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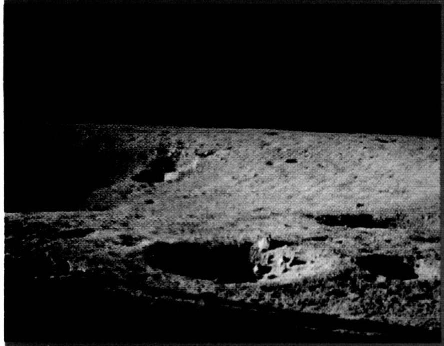
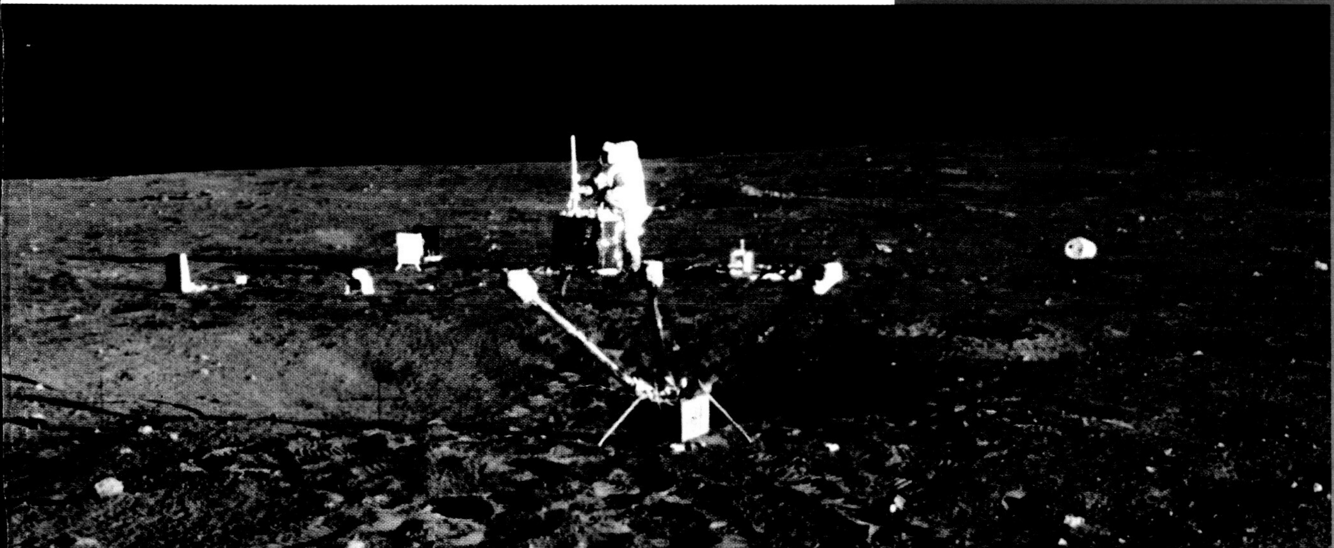


APOLLO 12

Preliminary Science Report



NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

6. Suprathermal Ion Detector Experiment (Lunar Ionosphere Detector)

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The suprathermal ion detector experiment (SIDE), a part of the Apollo lunar surface experiments package (ALSEP), is designed to achieve the following experimental objectives:

(1) Provide information on the energy and mass spectra of the positive ions close to the lunar surface that result from solar-ultraviolet or solar-wind ionization of gases from any of the following sources: residual primordial atmosphere of heavy gases, sporadic outgassing such as volcanic activity, evaporation of solar-wind gases accreted on the lunar surface, and exhaust gases from the lunar module descent and ascent motors and the astronauts' portable life-support equipment

(2) Measure the flux and energy spectrum of positive ions in the Earth's magnetotail and magnetosheath during those periods when the Moon passes through the magnetic tail of the Earth

(3) Provide data on the plasma interaction between the solar wind and the Moon

(4) Determine a preliminary value for the electric potential of the lunar surface

The Instrument

The suprathermal ion detector experiment consists of two positive ion detectors. The first of these, the mass analyzer, is provided with a crossed electric- and magnetic-field (or Wien) velocity filter and a curved-plate electrostatic energy-per-unit-charge filter in tandem in the ion flightpath. The requirement that the detected ion must pass through both filters allows a determination of its mass per unit charge. The ion sensor itself is a channel electron multiplier operated as an ion counter that yields saturated pulses for each input ion. The second detector, the total ion detector, employs only a curved-plate electrostatic energy-per-unit-charge filter. Again, the ion sensor itself is a channel electron multiplier operated as an ion counter. Both channel electron multipliers are biased with their input ends at −3.5 kV, thereby providing a post-analysis acceleration to boost the positive ion energies in order to yield high detection efficiencies. Figure 6–1 illustrates the general detector concept, and figure 6-2 is a cutaway drawing of the suprathermal ion detector experiment which illustrates the location of the filter elements and the channel electron multipliers.

A primary objective of the experiment is to provide a measurement of the approximate mass-per-unit-charge spectrum of the positive ions near the lunar surface as a function of energy for ions from approximately 50 eV down to near-thermal energies. Therefore, the mass analyzer measures mass spectra at six energy levels: 48.6, 16.2, 5.4, 1.8, 0.6, and 0.2 eV. However, for the Apollo 12 instrument, dependable laboratory calibrations were achieved only at the two highest energy levels. The total ion detector measures the differential positive ion energy spectrum from 3500 eV down to 10 eV in 20 energy steps. For the Apollo 12 mass analyzer, the range of the mass spectrum covered is approximately 10 to 1000 atomic mass units (amu). Twenty mass channels span this range. The relative width for each mass channel $\Delta M/M$ is approximately 0.2 near the lower masses. In principle, the flux of ions with masses less than 10 amu per unit charge can be obtained by subtracting the integrated mass spectrum flux obtained with the mass analyzer from the total

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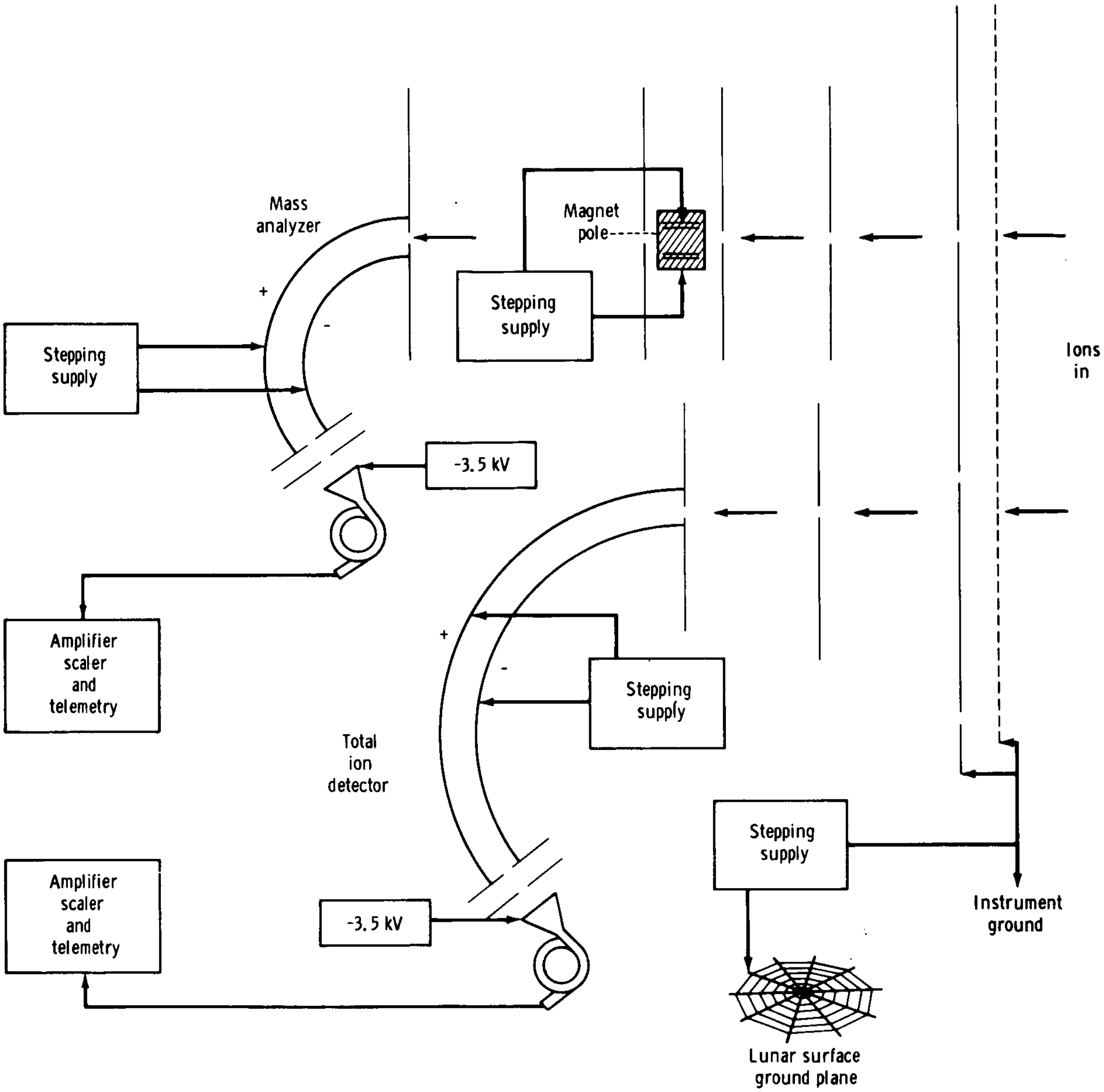

FIGURE 6-1. — A schematic diagram of the suprathermal ion detector experiment.

ion flux, at the same energy, obtained with the total ion detector.

To compensate for a possibly large (tens of volts) lunar surface electric potential, a wire screen is deployed on the lunar surface beneath the suprathermal ion detector. This screen is connected to one side of a stepped voltage supply, the other side of which is connected to the internal ground of the detector and to a grounded grid mounted immediately above the instrument and in front of the ion entrance apertures (fig. 6-1). The stepped voltage is advanced only after a complete energy and mass scan of the mass analyzer (i.e., every 2.58 min). The voltage supply is programed to step through the following voltages: 0, 0.6, 1.2, 1.8, 2.4, 3.6, 5.4, 7.8, 10.2, 16.2, 19.8, 27.6, 0, −0.6, −1.2, −1.8, −2.4, −3.6, −5.4, −7.8, −10.2, −16.2, −19.8, and −27.6. This stepped supply and its ground screen may function in either of two

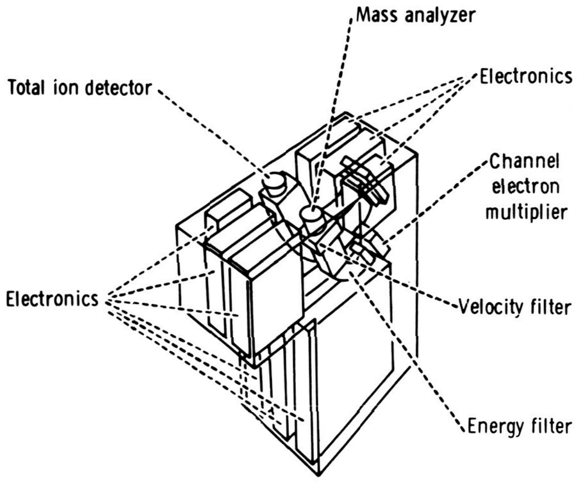

FIGURE 6-2. — A cutaway drawing showing the interior of the suprathermal ion detector experiment.

ways. If the lunar surface potential is large and positive, the stepped supply, when on the appropriate step, may counteract the effect of the lunar surface potential and, thereby, allow the low-energy ions to reach the instrument with their intrinsic energies. However, if the lunar surface potential is near zero, then on those voltage steps that match or nearly match the energy levels of the mass analyzer or the total ion detector (1.2, 5.4, etc.), thermal ions may be accelerated into the suprathermal ion detector at energies optimum for detection. The success of this method depends on the Debye length and on the extent to which the ground-screen potential approximates that of the lunar surface. It is not yet possible to assess either of these two factors.

Figure 6-3 shows the SIDE deployed on the lunar surface. The experiment is deployed approximately 50 ft from the ALSEP central station in a southwesterly direction. The top surface stands 20 in. above the lunar surface. The sensor look directions include the ecliptic plane, and the look axes are canted 15° from the local vertical and to the west. Figure 6–4 shows the look directions in an Earth-Sun coordinate system at various points along the lunar orbit. The field of view of each sensor is roughly a square solid angle, 6° on a side. The sensitivities of the total ion detector and mass analyzer are approximately 5×10^{17} and 10^{17} counts/sec/A of entering ion flux, respectively.

In addition to detecting ions directly, the suprathermal ion detector is also sensitive to the ambient neutral gas pressure through the back-

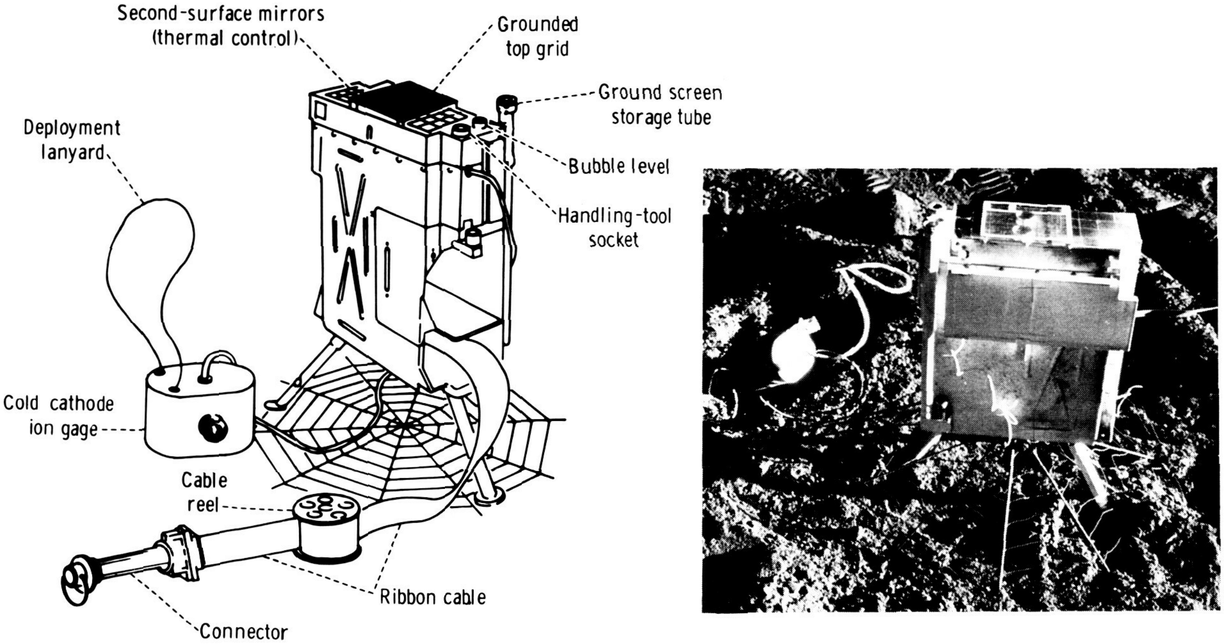

FIGURE 6-3. — The suprathermal ion detector experiment as deployed on the Moon.

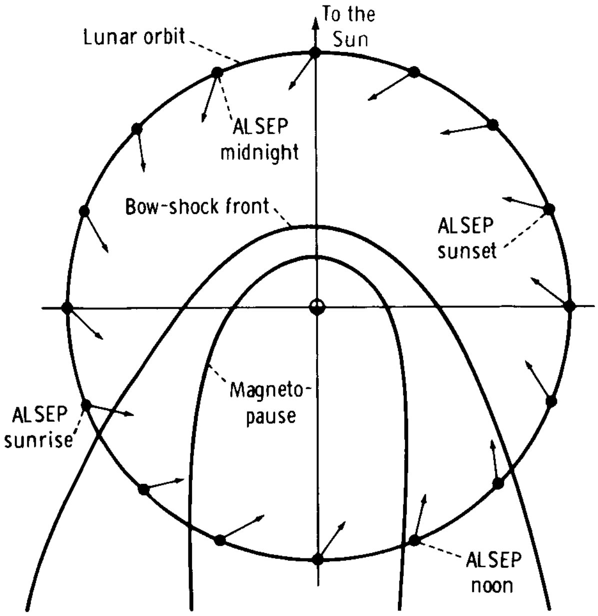

FIGURE 6-4. — The look directions of the suprathermal ion detector at various points along the lunar orbit. The diameter of the Earth is not drawn to scale.

ground counting rate of the channel electron multipliers. The background counting rate is defined as those counts present when the energy and velocity filter voltages are turned off, direct entrance of charged particles being, therefore, impossible. This property can provide a rough measure of the instrument outgassing.

Most of the data used for the preliminary analysis presented in this report consist of quick-look analog strip-chart recordings for which only counts of more than four per frame are detectable. This limitation prohibits the observation of low-intensity events in the quick-look data. Furthermore, no long-time averaging has yet been attempted. For these reasons, only the readily discernible features of the data will be discussed.

Performance of the Suprathermal Ion Detector

At the time of preparation of this report, 45 days after deployment, the operation of the suprathermal ion detector continues to be excellent. All temperatures and voltages have been nominal. Only two operational anomalies have been noted. First, outgassing associated with the high temperatures at lunar noon has caused the channel-electron-multiplier high voltage to be commanded off for several days on either side of lunar noon. The situation at the second lunar noon showed an improved situation over that experienced on the first lunar noon, and it is expected that 100-percent duty-cycle operation will be possible within the next 3 lunar days. Second, on a few occasions, a calibration signal for the total ion detector has been intermittent for a short time. The calibration signal is used as a diagnostic check on the digital logic and is not essential to the operation of the instrument as long as the digital logic functions properly.

General Results

Low-Energy Events

Shortly after turn-on of the SIDE, several low-energy events were detected in the total ion detector. These ions appear to come in clouds that remain for approximately 10 min. Several clouds were accompanied at the outset by higher energy ions (500 to 750 eV). One arrival of such a cloud was coincident with a magnetometer variation that indicated the passage of a current sheet nearby.

At the same time these low-energy events were seen by the total ion detector, the mass analyzer detected ions in the 48.6-eV range (frames 0 to 19). Figure 6–5 shows the total ion detector counts and the mass analyzer counts of a typical event. In figure 6–6, an average for five mass spectra is shown. The only mass spectra identified in the preliminary analysis originate in the period shortly after turn-on, and all these spectra show a shape similar to the one presented in figure 6–6, that is, with a peak between frames 2 and 6. The number of spectra detected to date is rather low because within a few hours after turn-on the background rate had increased with increasing temperature so that additional similar events may be hidden. Such low-magnitude events can be evaluated only after a detailed background study. Furthermore, the investigation was restricted to events that are simultaneously apparent in both detectors (the total ion detector and the mass analyzer) at about the same energy step. When this criterion was used,

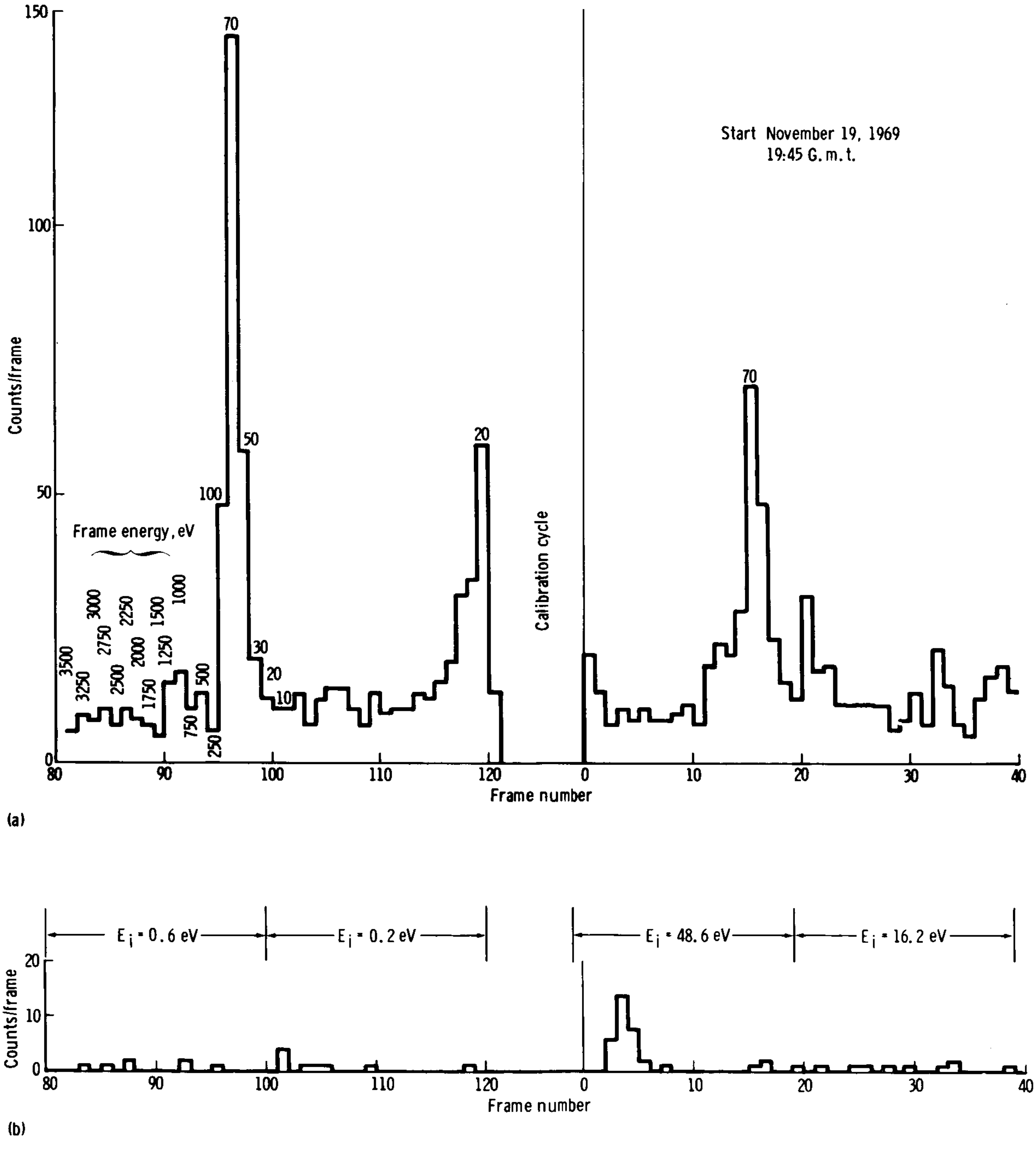

FIGURE 6-5. — Samples of the simultaneous total ion detector and mass analyzer data from November 19, 1969. Each frame is 1.2 sec long, and the counts are accumulated in that time interval. The total ion detector energy spectrum is repeated every 20 frames, except for a calibration cycle from frames 121 to 0. The mass analyzer sweeps through a mass spectrum at each energy in 20 frames; therefore, a complete spectrum at all six energies is obtained every 2.58 min (including the calibration cycle). Note the repeated peaks in the total ion detector data in the 20- to 100-eV energy range. Note also the peak in frames 2 to 6 in the mass analyzer data. (a) Total ion detector data. (b) Mass analyzer data.

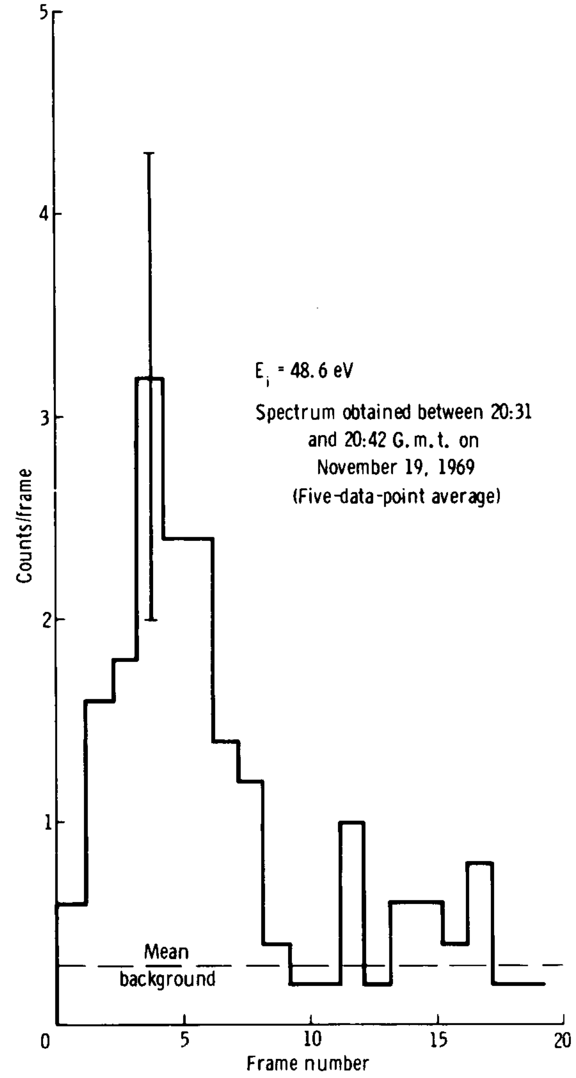

FIGURE 6-6. — A five-data-point average of the mass analyzer 48.6-eV range on November 19, 1969.

no events were found in the lower energy steps of the mass analyzer.

As mentioned previously, the only mass spectra found to date peak in frames 2 to 6, corresponding to a mass-per-unit-charge range of 18 to 50 amu/q. Evaluations of these events are not complete enough at this time to discuss what gases these events represent. However, it seems reasonable that ions would be found in this medium mass range since possible sources such as lunar module rocket exhaust products and thermalized or sputtered solar-wind ions may exist. It should be kept in mind that the light gases H, H_2, and He cannot be detected by the mass analyzer. They can be detected only by the total ion detector.

In addition to the previously described events that were detected in both the total ion detector and the mass analyzer, low-energy (10 to 250 eV) ions have often been seen in the total ion detector only. The total ion detector yields six complete energy spectra in the time required for a complete mass-energy spectrum from the mass analyzer. The probability is high, therefore, that the mass analyzer will not be at the appropriate energy level to simultaneously detect the ions seen by the total ion detector. These ions are often quite monoenergetic. For example, several consecutive spectra may occur with high counts seen in only one energy channel. Figure 6–7 is an example of such a spectrum. In other events, the peaks are wider, covering two to three energy channels, or monoenergetic peaks of different energies are mixed in several consecutive spectra.

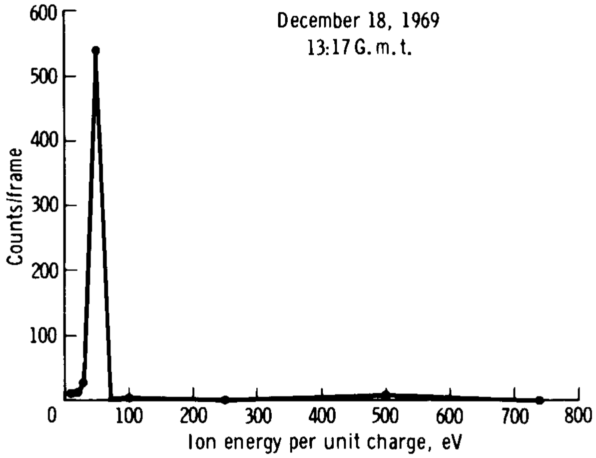

FIGURE 6-7. — The energy spectrum for a typical 50-eV monoenergetic event.

It is interesting to speculate on the possibility that the energization process for these ions is the E × B drift acceleration by the solar wind. The frequent appearance of such suprathermal ions suggests a general acceleration mechanism.

Higher Energy Phenomena

A variety of interesting higher energy spectra have been observed with the total ion detector. The majority of these have not yet been examined in detail; however, two categories of spectra have been singled out for illustration.

The first category is characterized by large counts near the upper end of the energy range of the total ion detector, that is, between 1 and 3 keV. Figure 6–8 is an example of several spectra of this category. Data of this type come predominantly from that portion of the orbit near, and up to 4 days following, sunset at the ALSEP site. These ions appear sporadically, often lasting for tens of minutes and then disappearing for hours. These ions have been tentatively identified as protons escaping from the bow shock front of the Earth and moving generally along the interplanetary magnetic field lines at the "garden hose" angle. Such effects have been reported at the much closer Earth orbit of the Vela satellites (ref. 6–1).

The second category of spectra is characterized by an energy peak near or slightly below solar-wind energies. The interesting feature of this type of spectra is that it has also been seen during the lunar night. Figure 6–9 shows examples of spectra taken approximately 3 days before the sunrise terminator crossing. At this time, the detector look direction is only 25° from the antisolar direction, and the ALSEP is nearly 40° from the sunrise terminator. The maximum flux found to date for these ions is approximately 10^6 ions/cm^2-sec-sr. The solar wind appears to be deflected in some way around the limb of the Moon for a substantial distance.

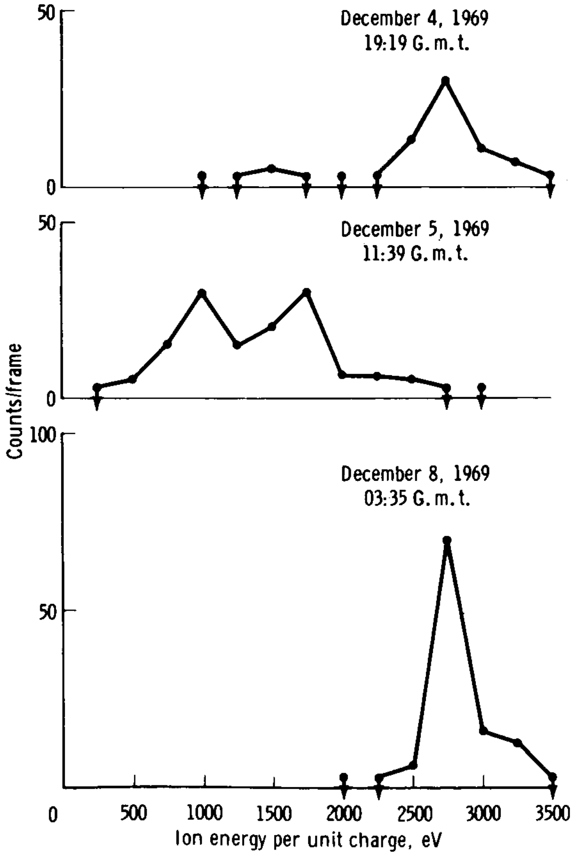

FIGURE 6-8. — Typical spectra showing the 1- to 3-keV ion seen after sunset.

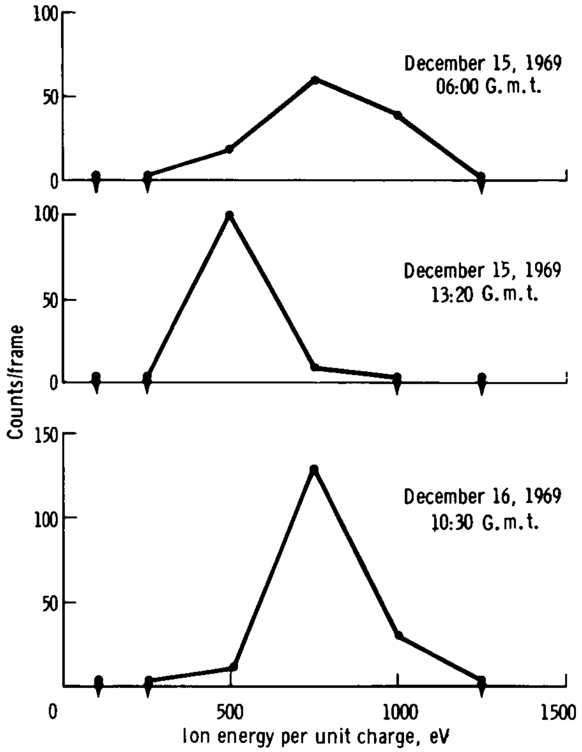

FIGURE 6-9. — Typical spectra showing the solar-wind energy ions seen before sunrise.

Special Events

Lunar Module Liftoff

At the time of liftoff of the lunar module ascent stage, there was a slight increase in the counting rates of the total ion detector in lower energy channels. No significant change was seen in the mass analyzer data, but the mass analyzer was looking at 5.4-eV and lower energy ions at the time. Four consecutive spectra taken during this event are shown in figure 6–10. The first spectrum is typical of several consecutive spectra prior to it. The next two spectra show the increased counting rates in the channels covering the broad energy range of 10 to 500 eV. By the time of the fourth spectrum, the counting rates had returned to background rate. The instrument was heating up during this period of time, and the consequent outgassing caused the fairly high background counting rates observed.

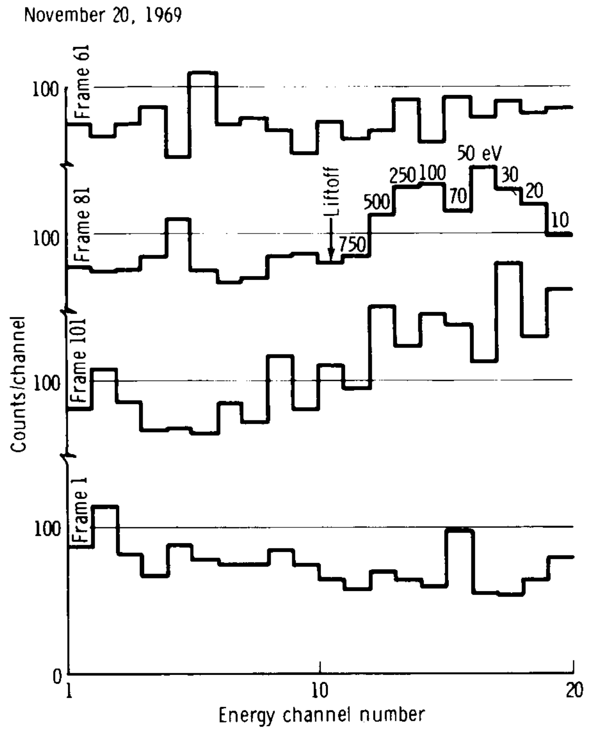

FIGURE 6-10. — Four successive total ion detector spectra before, during, and after lunar module ascent. An eight-frame calibration cycle occurs between the spectrum that starts with frame 101 and the spectrum that starts with frame 1.

Lunar Module Impact

At 22:17:17 G.m.t. on November 20, 1969, the lunar module ascent stage impacted the Moon 74 km east-southeast of the ALSEP. At this time, the total ion detector had been counting at an average rate of 142 counts per frame with no significant variations in any frame. Figure 6–11(a) is the first spectrum after the impact in which an increased counting rate was observed. A significant ion flux was detected in the 500- and 250-eV channels. These channels were sampled 52 sec after impact. After this spectrum, there were eight frames of instrument calibration followed by the spectrum shown in figure 6–11(b). The peak at 3000 eV is approximately 4σ above the background rate and is, therefore, certainly real, but the feature of main interest is the high flux of ions in the 70- to 1000-eV

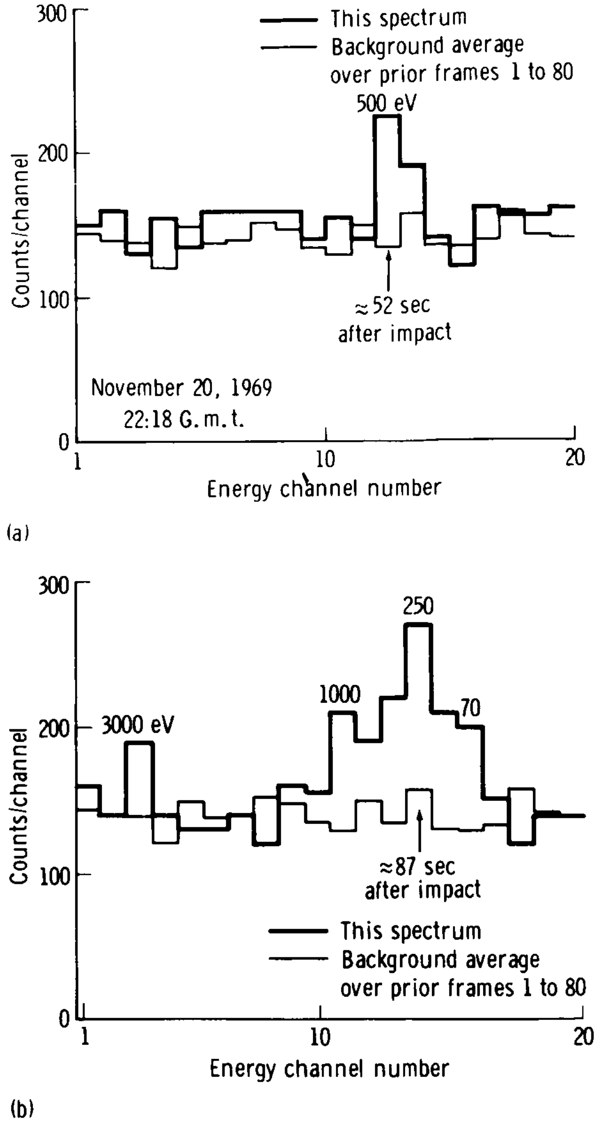

FIGURE 6-11. — Total ion detector spectra following lunar module impact. (a) First spectrum after ascent stage impact in which increased counting rate was observed. (b) Spectrum following instrument calibration frames.

channels. However, these high fluxes vanish within the next 12 sec. The following spectra show no counting rates that are significantly greater than the background rate.

On the basis of the foregoing, the inference exists that the gases liberated on lunar module impact with the lunar surface may have either triggered a temporary perturbation to the solar wind that rendered the solar wind partially detectable to the suprathermal ion detector or, more probably, these gases themselves may have been ionized as the spherical gas shell moved outward from the impact point. The ionized impact-generated gases and lunar module consumable gases may have then executed **E** × **B** drift motion brought on by the solar wind and, hence, gained access to the suprathermal ion detector along the general direction of solar-wind flow. In this connection, it is noted that the ALSEP was 68 km down solar wind of the impact point and that the time of arrival of the first gas burst at the suprathermal ion detector would correspond to a velocity of approximately 1 km/sec; for thermal expansion of the cloud, the requisite temperature is several thousand degrees Kelvin. The efficiency for such a mechanism is difficult to estimate because of the tortuous paths followed by the ions after pickup by the solar wind and because of the large gyroradii of the ions. However, a conservative order-of-magnitude estimate yields a flux consistent with the observed flux of approximately 10^7 ions/cm^2-sec-sr-keV.

High Background Rates Observed During the Second Lunar Day

Three hours following the first sunrise, the mass-analyzer background rate became very high and erratic. These high counts came in bursts, slowly at first but with gradually increasing frequency. They continued throughout the lunar day with slowly decreasing intensity and disappeared abruptly within 12 hr after sunset. Figure 6–12 shows the general intervals during which the counts were seen.

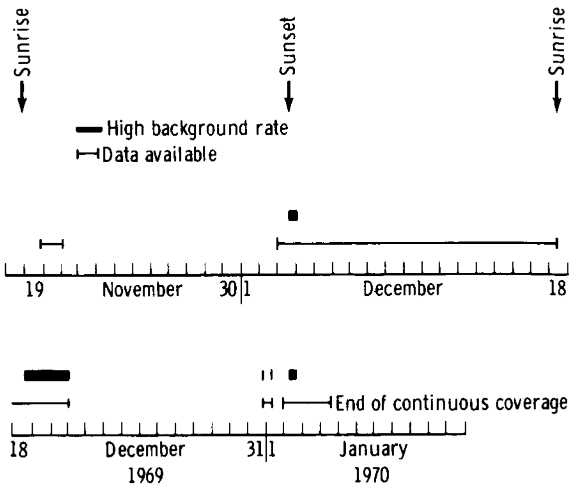

FIGURE 6-12. – A chart showing the time intervals during which the high, erratic background rates were observed in the mass analyzer data.

These high counts are clearly not the result of the low-energy positive ions the instrument was designed to detect since they are seen during background measurement frames and since neither the velocity-filter nor the energy-filter voltages appear to have an effect on the counting rates. Possible sources for the phenomena include a high ambient pressure of neutral gas or a temperature-sensitive malfunction of the channel electron multiplier. Channel electron multipliers are known to often exhibit high background rates in the event of cracks in the glass walls. Generally, however, such rates are relatively steady rather than highly erratic, as is the case observed for the Apollo 12 detector. Also, such rates have not been known to disappear once a crack or break has developed, whereas the background rate observed during the second lunar night was very low and perfectly normal.

Concerning the likelihood that these counts represent an enhanced lunar surface pressure, it is noted that approximately 1200 lb of propellant remained in the lunar module descent-stage tanks. These tanks are opened by the astronauts prior to departure. It is suspected, however, that the vents for the tanks may freeze and periodically inhibit the escape of the sublimating fuel (Aerozine 50) and oxidizer (N_2O_4). On the Apollo 11 mission, the passive seismic experiment saw seismic activity attributed to "venting or circulating gases or liquids or both" (ref. 6–2). This activity occurred for approximately 192 hr on the first lunar day after deployment. It seems possible that the high and erratic background rates of the mass analyzer indicate the periodic and impulsive escape of these gases. It is believed that a detailed comparison of the data with those from the Apollo 12 passive seismic experiment and a study of some apparent periodicities and decay rates of the bursts may resolve this question.

Summary

The performance of the suprathermal ion detector has been good. The preliminary data analysis yields the following features:

(1) Mass spectra of 50-eV ions are available from early in the experiment life. These spectra show a concentration of ions in the 18- to 50-amu/q mass-per-unit-charge range.

(2) Ions appear frequently in the ten- to several-hundred electron-volt range. This is highly suggestive of solar-wind acceleration of ambient ions of either natural or lunar-module-associated origin.

(3) One- to 3-keV ions are present sporadically early in the lunar night. These ions are thought to be energetic protons escaping upstream from the bow shock front of the Earth.

(4) Solar-wind energy ions are present on the nightside of the Moon approximately 4 days before lunar sunrise at the ALSEP site.

(5) Energetic ion fluxes are seen in good time correlation with the impact of the lunar module ascent stage onto the lunar surface. Again, there is a strong suggestion that the impact-released gases have been ionized and accelerated by the solar wind.

(6) High background count rates seen during the second lunar day may be indicative of large quantities of gas escaping impulsively from the lunar module descent-stage tanks.

Numerous other phenomena are apparent in the data. These have not been examined in sufficient detail to allow categorization or discussion at this time. Furthermore, no effort has been made to search for low-level phenomena that require averaging of the data.

References

6-1. Asbridge, J. R.; Bame, S. J.; and Strong, I. B.: Outward Flow of Protons From the Earth's Bow Shock. J. Geophys. Res., vol. 73, no. 17, Sept. 1, 1968, pp. 5777-5782.

6-2. Latham, G. V.; et al.: Passive Seismic Experiment. Sec. 6 of Apollo 11 Preliminary Science Report, NASA SP-214, 1969.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the dedicated support of many who have contributed to the success of the suprathermal ion detector experiment. In particular, thanks are extended to Wayne Andrew Smith, Rice University Program Manager; Paul Bailey, Rice University Assistant Program Manager; James Ballentyne, Rice University Reliability and Quality Assurance Engineer; Robert Shane and David Young, space science graduate students who participated in the design and calibration of the instrument; Alex Frosch, computer programer; and the staff of the Rice University Space Science Facilities. Thanks are also due to William Sandstrom, Dean Aalami, and the staff at Time Zero Corporation (formerly Marshall Laboratories), the subcontractor for design and fabrication of the suprathermal ion detector, and to James Boswell, Defense Contract Audit Service Representative. Derek Perkins of the Bendix Aerospace Systems Division and Jim Sanders and Ernie Weeks of the NASA Manned Spacecraft Center provided invaluable support to the project. Martha Fenner, space science graduate student, assisted with the data analysis.

This research has been supported by NASA contract NAS9-5911. H. Balsiger is a European Space Research Organization/National Aeronautics and Space Administration International Postdoctoral Fellow.