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TECHNICAL MEMORANDUM

FIRST EARTHSHINE POTOGRAPHY FROM LUNAR ORBIT

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ABSTRACT

During Apollo 15, fifteen photographs of the moon were taken under Earthshine illumination. These were the first Earthshine photographs taken from lunar orbit.

The photographs are of photometric interest, particularly as they involve double reflection of sunlight -- by the earth, then the moon -- prior to photographic exposure. Certain published data on the mean illumination of the moon by the crescent earth predicted lower exposure values than obtained for each measured area. The apparent albedo values obtained for the floor of the crater Aristarchus were anomalously higher than those obtained for the surrounding maria.

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Case 340

TECHNICAL MEMORANDUM

I. INTRODUCTION

On rev 34 of the Apollo 15 mission the first Earthshine pictures of the moon were taken from lunar orbit.

A series of two sets of pictures (4 plus 10) were taken at 1/16 sec and 1/8 sec, respectively.* The set of 10 can be considered the basic set with the preliminary set of 4 being for analytical comparison.

The set of 10 covered various types of lunar terrain including certain special lunar features. Most significant are two photographs of Aristarchus (AS-15-101-13591 and 13592); another photograph provides a view of Schroter's Valley (AS-15-101-13592) and a fourth shows the crater Herodotus (AS-15-101-13594). Copies of these photographs are provided as Figure 1. The other frames were of maria and were significantly underexposed. The location of the photographs is shown in Figure 2.

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* One additional photograph showing portions of the moon in Earthshine was, obtained as an unplanned result of Solar Corona photography.

II. TECHNICAL DISCUSSION

Camera and Film Used

The Earthshine photography was obtained with the 35 mm Nikon camera which was required by the Gegenschein experiment. This camera has a 55 mm focal length lens and an f# of 1.2. This low f# provides a capability for low light level photography greater than had been available on earlier missions.

The film selected was EK 2485, a high speed black and white recording film. The response characteristic curve (D/log E curve) for this film, as used for pre-flight exposure selection, is shown in Figure 3. The derivation of the pre-flight predicted film exposure values for maria (M) and Aristarchus (A) is provided below.

The film has a lower resolution capability than normally sought for aerospace photography and has historically been used for laboratory photographs of instruments, including cathode ray tubes. Its resolving power is 56 lines/mm for a target with a contrast of 1000:1 and 20 lines/mm for a target with a contrast of 1·6:1 (Reference 1). Its predicted low contrast resolution of 20 lines/mm was used (see below) in pre-flight selection of the optimum shutter speed.

Operations

The camera was hand-held by the CMP, Lt. Col. Al Worden, and pointed out of the hatch window, CM 3. The space-craft lights were dimmed and the timing of the photographs (approximately 30 sec intervals) performed by real time command from CAPCOMM.

All photographs were taken in accordance with the flight plan. The photograph taken of Schroter's Valley was oriented significantly to the north, a discretionary decision by the CMP involving the type of discretionary action encouraged during pre-flight briefings (by F. El-Baz and the writer).

The Earthshine photographs were taken on August 1, 1971, at mission time (GET) of 144:10:32 corresponding to GMT:13:45. At that time the moon, earth, sun relationship was as shown in Figure 4. The eastern limb of the moon is in sunlight; the sub-solar point is at +60.6°(E). The target is in Earthshine. Earthshine comes from the portion of the earth that is: (1) sunlit; and (2) visible from the moon. Visualization of these conditions is aided by the photograph, Figure 5, which was taken by Lunar Orbiter I under similar moon, earth, sun conditions.

Lighting Conditions

The primary factor that determines the magnitude of the reflected light from the target is the phase angle, g, (see Figure 4). This phase angle, g, is defined as the angle between the vector from the source of illumination to the target, and the viewing vector from the imaging system (camera in spacecraft) to the target. The phase angle, g, is dependent on the target's longitude and latitude. (Figure 4 should be recognized as now showing the effect of latitude on g.)

To determine the direction of the source illumination to the target, the photo target position in lunar coordinates must be adjusted for the extent of lunar libration. In the east-west direction, the libration at the time of photography placed the earth at -6.0°(W) as shown in Figure 4. The photo target coordinate of 47°W must be adjusted by this -6.0° to produce an angle of 41° in longitude between the source of illumination and the viewing vector for vertical photography. In the north-south direction there was a lunar libration of +6.3°(N). This must be added to the 23° latitude of the target, if an exact value of g is to be determined. These latitude adjustments produce a value of g a few degrees greater than 41°. A value of g = 45° was used for pre-flight exposure prediction purposes.

The primary factor that determines the magnitude of Earthshine illumination incident on the moon is the angle between the sun-earth and the moon-earth vectors. This angle can be called the Moon-Earth Phase. The Moon-Earth Phase affects the extent of the sunlit earth visible from the moon. At large Moon-Earth Phase angles the magnitude of the illumination is significantly reduced. Figure 6 shows the magnitude of the illumination as a function of Moon-Earth Phase. Figure 6 is data that was available pre-mission (Reference 2). For a sub-solar point of +60.6°(E) and a libration such that the earth is at -6°(W), the Moon-Earth Phase angle is 180° - 66.6°

or 113.4°. Figure 6 shows that for a Moon-Earth Phase angle of 113.4°, the mean illumination of the moon by the crescent earth is 1.35 lumens/sq meter.

Target Albedo

Albedo data based on photoelectric-photographic measurements from earth is available. The pre-flight albedo values used for pre-flight exposure prediction purposes were obatined from Reference 3. A value of 0.09 was used for the maria area and 0.18 for Aristarchus.

Predicted Exposure Calculation

The predicted exposure at the film is given by the formulae:

$$E = P_j \; u \; C \; t$$

where P_j = 1.35 lumens/sq meter when a crescent of the earth is illuminating the moon at a Moon-Earth Phase of 113.4°; and where

$u = \rho \; \Phi$, where ρ is the target albedo and Φ the target photometric function;

$\rho = .18$, for Aristarchus;

$\Phi = .33^* \times .8^{**}$ (for $g = 45°$); and

$C = \frac{L_t}{4 f_{\#}^2}$, where L_t = lens transmission, L_ℓ, times window transmission, L_w; and

$f_{\#} = 1.2$,

$L_t = .8$, where $L_\ell = .9$, based on manufacturer's data, and $L_w = .9$ is an estimate.

Then

$$E = 1.35 \times .18 \times .264 \times \frac{.8}{4(1.2)^2} \times t \text{ meter-candle-secs (mcs)}.$$

If the shutter speed t is selected to be 1/8 sec, then

$$E = 1.11 \times 10^{-3} \text{ mcs}$$

$$\text{Log}_{10}E = \overline{3} + .05 \quad \text{for } \rho = 0.18\text{(A)}$$

and

$$\text{Log}_{10}E = \overline{4} + .75 \quad \text{for } \rho = 0.09\text{(M)} .$$

---

* Fedorets data.

** To adjust Fedorets data to be consistent with the measurements of albedo data.

The calculation shown above uses a shutter speed of 1/8 sec and produces a slight underexposure of a target of an albedo of 0.18. The predicted density is shown as A on Figure 3. For an albedo of 0.09, such as the maria, the photograph can be expected to be significantly underexposed. The predicted density is shown as M on Figure 3.

Clearly, the shutter speed can be selected to produce any desired magnitude of exposure. If exposure were the only criteria, a shutter speed greater than 1/8 sec would have been selected to increase the predicted exposure of the maria. However, the 1/8 sec was selected based upon a consideration of the effect of smear when no image motion compensation is provided.

Selection of Shutter Speed

In the absence of smear the expected resolution on the film was 20 lines/mm (for low contrast targets) or on the ground, $\frac{110 \text{ km}}{55 \text{ mm}} \times 50\ \mu\text{m}$ or 100 m. The forward motion smear at 1/8 sec is approximately 210 m (for an estimated orbital velocity of 1.680 km/sec). To decrease smear to 40% of 100 m, commonly thought acceptable, would require an exposure of $\frac{40\% \times 100}{210} \times 1/8$ or about 1/40 sec. However, the resultant reduced film exposure would have been so low as to completely underexpose the film and to invalidate the resolution data of 20 lines/mm which is predicated on a reasonably exposed photograph. (A camera with a lower f# or with image motion compensation or a faster film are desirable hardware features, but these desirable features were not available.)

Results

Measurements made from the primary set of ten photographs provided density measurements from which the exposure obtained could be deduced. The density and exposure values obtained for general maria and for the floor of Aristarchus are shown in Figure 7 (at M and A, respectively) which also shows the pre-flight predicted values.

If the measured exposure values are compared to the predicted values, the following results are obtained:

1. for the maria area there is reasonably close agreement such that future photographic results can be predicted with reasonable confidence. However, the difference between theory and results is such that it is highly desirable that further analysis be performed to clarify the cause(s) of the difference.
2. for the floor of Aristarchus the value of exposure obtained is far greater than predicted.

If only the measured exposures are examined (no reference being made to the predicted value), there is a large <u>ratio</u> between the exposure for the floor of Aristarchus and the exposure for the maria. This ratio is about 7 (a difference of $Log_{10}E$ of about .85). This would suggest an "apparent albedo" of 7 x .09 or .64 -- a very high albedo value if it can be accepted as such. It should be noted that the measured ratio is independent of any possible errors in estimates of factors used in predicting exposure.

The preliminary set of four photographs taken at 1/16 sec produced grossly underexposed photographs. Clearly, such shutter speeds are not usable when the illumination of the moon is from an earth at large Earth-Moon Phase angle (low levels of illumination).

It is desirable to obtain Earthshine photographs when the earth is near full (low Earth-Moon Phase angles). Earthshine photographs taken when the earth is near full (early Apollo revs) could use a shutter speed of 1/16 sec, thus reducing the smear to half that obtained at 1/8 sec, yet producing reasonably exposed photographs. In highland areas a shutter speed of 1/32 could be used, reducing the smear to quite acceptable levels.

III. SUMMARY

The predicted exposure of the maria areas and the obtained exposures were in reasonably close agreement. This provides some rough confirmation of the assumptions and data used in the predictions. However, the difference between theory and results (a factor of about 2) is of scientific interest and merits further scientific analysis.

The "apparent albedo" values obtained for the floor of the crater Aristarchus were found to be about seven times greater than the maria. The ratio of 7 produces a computed "apparent albedo" of .63. This seems too high to believe and must be considered a preliminary result, not yet analyzed in terms of appropriateness or nonappropriateness as an indicator of albedo. This result merits further scientific analysis.

2015-DDL-ams

D. D. Lloyd

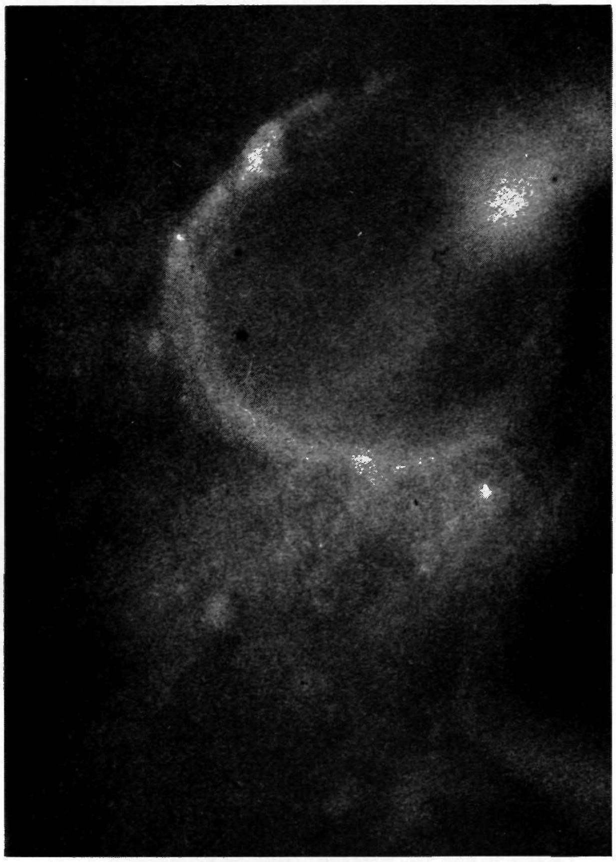
Attachments

References

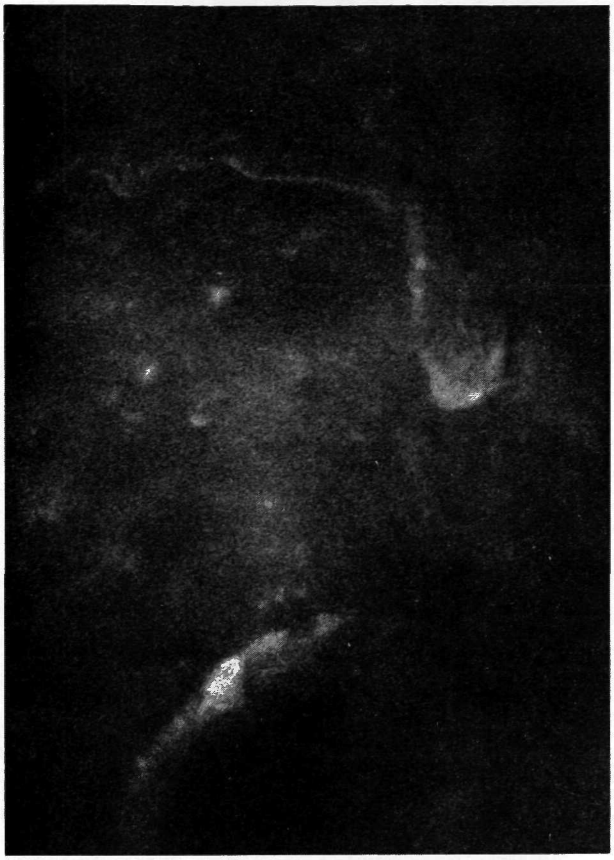
1. "Kodak 2485 High Speed Recording Film," Eastman Kodak Company, Data Release.

2. "Natural Environment and Physical Standards for the Apollo Program," NASA M-DE8020.008C, p. 5-2, July 10, 1969.

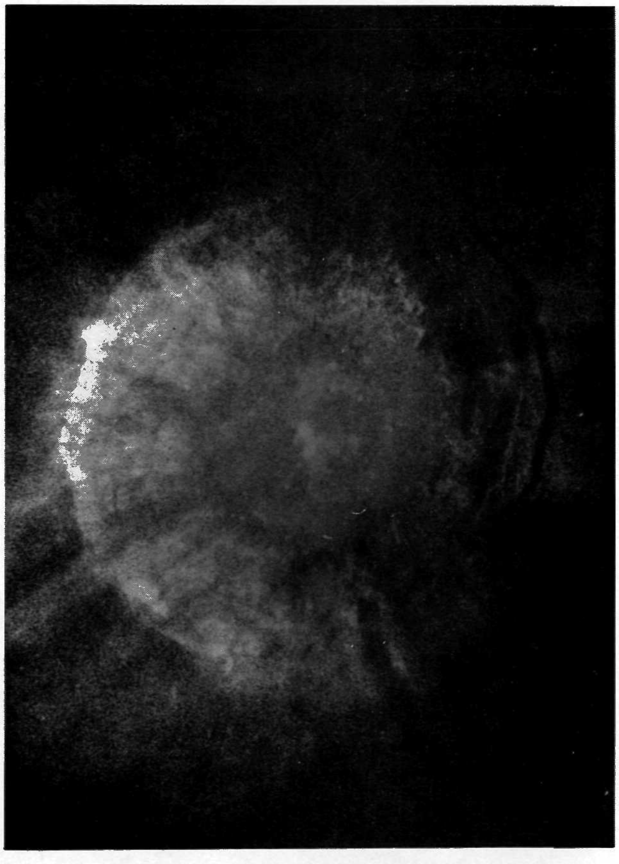
3. "Photoelectric-Photographic Map of the Normal Albedo of the Moon," Professional Paper 599-E, Plate 1, Department of the Interior Geological Survey, 1970-G69152.



AS-15-101-13594



AS-15-101-13593



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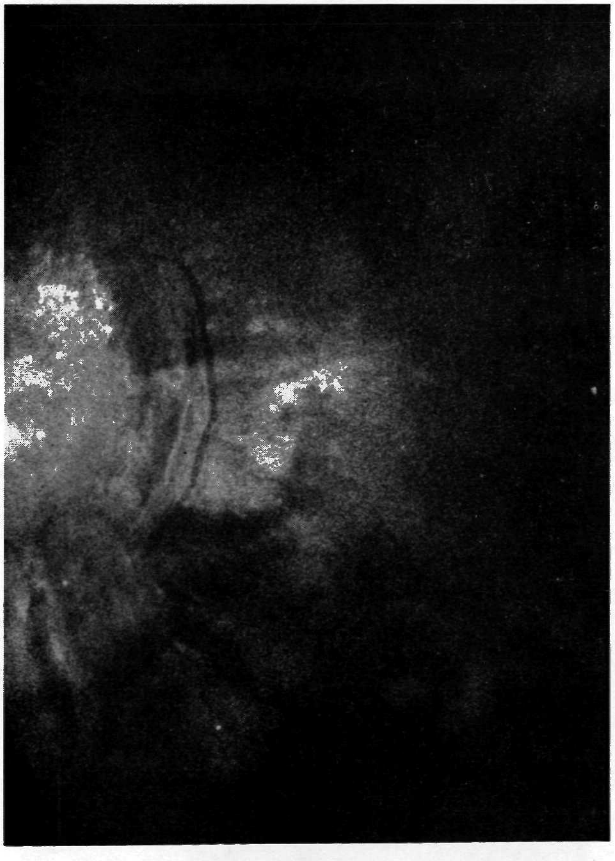
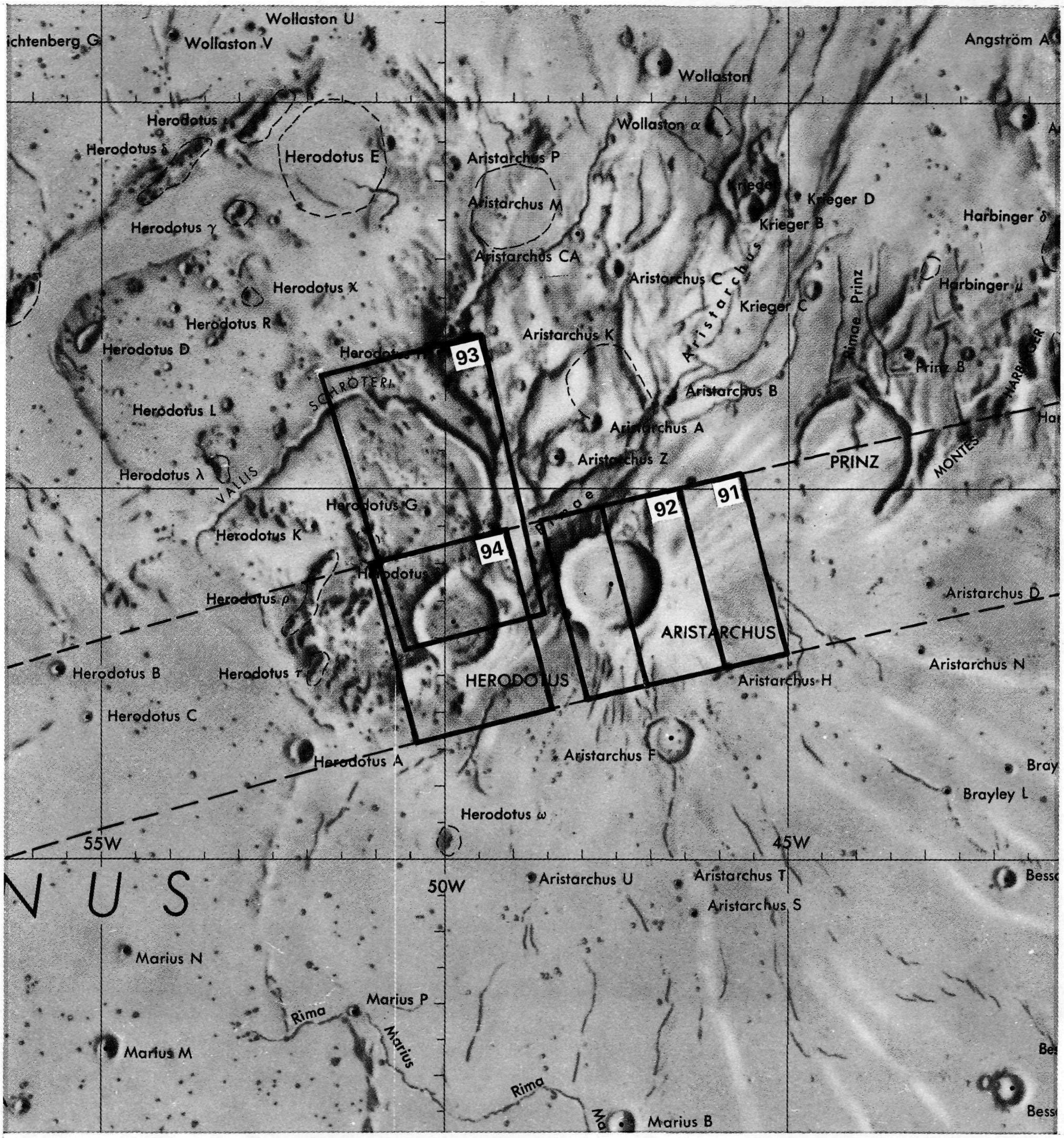


AS-15-101-13591

FIGURE 1



Wollaston U
Wollaston V
Wollaston
Angström A
Herodotus E
Herodotus γ
Herodotus R
Herodotus D
Herodotus L
Herodotus λ
Herodotus G
Herodotus K
Herodotus B
Herodotus C
Herodotus A
Herodotus ω
HERODOTUS
Wollaston α
Aristarchus P
Aristarchus M
Aristarchus CA
Aristarchus C
Aristarchus K
Aristarchus B
Aristarchus A
Aristarchus Z
Aristarchus D
Aristarchus N
Aristarchus H
Aristarchus F
Aristarchus U
Aristarchus T
Aristarchus S
ARISTARCHUS
Krieger D
Krieger B
Krieger C
Harbinger δ
Harbinger μ
Rimae Prinz
Prinz B
PRINZ
MONTES
Brayley L
Marius N
Marius P
Marius M
Marius B
Rima Marius
93
94
92
91
55W
50W
45W
N U S

FIGURE 2

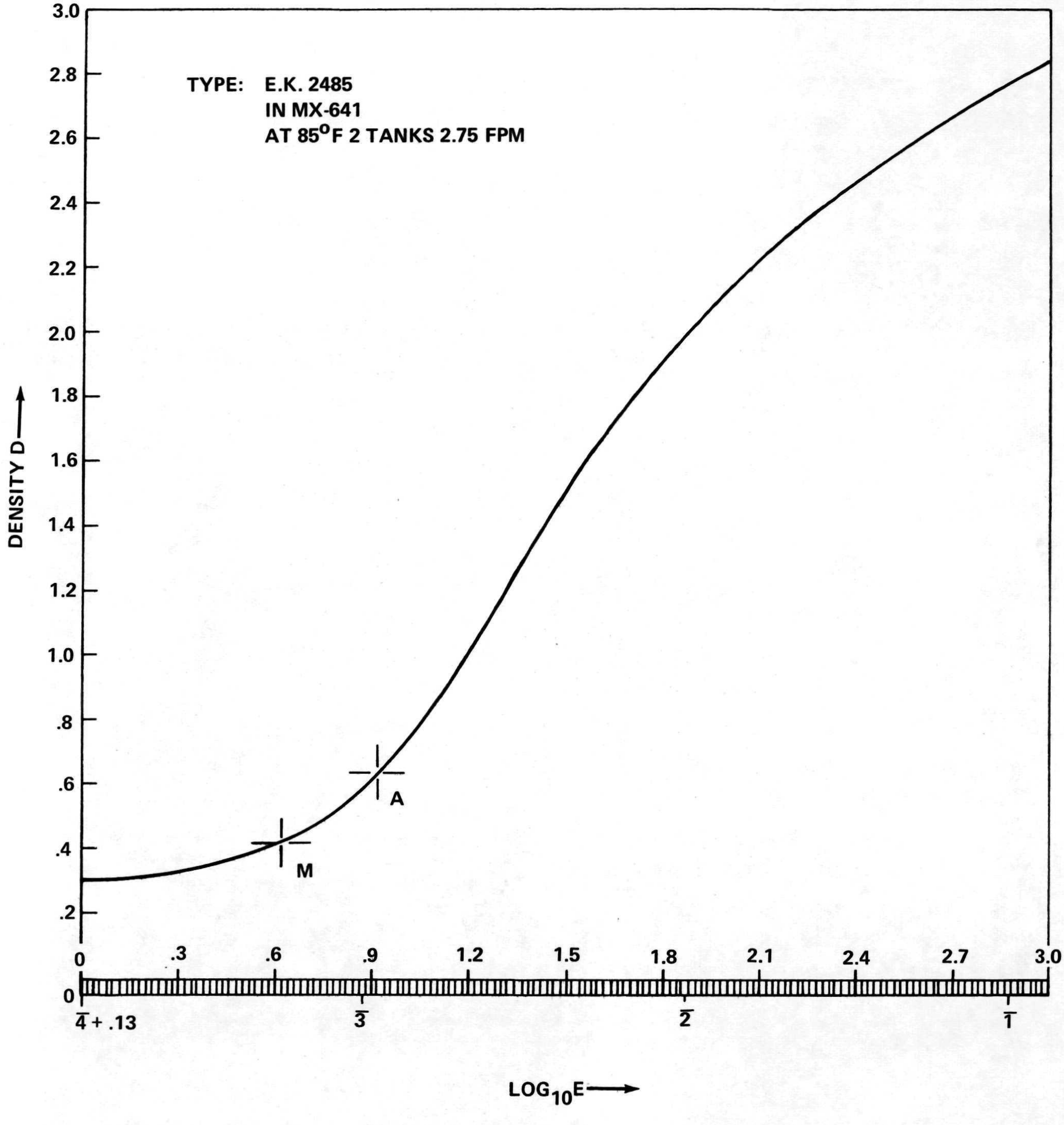

TYPE: E.K. 2485
IN MX-641
AT 85°F 2 TANKS 2.75 FPM
DENSITY D
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
M
A
0
.3
.6
.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
4̄ + .13
3̄
2̄
1̄
LOG10E

FIGURE 3

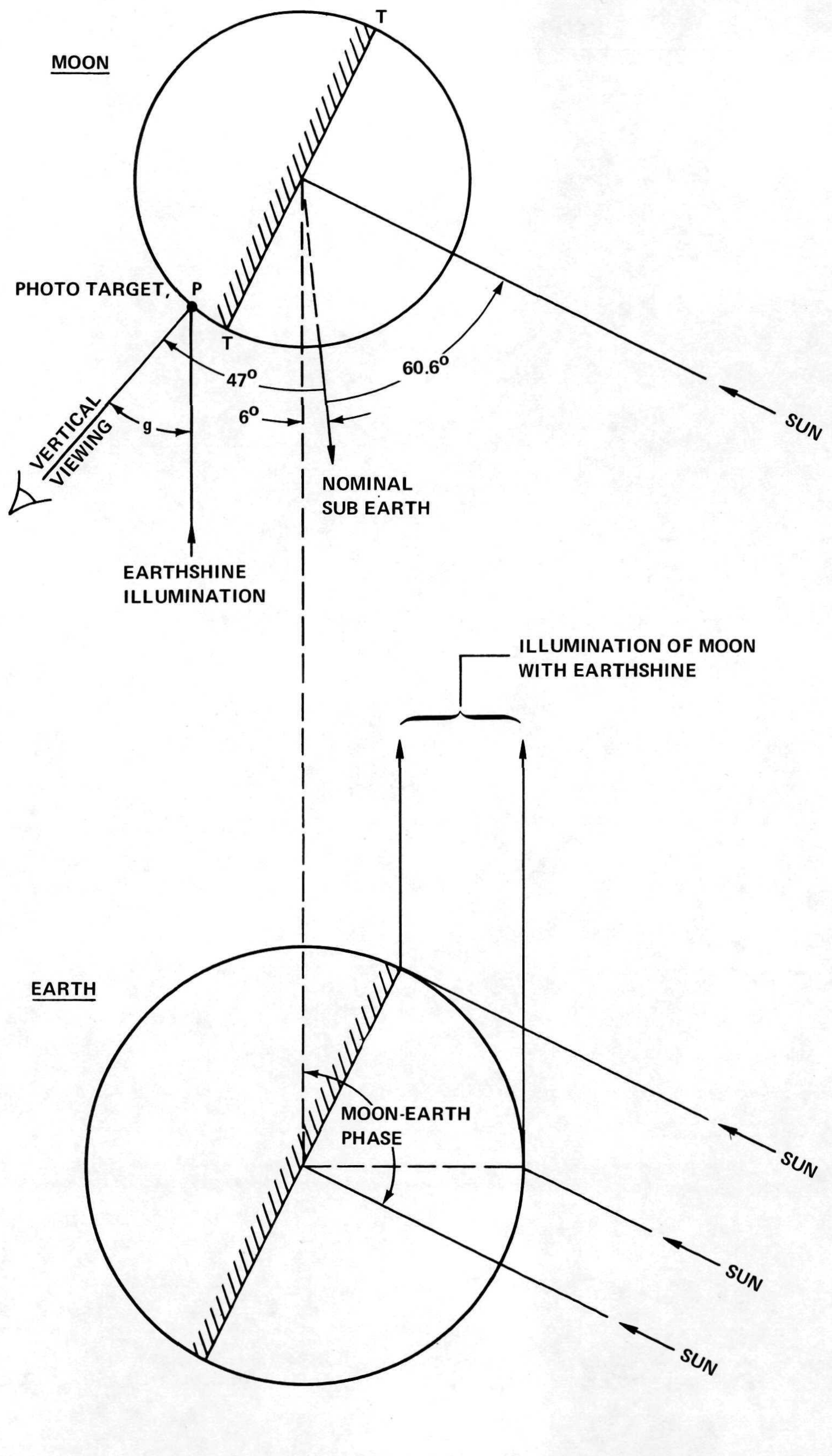

MOON
T
PHOTO TARGET, P
T
47°
60.6°
6°
g
VERTICAL VIEWING
NOMINAL SUB EARTH
SUN
EARTHSHINE ILLUMINATION
ILLUMINATION OF MOON WITH EARTHSHINE
EARTH
MOON-EARTH PHASE
SUN
SUN
SUN

FIGURE 4

LUNAR ORBITER I HIGH-RESOLUTION FRAME 102 FAR SIDE

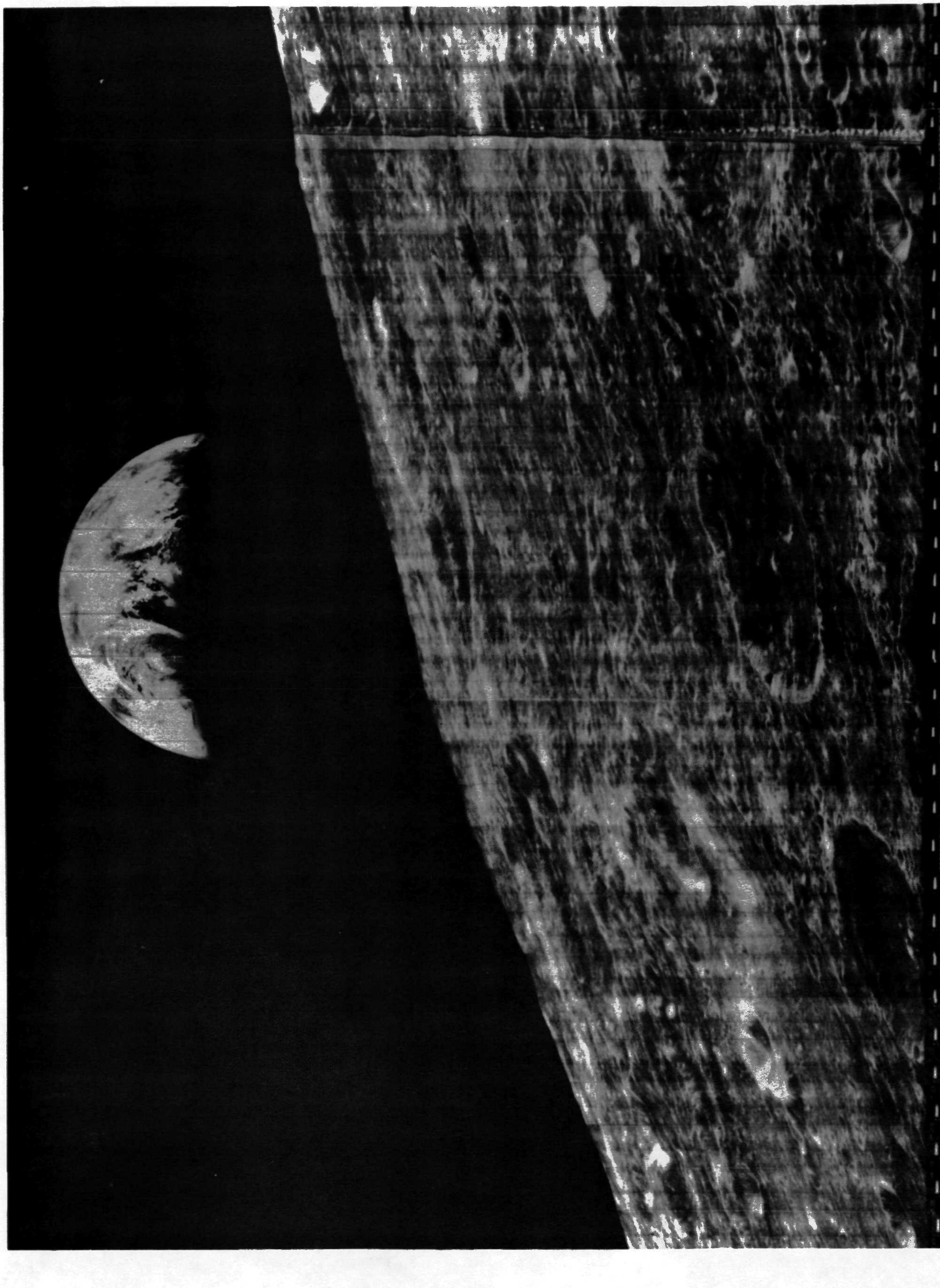


FIGURE 5

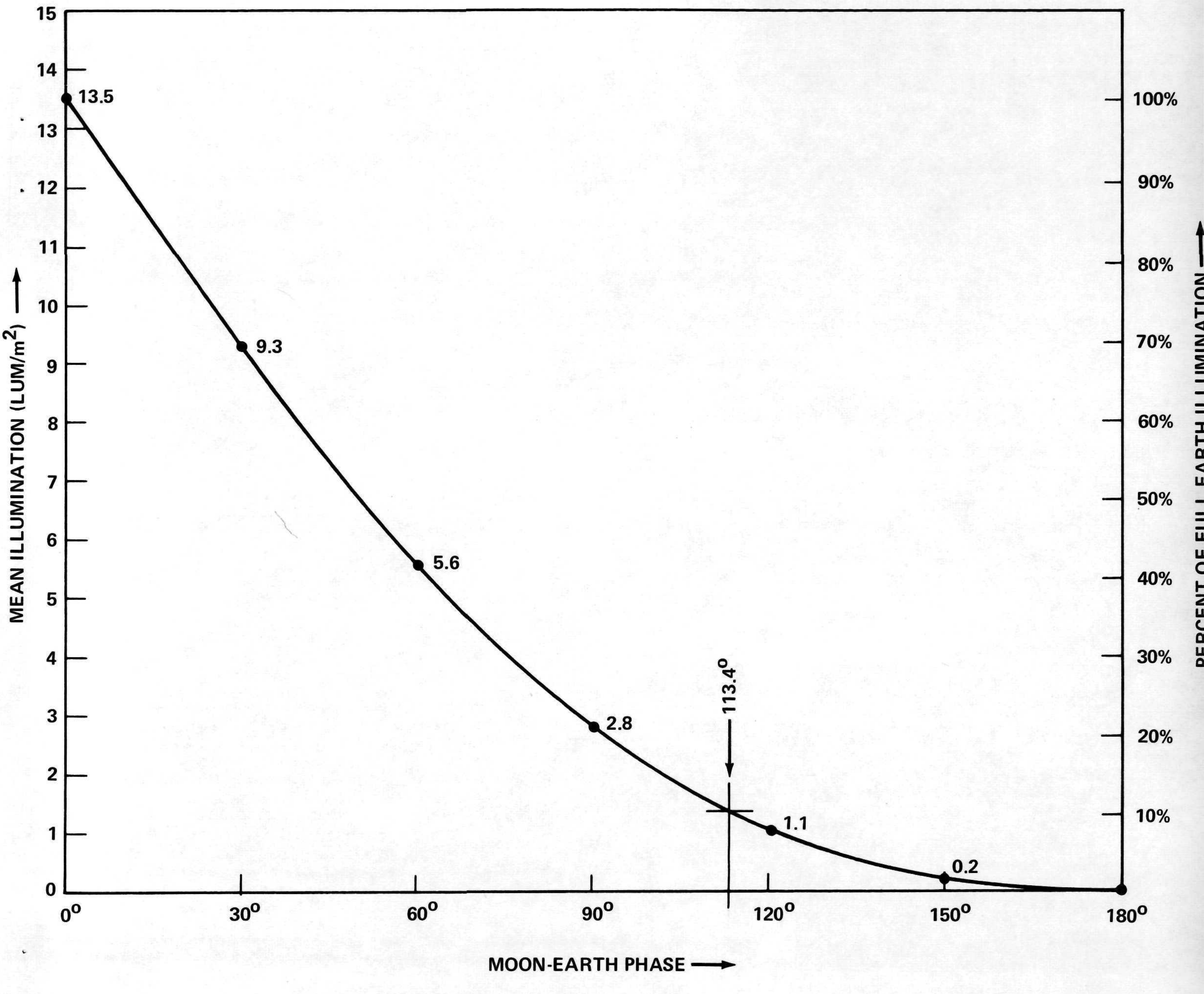


FIGURE 6 - MEAN ILLUMINATION OF MOON BY CRESCENT EARTH

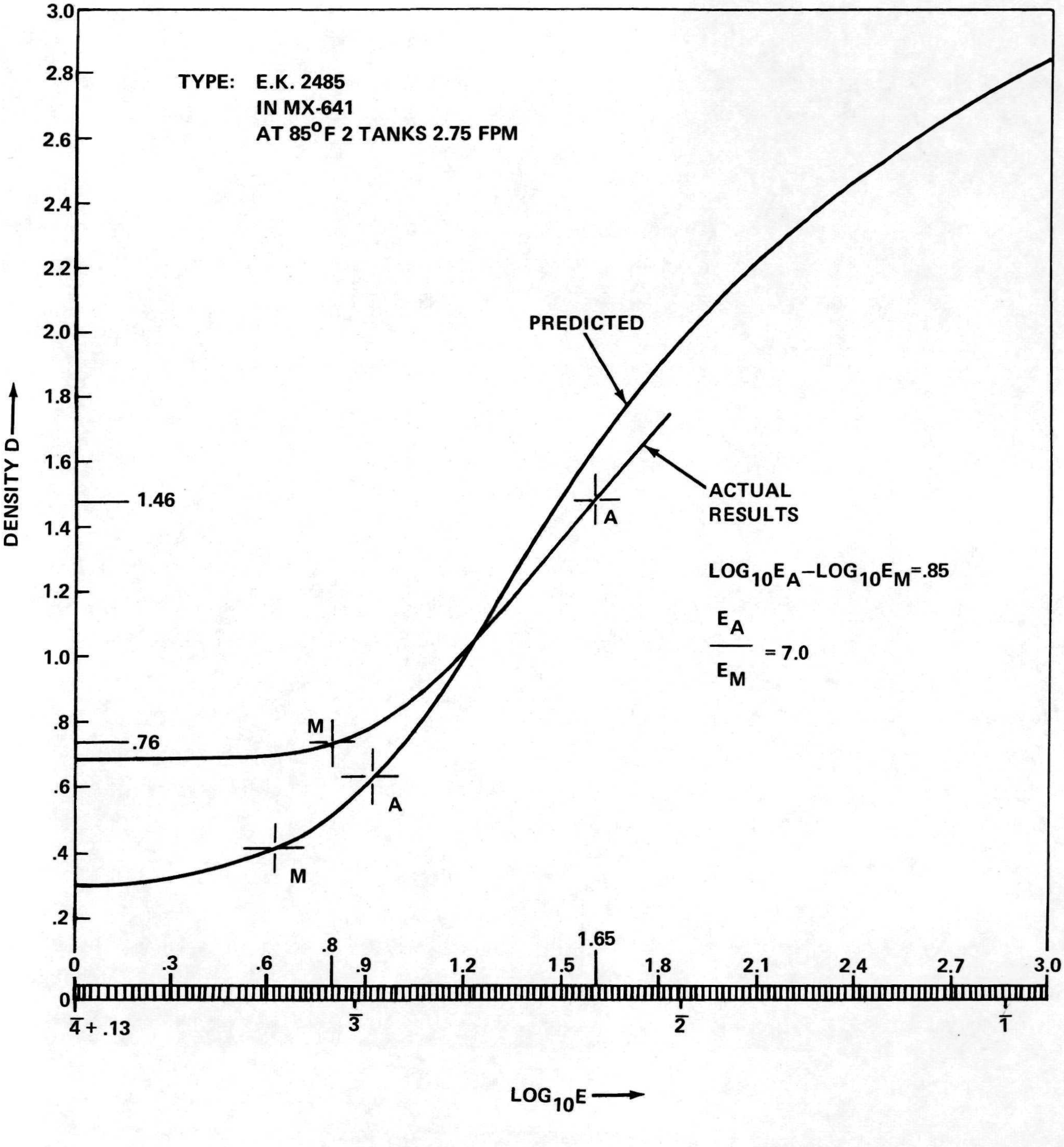

TYPE: E.K. 2485
IN MX-641
AT 85°F 2 TANKS 2.75 FPM
PREDICTED
ACTUAL RESULTS
LOG10EA–LOG10EM=.85
EA / EM = 7.0
DENSITY D
LOG10E
1.46
.76
1.65
.8
M
A
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.3
.6
.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
4̄ + .13
3̄
2̄
1̄

FIGURE 7