the EVA suit, regardless of the ambient thermal environment. The second assumption is that electrical power generation at a habitat or lander will be adequate for lunar night EVA operations. The third assumption is that regardless of the conclusions of this study, some form of integral EVA helmet lighting, similar to what is currently used on Space Shuttle EVA suits, and some form of vehicular lighting, will be required for normal operations. This is because regardless of the value of ambient illumination, shadowed areas will still be very dark, and normal safety considerations will dictate the requirement for some form of auxiliary lighting.

The final assumption is concerned with the surface lighting required for a first landing at a previously unprepared location on the lunar surface. During the Apollo program, mission rules dictated that all lunar landings would occur when the Sun was between 5 and 20° above the horizon and behind the lunar module as it made its final approach to the landing site. These conditions provided the crew with the maximum terrain information in the form of long shadows extending down-Sun from any significant terrain feature. It also insured that the sunlight would not be in the astronauts' eyes during the final maneuvering for landing. It is assumed that similar mission rules will be in effect for future manned landings at unprepared landing sites. This assumption will probably not apply to departure from the lunar surface, which will likely be dictated by orbital mechanics and vehicle design considerations rather than lighting constraints. It is further assumed that manned or man-tended outposts will have prepared landing pads with lighting and navigational aids, eliminating this requirement once the appropriate infrastructure is developed.

THE EFFECT OF EARTH-MOON SYSTEM GEOMETRY ON EARTHSHINE ILLUMINATION

The Moon is in synchronous, or captured, rotation with respect to the Earth, a situation that causes the period of its orbital rotation around the Earth to equal the ≈28-day interval of its rotation around its own axis. This geometry produces an effect that is familiar to most people; the same hemisphere, usually referred to as the lunar nearside, always faces the Earth, while the lunar farside always faces away. Libration effects, caused by the wobbling of the Moon's axis during its rotation, results in ≈60 percent visibility of the lunar surface from the Earth over a 12-month period, although only one-half of the Moon's surface is visible at any one time.

The synchronous rotation has several effects that pertain to the question of Earthshine illumination (fig. 1). To begin with, at any point on the lunar nearside, the Earth will remain in the same location throughout the ≈655-hour lunar day.[1] This will result in a constant lighting angle, and shadow length and location after lunar sunset. In addition, shadow length will increase away from the point at which the Earth is directly overhead (hereafter referred to as the sub-Earth point) to a maximum at the poles and limbs, resulting in a higher proportion of the ground in shadow as one moves toward either the poles or limbs. Also, the lunar farside will receive no illumination from Earthshine, which will result in the surface on the farside being extremely dark after lunar sunset. Finally, as the phase of the Earth changes, the value of Earthshine illumination reflect the different locations on the lunar surface. For example, at lunar dawn at the sub-Earth point, the Earth will be a phase angle, ϕ, of 90°, while the lunar dawn at a western limb location will have an Earth ϕ of 180° (fig. 1).

CREW OBSERVATIONS OF LUNAR SURFACE IN EARTHSHINE

During the Apollo Program, six separate Apollo missions spent up to 6 days in lunar orbit, and flight crews were able to observe the lunar surface in a variety of

[1] To avoid potential confusion, the terms "day" and "night" will refer to the terrestrial day and night. The prefix "lunar" will be added to refer to both day and night periods on the lunar surface.

illumination conditions. Captain John W. Young was one of three astronauts to fly two lunar flights, the first was as the command module pilot on Apollo 10, and the second was as Commander of Apollo 16. Many of the observations that follow were made by Captain Young.

In lunar orbit, it was possible to see all the features on the lunar surface in Earthshine as easily as they were seen on the sunlit portion of the Moon. Transition across the terminator from the sunlit portion to the Earthlit portion was rapid, and there was no time required for the eye to adjust to the Earthshine to pick out details on the lunar surface (personal communication with Captain John W. Young, Special Assistant for Engineering, Operations and Safety, Lyndon B. Johnson Space Center, 1990). Gross color differences, particularly the transition between the mare and the highlands, were visible, as were shadows cast by topographic features (fig. 2). High contrast features, such as bright-rayed craters or the bright swirl features on the maria like Reiner γ, were also visible and could be photographed with high-speed film (fig. 3), although the photographic film carried by the Apollo crews was never capable of recording a scene with the same veracity as the human eye. At times, it was even possible to see details within the shadows cast by Earthshine. On the basis of these observations, it should be possible to make a lunar module landing to an unprepared site using only Earthshine for illumination (personal communication with Captain John W. Young). Further, making a landing to a prepared landing site, using a minimum complement of landing lights and navigational aids, would be even less difficult than making a vertical night landing in a helicopter on Earth (personal communication with Captain John W. Young).

Transition from the Earthlit portion of the Moon into the unlit lunar farside was dramatic, and there was no sense of the gradual diminution in Earthshine illumination as the terminator was approached. It was extremely dark beyond the terminator, and no surface features could be seen. The horizon was distinguishable only by the lack of stars; otherwise, it was invisible.

CALCULATION OF VALUE OF ILLUMINATION BY FULL EARTHSHINE

The value of full-Earth illumination can be approximated using two techniques. Both of these techniques make use of the ratio of the albedos of the full Earth and the full Moon, and both are sensitive to the values chosen for these albedos. The first technique approximates the ratio of full-Earth illumination to full-Moon illumination, assuming that the reflectance of each body can be approximated by a flat plate of equal radius with the same albedo. The calculations are as follows:

- Earth radius = 6371 km
- Lunar radius = 1738 km

- Area of flat plate with 6371 km radius = 127.5×10^6 km^2
- Area of flat plate with 1738 km radius = 9.5×10^6 km^2
- Area ratio of both flat plates = 13.42
- Average Earth albedo = 0.4
- Average lunar albedo = 0.07
- Albedo ratio of Earth:Moon = 5.7
- Relative intensity of full Earthshine = (Albedo ratio Earth:Moon) (Area ratio Earth:Moon) = 76.49

On the basis of these calculations, full Earthshine on the Moon should be ≈76 times as bright as a full Moon on Earth.

The brightness, *B*, of the full Moon can be used along with the albedo ratios to approximate the illumination of the full Earth. As with the first calculation, the value of the approximation is sensitive to the chosen values for respective albedos. This calculation also involves changing units from a 2-dimensional area unit of brightness (candela/centimeter2) to a solid-angle unit (lumen/steradian1/centimeter2), back to an area unit for illumination (lumen/meter2). In each of these unit changes, the value of the unit stays the same; that is, lumen/meter2 is equivalent to candela/centimeter2, which is also equivalent to lumen/steradian1/centimeter2. The conversion is necessary to change from units of brightness to units of illumination by accounting for the solid angle, Θ, subtended by the Earth when seen from the Moon. These calculations are as follows:

- $B_{Earth} = B_{Moon} \bullet (Albedo_{Earth}/Albedo_{Moon})$
- $B_{Moon} = 0.25$ cd/cm^2 (ref. 3)
- $B_{Earth} = 1.43$ $cd/cm^2 = 1.43$ $lm/sr/cm^2$

Conversion from brightness, *B*; to illumination, *E*; uses the equation:

$$E = \pi B \sin^2\Theta$$

$$\Theta = 0.95°$$

$$E = 1.24 \quad 10^{-3}\ lm/cm^2 = 12.4\ lm/m^2$$

This value can be compared to values used for planning during the Apollo Program shown in table 1. These figures were published in NASA TM X-68863, Natural Environment and Physical Standards for the Apollo Program (1) representing the NASA program standards used in the Apollo planning. These values will likely remain for future programs and will be used for the balance of this paper. The document does not indicate whether these were calculated values or measured values. At present, no record exists of any experiments that actually measure the value for Earthshine illumination, either on the unmanned Surveyor Program or on Apollos 8 or 10, which preceded the publication of this document. As can be seen, the value for full-Earth illumination from this document agrees favorably with the value calculated above.

CASTING EARTHSHINE ILLUMINATION VALUES IN REAL WORLD TERMS

There are several physical situations which allow an understanding of the magnitude of illumination available from Earthshine. The first of these is the value of illumination of the full Moon, 0.25 lm/m^2 (2). It is possible, on full, Moonlit nights, to operate agricultural machinery; to move around outside on foot without lights; and to generally conduct tasks without lighting that do not require great amounts of visual acuity, such as reading. As calculated above, full Earthshine illumination is ≈76 times as bright as a full Moon, suggesting that a significant amount of activity can take place under full Earthshine without the need for additional artificial lighting.

Another comparison comes from terrestrial nautical and aeronautical navigation. Civil twilight, in nautical terms, is the time after sunset and before full dark, or before sunrise but after full dark, when it is possible to see the horizon and still see the brightest stars. In aviation, civil twilight is the time after sunset, or before sunrise, when it is possible to safely operate an aircraft without the need for position lights, navigation lights, landing lights, interior cockpit lights, or runway and taxiway lighting. The value for terrestrial civil twilight is 6.5 lm/m^2 (3), or about half that of full Earthshine. The illumination shown by the terrestrial sky, just prior to sunrise (or just after sunset), is 540 lm/m^2 (3). Finally, the value of illumination in typical interior lighting is 100 lm/m^2. Using these values, and plotting Earthshine illumination as a function of Earth phase angle, it is possible to depict the range in Earthshine illumination at the sub-Earth point (fig. 4). This shows graphically that the minimum lunar-night illumination at the sub-Earth point is significantly higher than full-Moon illumination on Earth, and that a substantial portion of the lunar night has illumination values greater than terrestrial civil twilight.

To put these illumination values into further real world values, they can be compared to the illumination given off by a 60-W incandescent light bulb, which generates 840 lm of light. The distance, r, at which a 60-W bulb produces an illumination of 13.5 lm/m^2 can be calculated using the following equation:

$$13.5 \text{ lm/m}^2 = 840 \text{ lm}/4 \pi r^2$$

$$r = 2.2 \text{ m}$$

This means that working on the lunar surface at the sub-Earth point under full Earthshine will be roughly equivalent to working under a 60-W bulb which is 2.2 m away from the working surface. This level of illumination is similar to the natural light available outside in July at the latitude of Houston, Texas at ≈8:00 p.m. central standard time. Using the same formula, the minimum value of Earthshine, impinging on the lunar surface at an Earth ϕ of 90°, is equivalent to working under a 60-W light bulb elevated 4.9 m above the working surface. Both of these conditions should provide adequate lighting for the conduction of lunar EVAs. A schematic illustration to scale of these two conditions is shown in figures 5 and 6.

At locations on the lunar nearside away from the sub-Earth point, the illumination profile throughout the lunar night will be different because the Earth phase angle will be different. Several end-member cases were investigated, among them: (1) locations on the western and eastern limb at 80° longitude, and (2) a location at 80° north latitude, 0° longitude. The 80°-longitude cases were chosen because longitudes >81.4° west or east will not always have the Earth in the sky due to the lunar libration effects discussed earlier.

For a western limb location, Earthshine at sunset will be from a full Earth and will constantly be at a maximum of 13.5 lm/m^2. As the lunar night progresses, the level of illumination will gradually be reduced to a level of 2.8 lm/m^2 at lunar "midnight,"[2] ≈164 hours after sunset, and further reduced to full dark and "new" Earth just before sunrise. On the eastern limb, the profile will be the opposite: minimum illumination will occur with a "new" Earth at sunset, gradually increasing to a maximum of 13.5 lm/m^2 just prior to sunrise. At pole locations, the illumination profile will be similar to that at the sub-Earth point: 2.8 lm/m^2 at sunset, increasing to 13.5 lm/m^2 at lunar midnight, then decreasing to a minimum of 2.8 lm/m^2 at sunrise. One significant difference at polar locations, however, will be that the Earth will be very low on the horizon, and the amount of ground covered in shadow will be greatly increased from lower latitude sites. Consequently, the level of illumination will not be as useful as in equatorial locations. These variations are detailed in table 2.

[2] Midnight refers to the midpoint between lunar sunset and sunrise.

LIGHTING CONSTRAINTS TO LUNAR SURFACE OPERATIONS DURING THE LUNAR DAY

Determination of slope on the lunar surface is primarily a function of two different sources of information. Within ≈100 m of a particular location, shadows cast by positive features, such as rocks; and by negative features, such as craters, provide the most information on centimeter to meter-scale variations in local topography. For topography located at greater distances from an observer, broad-scale topographic changes are discernible by variations in brightness. Assuming a uniform surface color, the closer a surface is oriented at right angles to the direction of sunlight, the brighter it will be.

An examination of panoramic photographs from Apollos 15, 16, and 17 indicates that as an observer gets closer to looking directly down-Sun, the amount of information available on local topography diminishes to virtually zero (figs. 7a and 7b). In particular, the problem appears to become critical within ≈20° of directly down-Sun. This suggests that when the Sun is within 20° of the zenith, topography may be sufficiently subdued to make EVA operations on unfamiliar terrain difficult. The underlying assumption is that conditions near down-Sun under low-Sun-angle conditions can be extrapolated to high-Sun-angle conditions. A plot of Sun angle as a function of mission day (fig. 8) indicates that the Sun will be within 20° of vertical between ≈130 and 200 hours after lunar sunrise. The difficulty in distinguishing surface topography may require some restrictions in EVA surface operations during this time, such as operations only in familiar terrain, or operation of rovers only along known tracks that are marked. Similar operational restrictions are implemented in Antarctica during periods of reduced visibility.

APPLICATION OF RESULTS TO OPERATIONAL SCHEDULES

The results of this study have been used to develop a series of figures that graphically depict the lighting conditions throughout the lunar day, and possible lighting constraints to lunar surface operations (figs. 9a, 9b, and 9c). The figures were created with several conditions in mind. The first is that a minimum illumination of 1 lm/m^2 will be necessary for safe EVA operations. This figure is chosen to follow conservative guidelines; <1 lm/m^2 may prove to be too dark for reading checklists or for performing other activities that require a reasonable level of visual acuity. An illumination of ≥1 lm/m^2 is likely to supply a sufficient level of light to carry out all EVA activities. It should be pointed out, however, that lighting levels as low as 0.25 lm/m^2, equivalent to full-Moon illumination on Earth, should be sufficient under emergency conditions to carry out EVA operations.

The second condition is that the mission rules requiring low Sun elevation with a backlit landing area, as was used for the Apollo missions, will continue to be in force for the initial landings at previously unexplored locations, although the specific restrictions of from 5 to 20° Sun elevation may not be necessary. Less restrictive Sun angle conditions were suggested by discussions with Captain John W. Young. His observations during the lunar landing on Apollo 16 indicate that terrain scale is as important as terrain form, and that almost any degree of backlighting will be sufficient to highlight the terrain. What is lacking on the lunar surface, however, is an adequate reference for scale measurement. The most useful information on the topographic scale during the Apollo landings became the shadow of the lunar module, which was out ahead of the landing point during the transition from powered descent to hovering flight. Using the width across the landing legs of the lander, ≈10 m, it was possible to gauge the scale of the topography at the landing site, and determine whether the chosen touchdown point would be safe. On the basis of this experience, it appears that while the restriction to a particular range of Sun angles may not be necessary, backlighting will be extremely useful during future landing approaches to the lunar surface (personal communication with Captain John W. Young, 1990).

The charts lay out the suggested times during which lighting conditions will be optimal for lunar EVAs in central equatorial regions in the vicinity of the sub-Earth point, in western limb locations, and in eastern limb locations. The diagram also shows the approximate phase of the Earth at sunset, sunrise, midnight, and the portion of the lunar night when the ambient lighting is <1 lm/m^2, and the portion of the lunar day when the Sun elevation angle is within 20° of vertical. Finally, the portion of the lunar day where the Sun angle is between 5 and 20° above the horizon is shown.

Based on these charts, it appears that for the central equatorial region of the lunar nearside, Earthshine illumination should be adequate to conduct EVAs throughout the lunar night without the need for extensive artificial lighting. For the limb regions, there will be a portion of the lunar night, ≈120 hours long, when ambient lighting will be ≤ 1 lm/m^2. At these times, it may be necessary to restrict EVAs to areas of known topography, or areas where sufficient artificial illumination is available. In addition, shadow length at limb locations will be great, and consequently large amounts of ground will be covered by shadow. This may require the use of limited artificial lighting, either on EVA helmets or on roving vehicles during EVAs.

CONCLUSIONS

1. Orbital geometry of the Earth-Moon system will keep the Earth in approximately the same location in the nearside sky during the lunar night; consequently, illumination will be a sole function of Earth phase angle. Also, shadow lengths will remain constant in length and orientation throughout the lunar night.

2. The lunar farside will receive no illumination from Earthshine during the lunar night; consequently, artificial lighting will be required on all lunar night EVAs at farside sites.

3. Regardless of the amount of illumination provided by Earthshine, some form of artificial lighting will be required on EVA helmets and rovers to augment the ambient illumination, and in particular, for viewing shadowed areas.

4. For central equatorial regions, Earthshine will provide significant illumination throughout the lunar night and allow unrestricted EVA operations without extensive use of artificial lighting. At the maximum, the level of illumination will be approximately equivalent to the light available in the southern United States at ≈8:00 p.m. on a July evening. For polar regions, a similar level of illumination will be available, although the percentage of the lunar surface covered by shadows will be extensive.

5. For eastern limb locations, the amount of illumination will be minimal at lunar sunset due to the Earth phase angle causing a "new" Earth. For the first ≈60 hours of the lunar night, the illumination will be <1 lm/m^2, < 4 times the light level from the full Moon on Earth. During this time period, it may be necessary to restrict EVA activities to areas of known topography or to those with extensive artificial lighting. For the rest of the lunar night, the light level will increase to the maximum available just prior to lunar sunrise.

6. For western limb locations, the cycle will be reversed, with the maximum illumination available directly after lunar sunset and decreasing to a minimum at sunrise. The last ≈60 hours of lunar night will have illumination levels <1 lm/m^2.

7. Daytime EVA activities may have to be curtailed when the Sun is within 20° of vertical, due to a loss of shadows and concomitant poor surface definition. There will also be a loss of slope information due to poor color contrast in the bright sunlight.

ACKNOWLEDGMENTS

This study benefitted greatly from discussions with Dr. James Zimbelman of the Center for Earth and Planetary Studies, the National Air and Space Museum, and Smithsonian Institution; Mr. Michael Ravine of the Mars Observer Camera Team; Mr. Kent Joosten of the Lunar and Mars Exploration Program Office; and Captain John W. Young, Special Assistant for Engineering, Operations, and Safety at the Lyndon B.

Johnson Space Center. The technical support provided by Alida Andrews and Amy Weidenhoff of Barrios Technology was greatly appreciated. The manuscript benefitted from technical reviews by Nancy Ann Budden and Captain John W. Young.

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2. Smith, J. W.: Modern Optical Engineering: The Design of Optical Systems. McGraw Hill Book Company, New York, p. 476, 1966.

3. Her Majesty's Nautical Information Office, Explanatory Statement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac. H.M. Stationary Office, London, United Kingdom, pp. 398-406, 1961.

TABLE 1. EARTHSHINE ILLUMINATION VALUES USED IN THE APOLLO PROGRAM

Earth phase angle	Mean illumination*
0°	13.5 lm/m^2
30°	9.3 lm/m^2
60°	5.6 lm/m^2
90°	2.8 lm/m^2
120°	1.1 lm/m^2
150°	0.2 lm/m^2

*Data from Apollo program document M-DE 8020.008C, Natural Environment and Physical Standards for the Apollo Program, NASA TM X-68863

TABLE 2. VARIATIONS IN EARTHSHINE ILLUMINATION WITH LOCATION ON THE LUNAR SURFACE

Location	Lunar time	Earth-phase angle	Illumination
80° W. longitude* 0° latitude	Sunset Midnight Dawn	0° 90° 180°	13.5 lm/m^2 2.8 lm/m^2 0
80° E. longitude* 0° latitude	Sunset Midnight Dawn	180° 90° 0°	0 2.8 lm/m^2 13.5 lm/m^2
0° longitude 80° N. latitude	Sunset Midnight Dawn	90° 0° 90°	2.8 lm/m^2 13.5 lm/m^2 2.8 lm/m^2

*Because of lunar libration, the Earth will not remain constantly above the horizon at longitudes >81.4° west or east longitude.

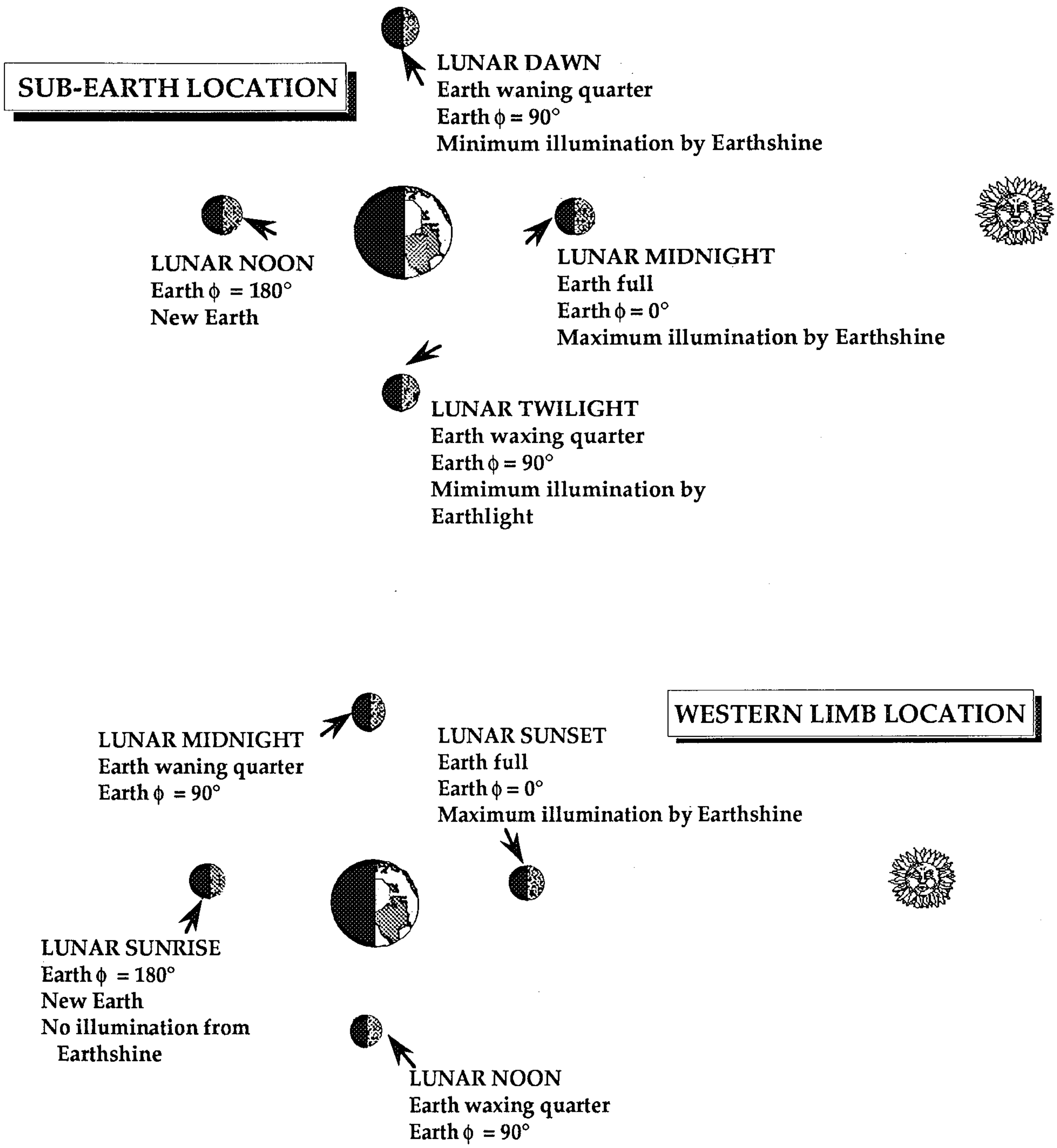

Figure 1. Variations in the level of Earthshine illumination as a function of Earth phase angle and lunar surface location.

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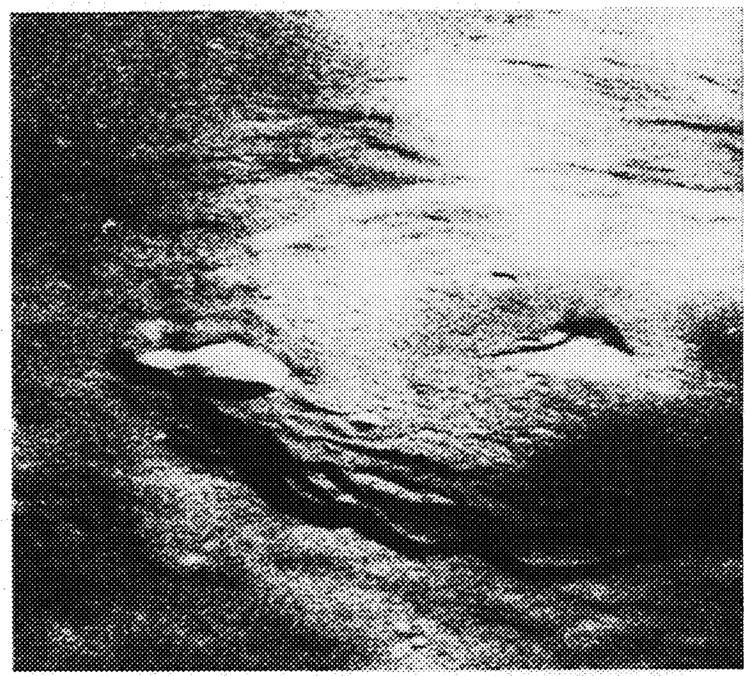

Figure 2. Apollo 17 photograph of the crater Schlüter (58° W. longitude, 6° S. latitude) in Earthshine. Note the shadow of the central peak; according to Captain John W. Young, it was possible to distinguish features in the shadows on the surface in Earthshine, although the photographic films available were not able to capture the same detail. NASA photograph AS17-161-24013, taken with Kodak type 2485 film, which has ≈1000 ASA.

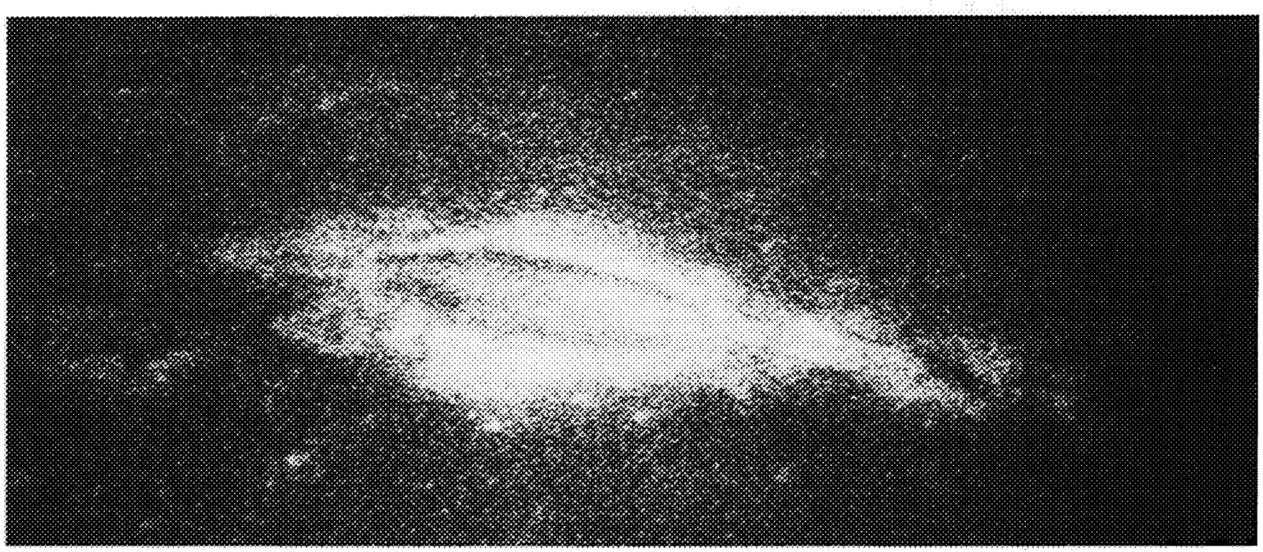

Figure 3. Apollo 17 Earthshine photograph of Reiner γ, a bright swirl feature on Mare Procellarum. NASA photograph AS17-158-23897, taken with type 2485 film.

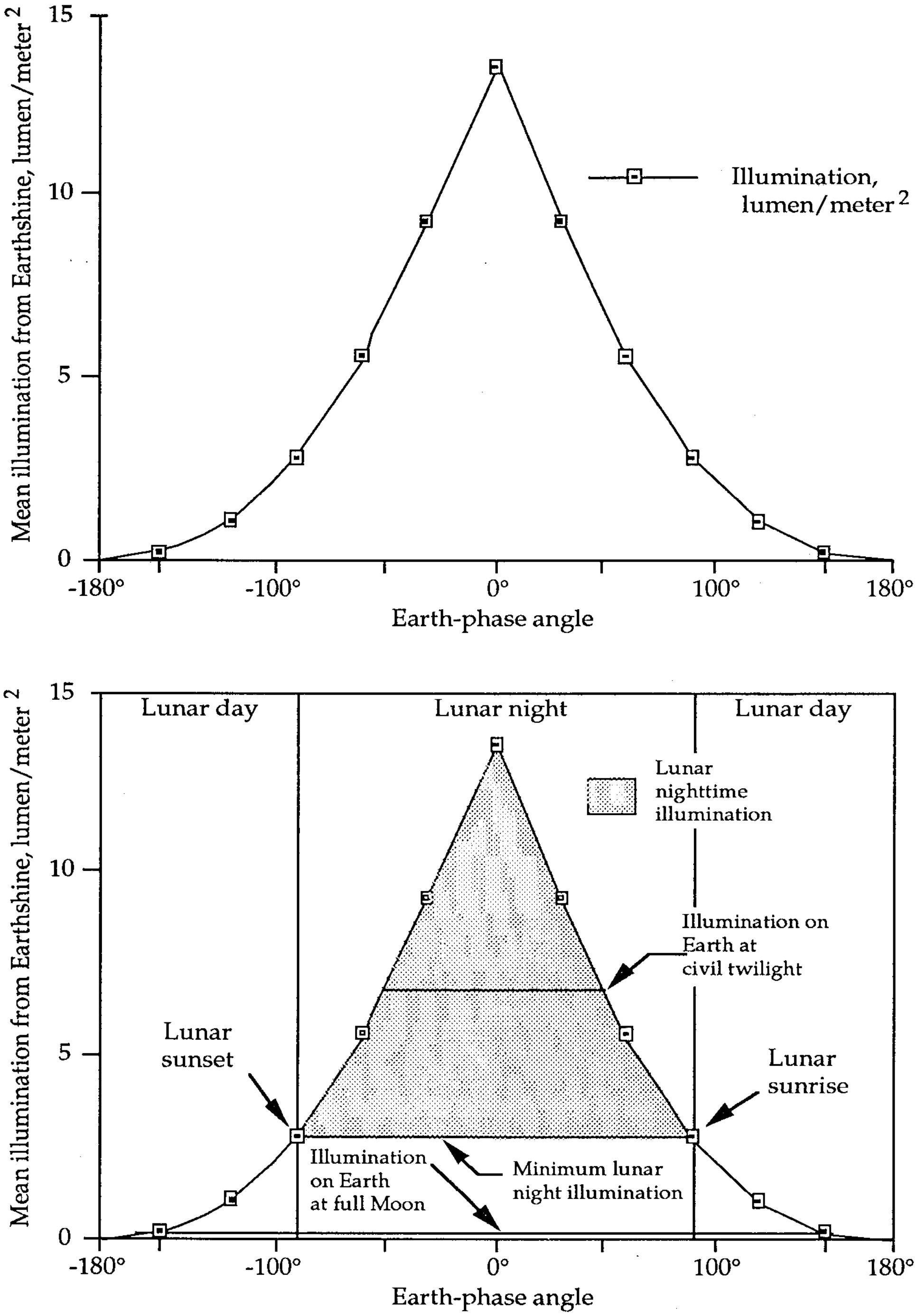

Figure 4. Variation in the level of Earthshine illumination as a function of Earth phase angle for the sub-Earth point. The top plot is raw data; the bottom plot is overlaid with the various levels of illumination from terrestrial civil twilight to a full Moon. The grey area represents the envelope of lunar night illumination at the sub-Earth point.

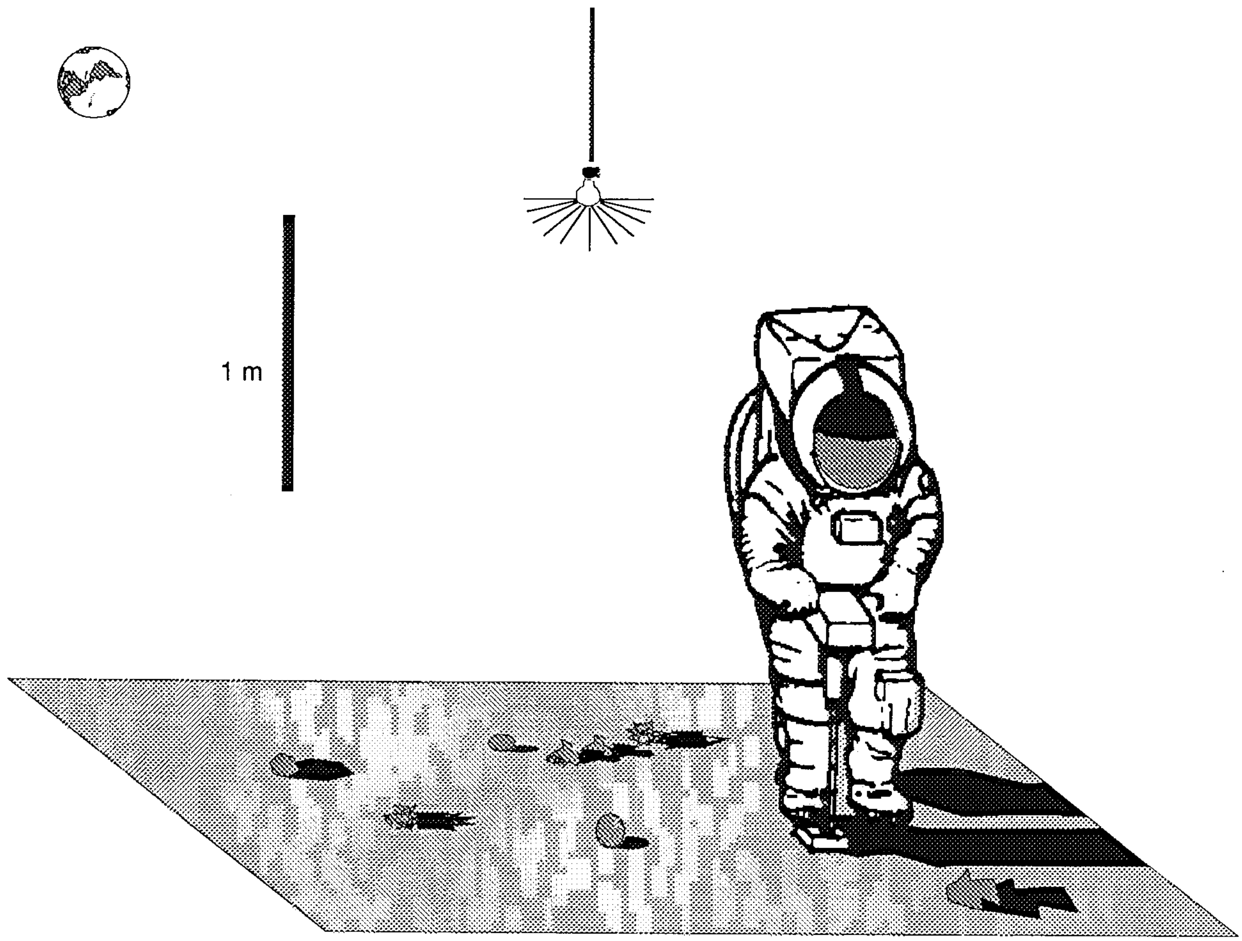

Figure 5. Analog scale drawing of the degree of illumination available under full Earth-shine. The schematic 60-W light bulb is elevated 2.2 m above the working surface.

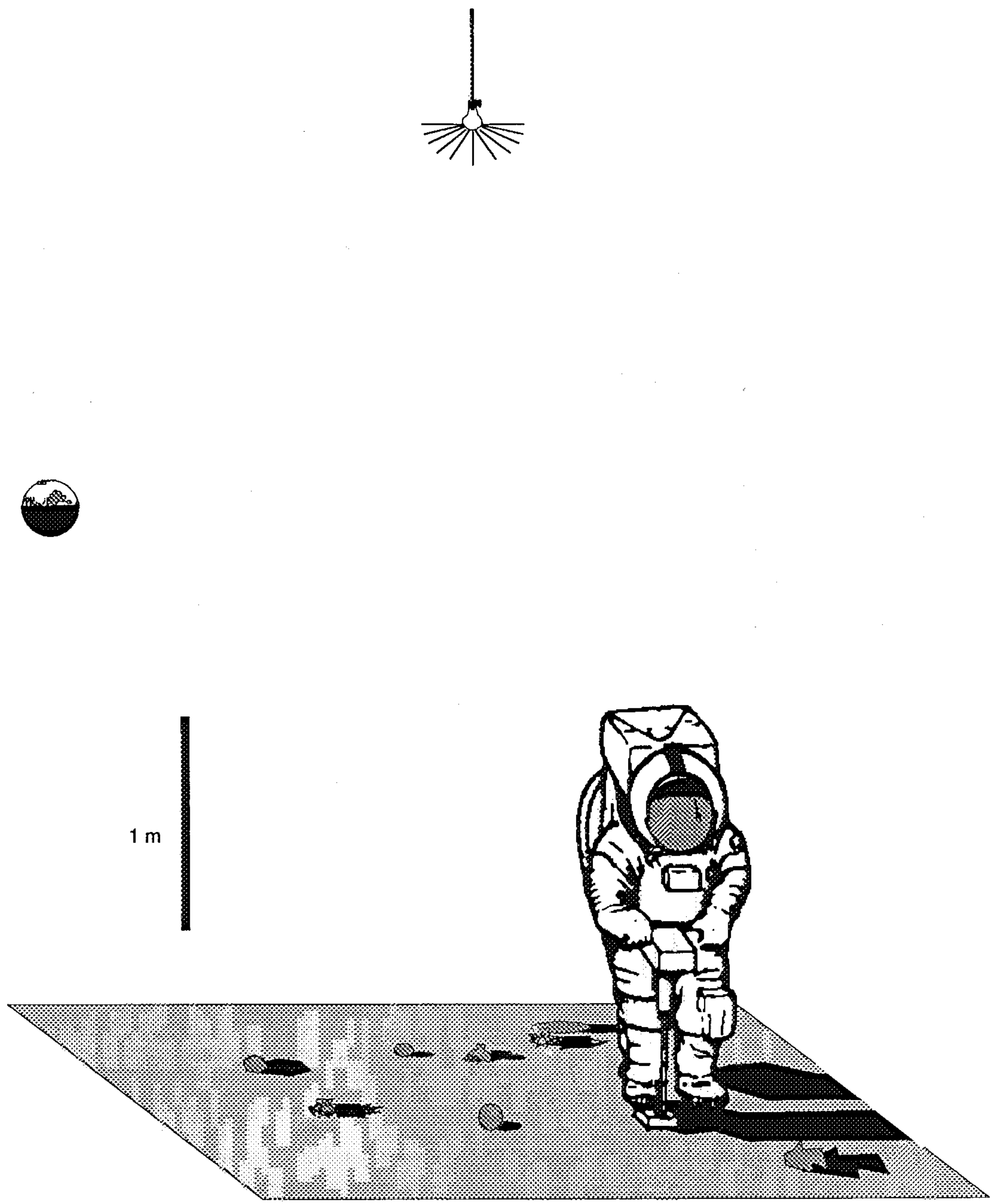

Figure 6. Analog scale drawing of the degree of illumination available under the minimum Earthshine available at the sub-Earth point. The schematic 60-W light bulb is elevated 4.9 m above the working surface.

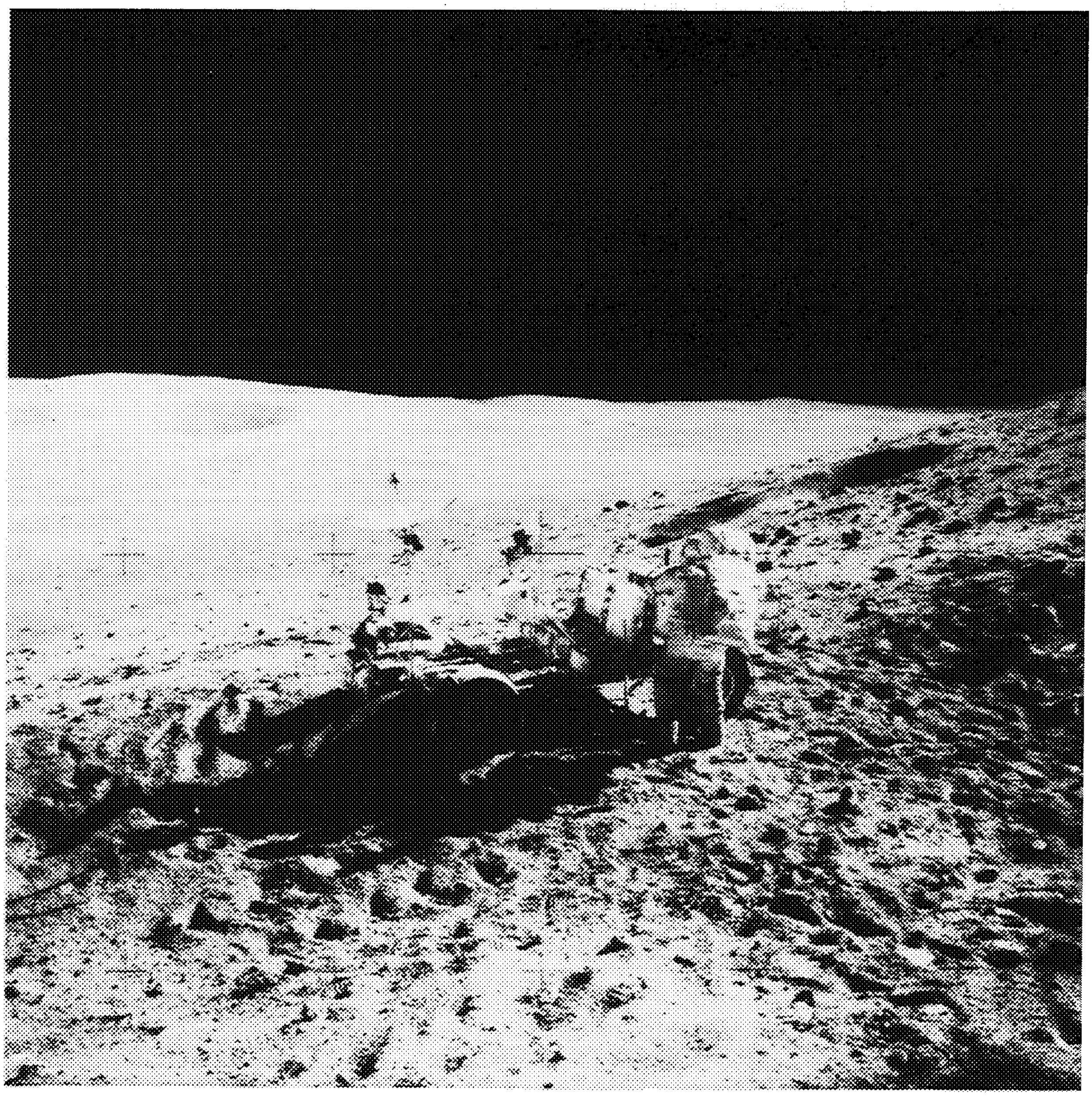

Figure 7. Apollo 16 photograph taken 90° to the down-Sun direction. Notice the level of centimeter- to meter-scale topographic information available due to shadows. NASA photograph AS16-110-17960.

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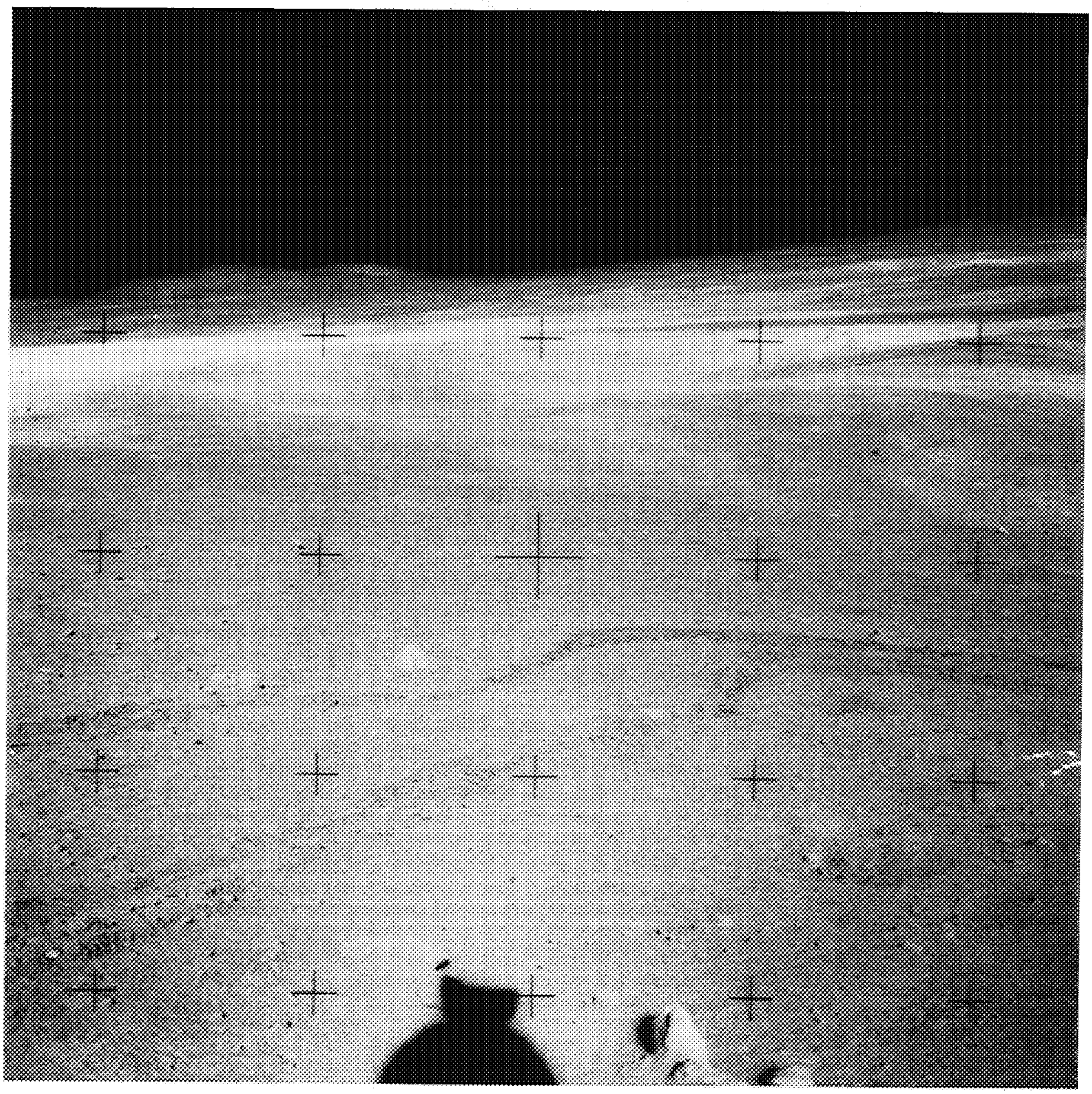
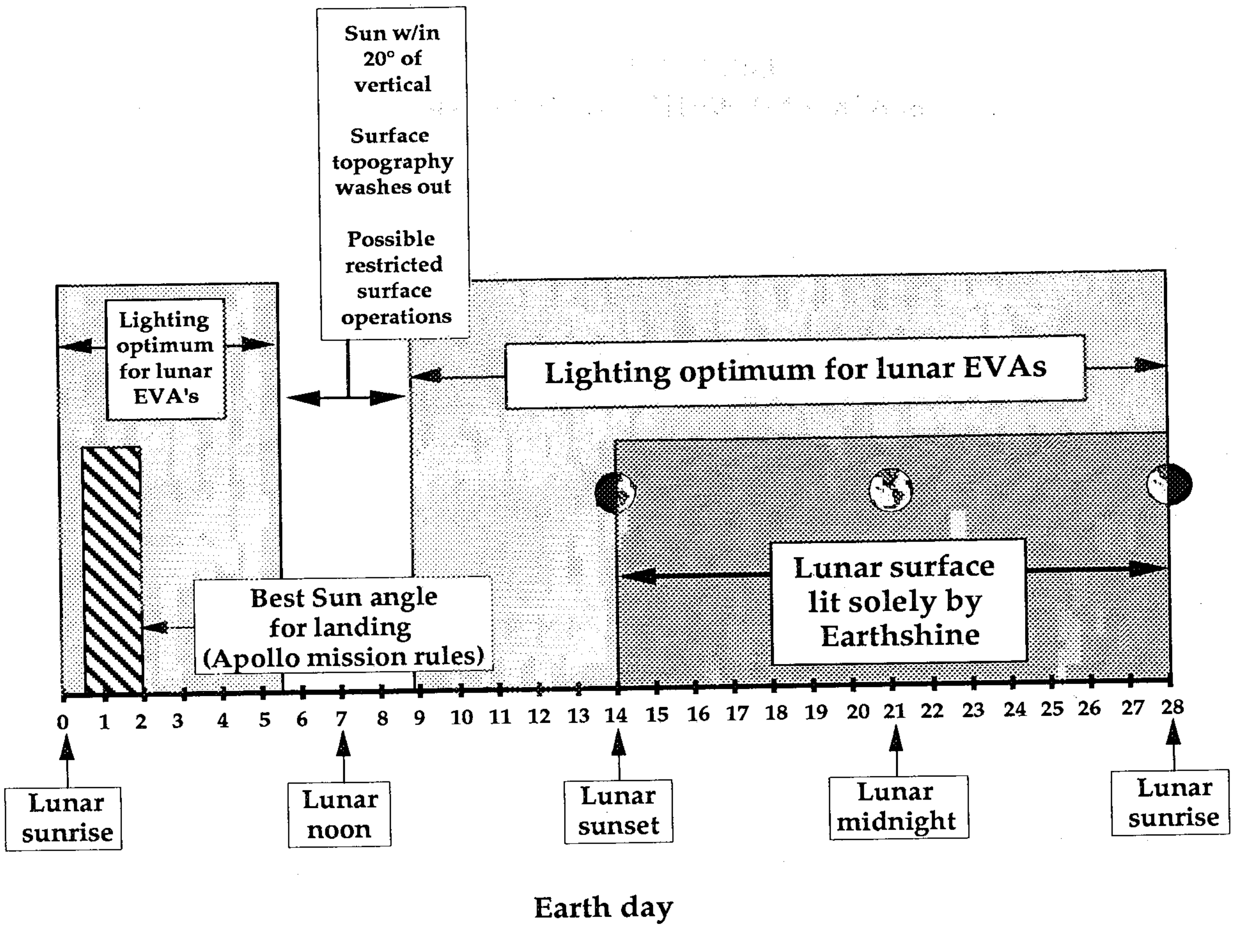
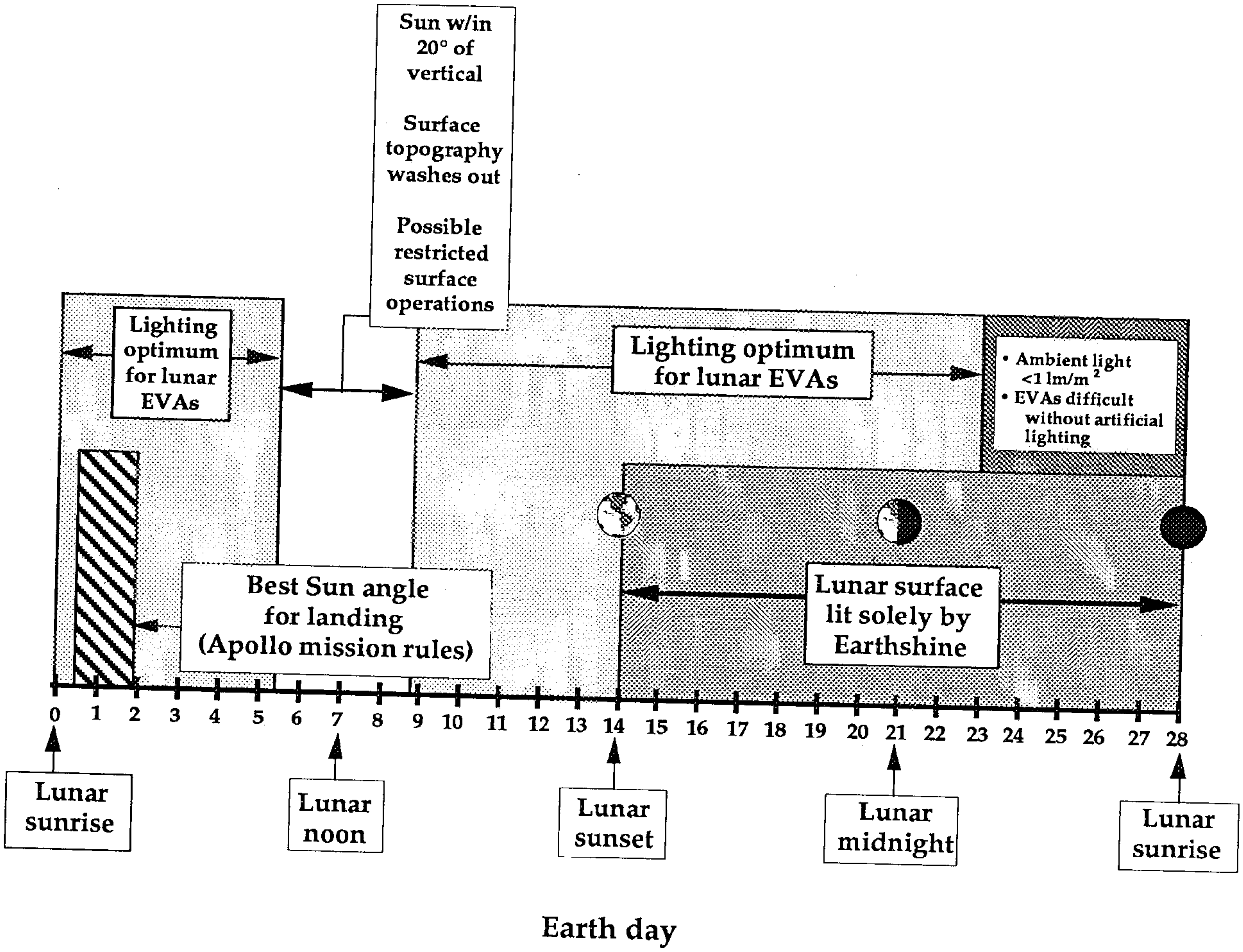


Figure 8. Apollo 16 photograph taken directly down Sun at the same location as figure 7. Notice the diminution of topographic information due to the lack of shadows. NASA photograph AS16-110-17952.



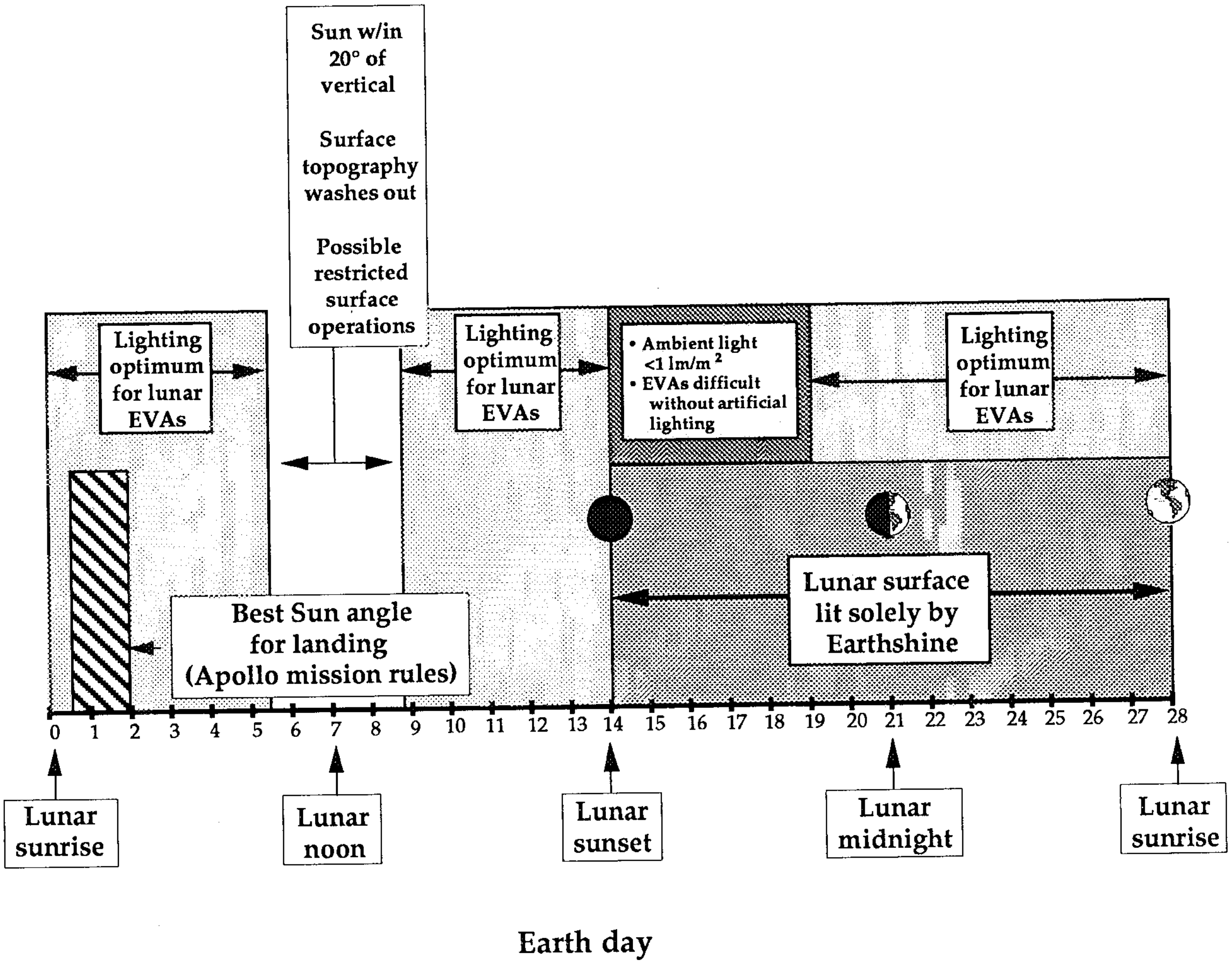
9a) At sub-Earth point.

Figure 9. Operational diagrams showing the range of lighting conditions on the lunar surface.



9b) At a western limb location.

Figure 9. Continued.



9c) At an eastern limb location.

Figure 9. Concluded.

NASA
National Aeronautics and Space Administration

REPORT DOCUMENTATION PAGE

1. Report No. NASA TM-4271	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Lighting Constraints on Lunar Surface Operations		5. Report Date: May 1991
		6. Performing Organization Code: XM
7. Author(s): Dean B. Eppler		8. Performing Organization Report No.: S-632
9. Performing Organization Name and Address: Lunar & Mars Exploration Program Office, NASA-Johnson Space Center, Houston, Texas 77058		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, D.C. 20546		13. Type of Report and Period Covered: Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

An investigation into the levels of ambient lighting on the lunar surface indicates that for most nearside locations, illumination will be adequate throughout most of the lunar night to conduct EVAs with only minor artificial illumination. The maximum lighting available during the lunar night from Earthshine will be similar to the light level on a July evening at approximately 8:00 p.m. in the southern United States (approximately 15 minutes after sunset). Because of the captured rotation of the Moon about the Earth, the location of the Earth will remain approximately constant throughout the lunar night, with consequent constant shadow length and angle. Variations in the level of Earthshine illumination will be solely a function of Earth phase angle. Experience during the Apollo Program suggests that EVA activities during the period around the lunar noon may be difficult due to lack of surface definition caused by elimination of shadows.

17. Key Words (Suggested by Author(s)): Earthshine, lunar lighting conditions, lunar surface operations		18. Distribution Statement: Unclassified - Unlimited; Subject Category 91	
19. Security Classification (of this report): Unclassified	20. Security Classification (of this page): Unclassified	21. No. of Pages: 24	22. Price: A03