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EFFECTS ON THE LUNAR ATMOSPHERE RESULTING FROM LARGE-SCALE MANNED OPERATIONS; Richard R. Vondrak and John W. Freeman, Stanford Research Institute, Menlo Park, California 94025 and Department of Space Physics and Astronomy, Rice University, Houston, Texas 77001.

The present lunar atmosphere is a collisionless exosphere with surface number densities less than 10^7 cm^{-3} and a total mass of approximately 10^4 kgm. This tenuous state is maintained by the solar wind which promptly removes the majority of the ionized gas from the lunar vicinity through the action of the interplanetary electric field. The mean atmosphere life of an atom or molecule is the ionization lifetime (typically 10^6 to 10^7 seconds). This process determines the loss rate for all except the lightest atoms for which thermal escape dominates. The accelerated ions have been directly detected for both the natural lunar atmosphere and gasses associated with the Apollo missions (1). For the Apollo exhaust gases decay times of the order of one month were observed (2).

This solar wind loss mechanism is the dominant process only so long as the solar wind has direct access to the majority of the atmosphere. As the atmosphere becomes more dense, newly formed ions of atmospheric origin load down the solar wind and cause it to be diverted around the moon. Furthermore, the solar wind can carry away no more mass from the planet than its own mass flux to the planet. Venus and Mars each lose about 10 gm/sec to the solar wind. This represents about 1% for Venus and 20% for Mars of the mass flux of the solar wind through the respective planetary cross-sectional areas.

We wish to explore what happens if the atmospheric source rate from natural or artificial sources exceeds the solar wind's ability to carry off the gas. As the atmosphere becomes more dense, the base of the exosphere will rise above the surface and we expect the exospheric temperature to become greater than that of the lunar surface. Thermal escape will then become the dominant loss mechanism for the majority of the atmosphere and the atmosphere may become long-lived, since thermal escape times are thousands of years for gases heavier than helium.

The transition from a thin to a thick long-lived atmosphere is difficult to evaluate quantitatively because of our lack of understanding of exactly when a bow shock wave will form to begin to deflect the solar wind around the moon. Also, anomalous ionization may take place via Alfvén's critical velocity mechanism (3). We may simplify the problem by assuming the upper limit of mass loss due to the solar wind to equal the solar wind mass flux intercepted by the lunar disk, or about 50 gm/sec. Assuming source and loss equilibrium and a mean time to ionization of 10^7 seconds, this means an atmospheric mass of 5 x 10^5 kgm. We may further assume that this represents the critical mass and source rate beyond which thermal escape can become the important loss mechanism. Thermal escape will remain small, however, until the exospheric temperature rises. A quantitative evaluation of these atmospheric loss mechanisms is shown in Figure 1.

Finally, we estimate that for a total atmospheric mass of 10^8 kgm and an exospheric temperature of 800°K the thermal escape loss rate would be 60 kgm/sec. For atmospheres in excess of 10^8 kgm the loss rate cannot increase substantially and the atmosphere can grow indefinitely if the source rate exceeds 60 kgm/sec. Therefore, a constant addition rate of the order of 100 kgm/sec is required to transform the lunar exosphere into a long-lived state (4).

Figure 2 shows the ultimate atmospheric masses which result from various constant gas addition rates, Q. The effect of inducing a transition from an exosphere with rapid loss to a thick atmosphere with slow loss is illustrated by considering the result when the gas source is shut off (Q=0). The thick atmosphere decays with an exponential lifetime of several hundred years, whereas the thin exosphere decays in a few weeks.

Each Apollo mission deposited nearly 10^4 kgm of rocket exhaust in the lunar environment. A permanent base might be expected to release gas at the rate of 10^{-2} kg/sec.-man assuming supply traffic equal to one Apollo mission/man-month. Small colonies would not be expected to produce a long-lived atmosphere. However, even modest exploration releases gas much faster than the present natural rate of about 20 gm/sec, resulting in a lunar atmosphere in which the gases of natural origin would be only trace components.

Vigorous exploration or industrial production could result in gas rates greater than the 100 kgm/sec necessary to form a long-lived atmosphere.

References

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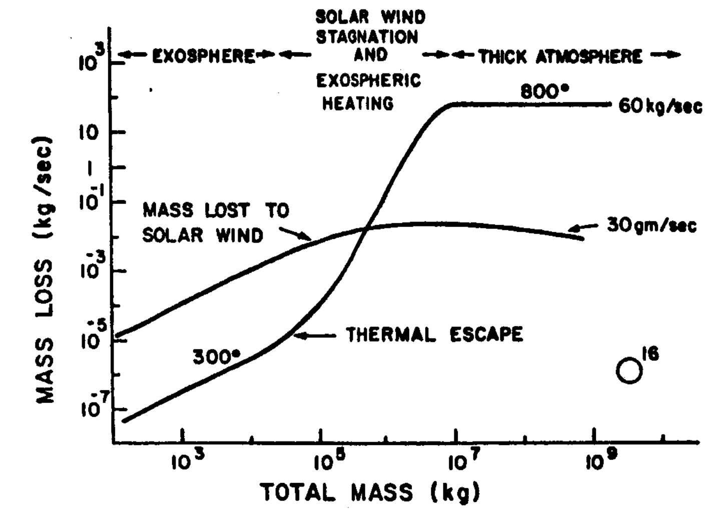

Figure 1. Loss rates from an oxygen (mass 16 a.m.u.) atmosphere

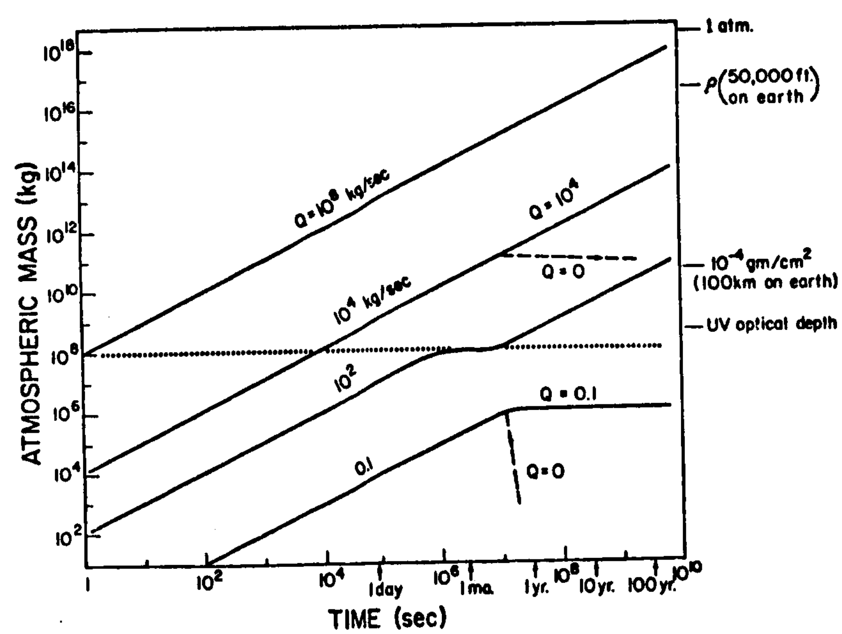

Figure 2. Growth curves of the lunar atmosphere. Dashed lines indicate decay in total mass if the gas source is shut off.

DISCUSSION - (Vondrak and Freeman)

SPEAKER 1: This is perhaps a comment rather than a question. Again, trying to compare a space colony and a lunar surface colony, I'm sure that in a space colony one would go to enormous efforts not to release gas simply because it was a valuable commodity and you could recycle it. I don't know what the economics would be on the Moon, but I think it's at least suggestible that the recovery of gas might be an equally important value and that you might turn out not to vent as much gas as terrestrial or Apollo experience would indicate.

FREEMAN: Yes. I think that's certainly a valid comment.