Apollo XII

Suprathermal Ion Detector Experiment

One Year Report

October, 1970

Prepared by Rice University under NASA Contract NAS9-5911

SUPRATHERMAL ION DETECTOR EXPERIMENT

(Lunar Ionosphere Detector)

This report reviews the lunar surface operation of the Suprathermal Ion Detector Experiment (SIDE) and gives the status of the experiment as of September 1, 1970, including observations of scientific and engineering interest which have been made since the 45-day preliminary report (reference 1). The SIDE is designed to achieve the following experimental objectives:

(1) Provide information on the energy and mass spectra of positive ions close to the lunar surface, whether these ions are of natural origin such as the moon or the solar wind, or are due to the Apollo vehicle and life-support systems.

(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 interaction between the solar wind plasma and the Moon.

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

The SIDE consists of two positive ion detectors, called the total ion detector and the mass analyzer. The total ion detector registers ions in twenty energy ranges from 10eV through 3500eV, and the mass analyzer covers the mass-per-unit-charge range 10 through 1000amu/q (this mass range varies from unit to unit) with 20 channels at each of 6 energy levels from 0.2 to 48.6 eV. The sensor fields of view are roughly square solid angles 6° on a side, and include the ecliptic plane. The look axes are canted 15° from the local vertical and to the west, with the look directions at various points along the lunar orbit as shown in Figure 1. The sensitivities of the total ion detector and of the mass analyzer are approximately 5 x 10^{17} and 10^{17}counts/sec/amp of entering positive ion flux, respectively. The entrance aperture areas are approximately 24mm^2 and 16mm^2, respectively. A more detailed description of the instrument is given in the preliminary report (reference 1).

Performance

The performance of the SIDE continues to be excellent. All temperatures and voltages have been nominal and no new anomalies in operation have appeared since the preliminary report. The calibration signal for the total ion detector has been intermittent for a short time on several occasions. This is used as a diagnostic check on the digital logic and is not essential as long as the digital logic functions properly.

The detector high voltage (-3.5 kV) power supply had to be commanded off for a period of about 11 days centered on lunar noon during the first three lunar cycles after deployment. This was done because of the spontaneous execution of mode change commands by the SIDE when its temperature exceeded some threshold value. Since these spurious commands were assumed to be caused by high voltage corona or arcing in the SIDE, probably due to outgassing as the temperatures increased, the high voltage was commanded off after such a mode change in order to prevent further arcing and possible damage to components. The threshold temperature above which spontaneous mode changes occurred increased significantly (from 36° to 51°C) on the 2nd lunar day, apparently as outgassing proceeded. However, improvement has been slow since then and the current critical temperature range is about 50-55°C. An operational method has been devised to circumvent this problem, and has resulted in acquisition of very interesting data in the earth's tail and magnetosheath regions. When the SIDE temperature reaches 50-55°C, or after a spontaneous mode change occurs, the instrument power is cycled off and on, which produces a temperature history such as that shown in Figure 2, keeping the package below about 55°C and hence obtaining data without undue risk of high voltage arcing damage to components. In the lunar afternoon the instrument is turned on and left on until it is necessary to cycle it off and on again in the next lunar day. The duty cycle can be increased above what is shown in Figure 2, but a high duty factor has been utilized only in periods of highly interesting data. The remainder of the time the normal 2hr/day real-time support periods have been utilized to obtain data for monitoring purposes.

The thermal design of SIDE kept the internal temperatures within the desired nominal operating range of -20°C to +80°C. The peak operating temperatures reached 79°C during each of the three lunar days when the power was left on continuously. During the night-time the internal temperatures are maintained at constant values (-9°C to +22°C, depending on proximity to the heaters) by means of 4 watts of heater power dissipation in addition to the 6 watts dissipated in the electronics. A study of the temperature vs sun-angle data from deployment until the present shows that there has been no degradation of the thermal control during this time (about 9 months).

The Cold Cathode Gauge Experiment (CCGE) electronics are carried in the SIDE package, and the CCGE high voltage (4.5 kv) power supply failed at about 14 hours after deployment. Extensive testing and failure analysis of similar units subsequently indicated that a transistor in this power supply was susceptible to failure in this application due to transient noise. A different transistor, better suited for this application, has been installed in the Apollo XIV and XV flight units to improve the reliability of the instrument. Additional care has also been taken to minimize the likelihood of high voltage corona within the instrument.

General Results

Low-Energy Events

As reported in references 1 and 2, several low-energy (10 to 250 eV) events were detected by the total ion detector shortly after initial turn-on of the SIDE. These ions appeared as intermittent clouds, several of which were accompanied at the outset hy 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, with the peak of the mass spectrum in the mass-per-unit-charge range of

18 to 50 amu/q. It should be noted that the light gases H, H_2, and He cannot be detected by the Apollo XII mass analyzer; they can be detected only by the total ion detector.

Other low-energy ion events have often been seen by the total ion detector only. Since the sensitivity of the mass analyzer is lower than that of the total ion detector, this could be because there were few of the heavier ions present, but it could also be because of the small fraction of the time that the energy channel of the mass analyzer coincides with a similar energy channel of the total ion detector. A study is currently in progress to investigate possible long-term low-level mass spectra in the mass analyzer data. Sometimes the ions in these low-energy events have rather broad spectra covering two or three energy channels, although frequently the spectrum is quite monoenergetic, with all energies falling within a single energy channel.

The frequent appearance of these suprathermal ions suggests the operation of a general acceleration mechanism. One interesting possibility to speculate on is the $\vec{E} \times \vec{B}$ drift acceleration by the solar wind. This mechanism has been proposed as the source of large quantities of Ar^{40} found in the lunar surface samples (reference 3). We may therefore have direct evidence for such a process.

Higher Energy Phenomena

Reference 1 also reported the detection of high energy (1 to 3 keV) ions sporadically in the portion of the lunar orbit near, and up to 4 days after, sunset at the ALSEP site. In the earlier part of this time period there are lower energy ions, also. These ions have been tentatively identified as protons escaping from the Earth's bow shock front and moving generally along the interplanetary magnetic field lines at the "garden hose" angle. Such observations have been reported at the much closer Earth orbit of the Vela satellites (reference 4).

Low-energy protons escaping from the bow shock cannot drift upstream as close to the interplanetary field direction as higher energy protons can. Thus there should be a change to a more energetic spectrum at later times, as is observed. However, the actual energies and directions of such escaped protons are expected to be modified in an unknown manner by magnetic and electric fields in the vicinity of the moon, of both local and long-range scale. Note that the ALSEP magnetometer measures a steady 36γ magnetic field which is probably of local origin (reference 5).

Ions of solar wind energy observed several days before local sunrise, as if due to a deflection of the solar wind, were previously reported (reference 1). These have been observed each lunar cycle. Intermittent day-time events are also seen each cycle.

Earth's Wake in the Solar Wind

Beginning in February, 1970, observations were made during many short segments of time throughout the region of the Earth's magnetospheric tail and the magnetosheath region between the bow shock front and the tail. Very intense ion fluxes are observed in the magnetosheath as the moon leaves the magnetospheric tail, while only very low and sporadic ion fluxes are seen in the magnetosheath where the moon enters the tail. The detector is looking roughly "upstream" parallel to the bow shock front in the former case, whereas in the latter the detector looks almost perpendicular to the shock front. In both cases when the moon is outside the shock front the detector look direction is such that the solar wind in interplanetary space is undetectable. The intense fluxes of ions are observed behind the bow shock, so they do not constitute the undisturbed solar wind, but rather the solar wind after passing through the bow shock. There is also an indication that effects of the solar wind interaction with the moon are being observed as well. A preliminary description of this data has been presented in reference 6. A general factor of the magnetosheath data is the observation of three characteristic types of spectra, which appear at different times. Typical spectra of each of these types are exhibited in figure 3, each panel of which displays total ion detector counts per frame for three scans through the energy spectrum. The intensity and constancy of the fluxes, and the presence of higher energy ions, as listed in the figure, are used to characterize the different types of spectra shown. As a simplified description, the type I spectra are typically observed near the magnetopause, shortly after entering the magnetosheath. The more intense type II spectra appear later, and type III spectra are typically observed near the bow shock, as the moon is leaving the magnetosheath.

The magnetosheath is a very complex region, and it is expected that further SIDE data from this region will yield extremely useful information on the interaction and acceleration mechanisms operating there, both in magnetically disturbed times and in relatively quiet times.

Impact Events

The impacts of the Apollo XII lunar module (LM) ascent stage and of the Apollo XIII S-IVB rocket, which were crashed into the lunar surface as known sources of seismic signals, both created ion clouds which were detected by the SIDE for periods of a few minutes. The ions observed from the LM impact had energies of about 250 eV to 500 eV, mainly, which is far above the range detectable by the mass analyzer. However, the ions from the S-IVB impact had energies of about 50 to 70 eV, and consequently were visible to the mass analyzer. At least 10% and perhaps most of these ions had masses between 10 and 80 amu/q. We have learned that an impact such as that of the S-IVB produces a gas cloud of sufficient density to deflect the solar wind in the vicinity of the impact and accelerate the gas cloud ions to suprathermal energies. Figure 4 shows the time history of the maximum intensity per channel from the spectra recorded at S-IVB impact. The energy corresponding to each channel is noted. The decrease and later increase in energy of the most abundant ions is of particular interest. A more detailed discussion of the complex effects on the ions of the cloud and of the solar wind is in preparation (references 7 and 8).

There have been several large natural impact events detected by the Apollo XII Passive Seismic Experiment (G. Lathan, private communication, 1970), and there remains the possibility that a large enough natural impact may occur close enough to produce a detectable flux of ions at the ALSEP site. In the first several months of operation there have been no clear ion events of this type.

Eclipses

Partial lunar eclipses have occurred twice (February 21 and August 16, 1970) since the deployment of ALSEP, and both constituted partial solar eclipses as seen from the ALSEP site. The February eclipse was very slight at ALSEP and produced no effects discernible in the SIDE ion flux data. There was a cooling effect on the instrument package, as expected, with the temperature sensor in the CCGE package (in contact with the lunar surface) indicating a temperature drop from 364°K down to 294°K. Very interesting activity in the form of highly variable ion fluxes was observed in the SIDE data during the August eclipse. However, this may have been due to a time coincident intense solar flare event which resulted in a large magnetic storm at Earth. Data from additional magnetic storms and eclipses will be necessary to resolve this ambiguity.

In view of the large and rapid temperature decrease observed during an eclipse, a total eclipse is more interesting than a partial one for observations of possible gas liberation. Thus the total lunar eclipse of February 10, 1971 will be of special interest. It should be noted that Apollo XIV is scheduled for launch January 31, 1971, and that the Apollo XII SIDE is still operating properly so there is a chance that both the Apollo XII and the Apollo XIV SIDE instruments will be able to observe this total eclipse. There is also a second total lunar eclipse in 1971 on August 6.

Present and Future Data Analysis Activities

The following list represents the distribution of effort of various project scientific personnel and their present areas of concentration:

1. Dr. J. W. Freeman is analyzing the Apollo XIII S-IVB impact event. This analysis is nearly complete and a paper is in preparation that will be presented at the December (1970) Western National Meeting of the American Geophysical Union. A paper on this subject will be submitted jointly with Drs. Conway Snyder and H. Kent Hills (for publication) (reference 7).

2. Dr. Kent Hills is interested in the night side high-energy phenomena. A paper on this subject was presented by him at the April (1970) National Meeting of the American Geophysical Union (reference 9). A paper for publication will be in preparation shortly.

3. Dr. Jürg Meister is investigating possible SIDE data correlations with optical lunar transient events reported by the LION network. Dr. Meister is an ESRO/NASA International Post-Doctoral Fellow who only recently arrived at Rice to work with the SIDE group.

4. Miss Martha Fenner (a Rice Space Science graduate student) has been pursuing the data from the outbound magnetosheath passes. She presented a paper on the SIDE data from this region at the April (1970) National Meeting of the American Geophysical Union (reference 6).

5. Mr. Robert Lindeman (a Rice Space Science graduate student) is preparing a computer program to analyze low-level night side events by computing long-term averages.

6. Mr. René Medrano (a Rice Space Science graduate student) is performing a power spectrum analysis to determine the origin of the mass analyzer counting rates seen during the lunar day.

7. Mr. Tom Rich (a Rice undergraduate) is performing a hand analysis of pre-dawn solar wind energy ion-cloud events to determine their distribution along the lunar orbit.

The following list represents a partial enumeration of areas awaiting detailed investigations:

1. The ground plane voltage influence on SIDE counting rates. (This will provide information on the lunar surface electric field.)

2. Long-term averages of the mass analyzer fluxes during the lunar day.

3. Quiet-time and seasonal plasma fluxes in the magnetotail.

4. Analysis of lunar eclipse data.

5. Investigation of the variation in the fluxes seen during large geomagnetic storms.

6. More complete examination of the concept of a general acceleration mechanism for thermal ions in the lunar ionosphere (reference 8).

7. Correlation of SIDE data with PSE data (detected natural impact events) and with LSM data.

It should be noted that most of these specific areas of research will be greatly aided by data from the SIDE's on additional ALSEP missions. This is true because of the different locations and SIDE detector look directions planned for future ALSEP's, hopefully with time concurrent data.

Conclusion

A brief summary of the salient features of this report follows.

(1) The SIDE continues to operate normally, with no indication of degradation of performance or of thermal control capabilities.

(2) Mass spectra of 50 eV ions were obtained soon after deployment. These show concentrations of ions in the 18 to 50 amu/q mass-per-charge range.

(3) Clouds of 10 to 250 eV ions have been detected, as well as other events, which suggests the operation of a general acceleration mechanism.

(4) Solar wind energy ions are observed several days before local sunrise.

(5) Ions of 250 to 3000 eV presumed to be protons which escaped from the bow shock, are observed in the time period between sunset and midnight.

(6) Data on the complex features of the interaction of the solar wind with the earth's magnetic field and with the moon are being accumulated.

(7) The Apollo XIII S-IVB impact resulted in a cloud of 50 to 70 eV ions being detected at the SIDE, with a large number of ions of mass about 10 to 80 amu/q. No mass data is available from the Apollo XII LM impact, which resulted in ions of 250 to 500 eV at the SIDE.

(8) Two partial lunar eclipses have been monitored, but no ion events have been clearly attributed to an eclipse. High fluxes during the second eclipse may be associated with a large solar flare rather than with the eclipse.

References

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3. Heymann, D., A. Yaniv, J.A.S. Adams, and G.E. Fryer: Inert Gases in Lunar Samples. Science 167, pp.555-558 (1970).

4. Asbridge, J.R., S.J. Bame, and I.B. Strong: Outward Flow of Protons from the Earth's Bow Shock. J. Geophys. Res., 73, pp.5777-5782 (1968).

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7. Freeman, J.W., Jr. and H.K. Hills: Positive Ions Resulting from the Apollo XIII S-IVB Lunar Impact. In preparation.

8. Balsiger, H., J.W. Freeman, Jr., and H.K. Hills: Acceleration of Thermal Ions at the Lunar Surface: Apollo XII Observations. Rice University Report, June, 1970.

9. Hills, H.K., J.W. Freeman, Jr., and H. Balsiger: Energetic Protons Observed at the Lunar Surface on the Night Side of the Moon. Transactions, Amer. Geophys. Union, <u>51</u>, 4, p.407 (1970) (Abstract).

Figure Captions

Figure 1. The look directions of the SIDE at various points along the lunar orbit. The Earth is not drawn to scale.

Figure 2. Temperature history during the cyclic operation of the SIDE. The dashed curve was taken from earlier times when the power was left on, and only the internal high voltage supplies were turned off.

Figure 3. Three typical spectra observed in the magnetosheath region with the total ion detector. Each frame is 1.2 seconds long, and the counts are accumulated in that time interval. Each panel shows three scans of the spectrum, starting with the 3500 eV channel, then repeating. Some characteristics of each type of spectra are tabulated below the spectra.

Figure 4. Maximum counts per channel of the total ion detector during the S-IVB impact event. Each bar represents the maximum count in a 20-frame spectrum scan, and is labeled with its appropriate energy. Note that the spectrum peak was at 50 and 70 eV initially, and shifted down to 10 eV, then increased to several hundred eV.

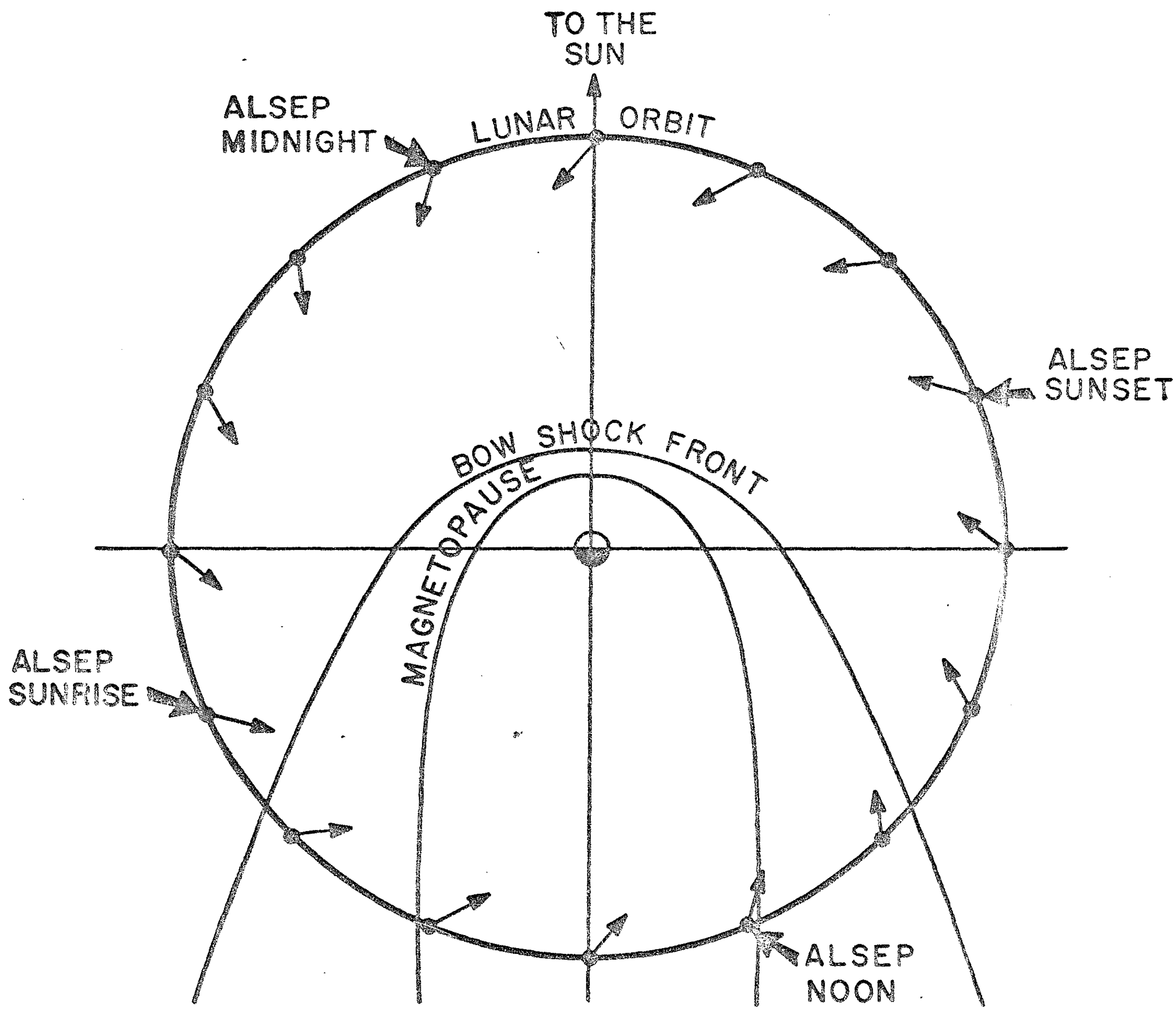

TO THE SUN
ALSEP MIDNIGHT
LUNAR ORBIT
ALSEP SUNSET
BOW SHOCK FRONT
MAGNETOPAUSE
ALSEP SUNRISE
ALSEP NOON

FIGURE 1

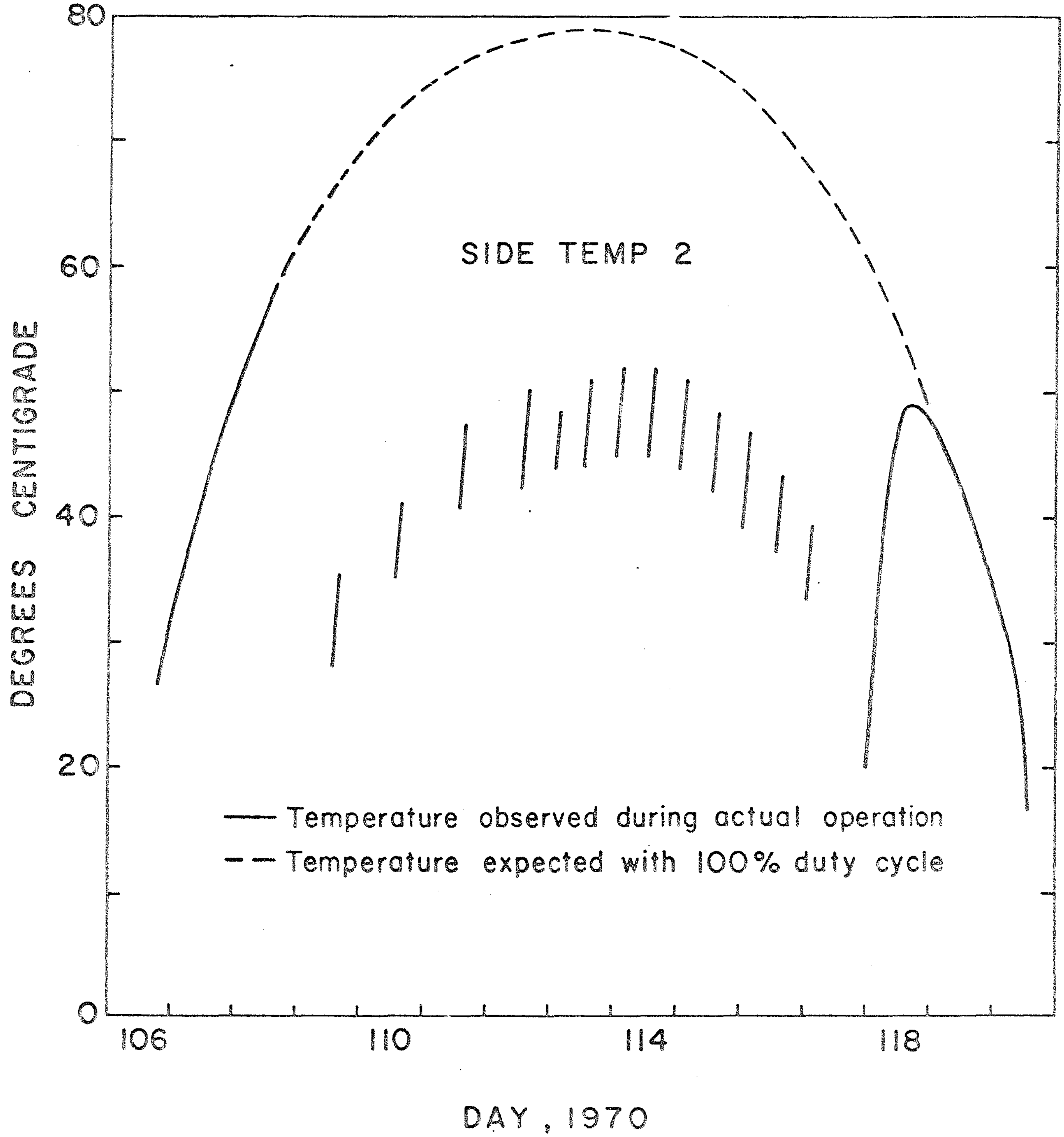
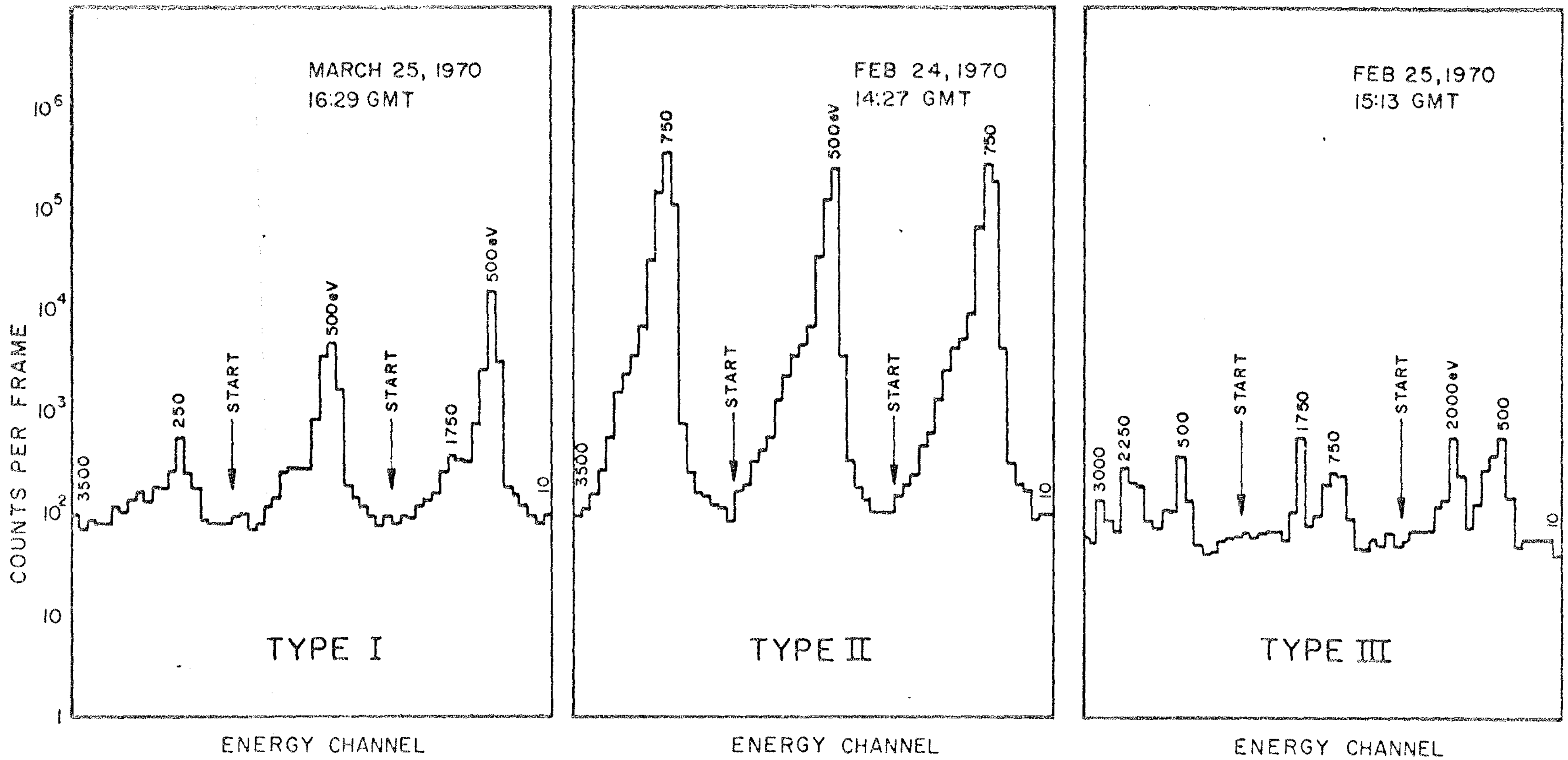

SIDE TEMP 2
80
60
40
20
0
DEGREES CENTIGRADE
106
110
114
118
DAY, 1970
Temperature observed during actual operation
Temperature expected with 100% duty cycle

FIGURE 2



AVERAGE RATE AT SW ENERGIES 10^4 COUNTS

OCCASIONAL BRIEF LAPSES TO BACKGROUND RATES

HIGHER ENERGY PEAKS (ASSOCIATED WITH LAPSES)

AVERAGE RATE AT SW ENERGIES 10^5 COUNTS

CONTINUOUS HIGH RATES

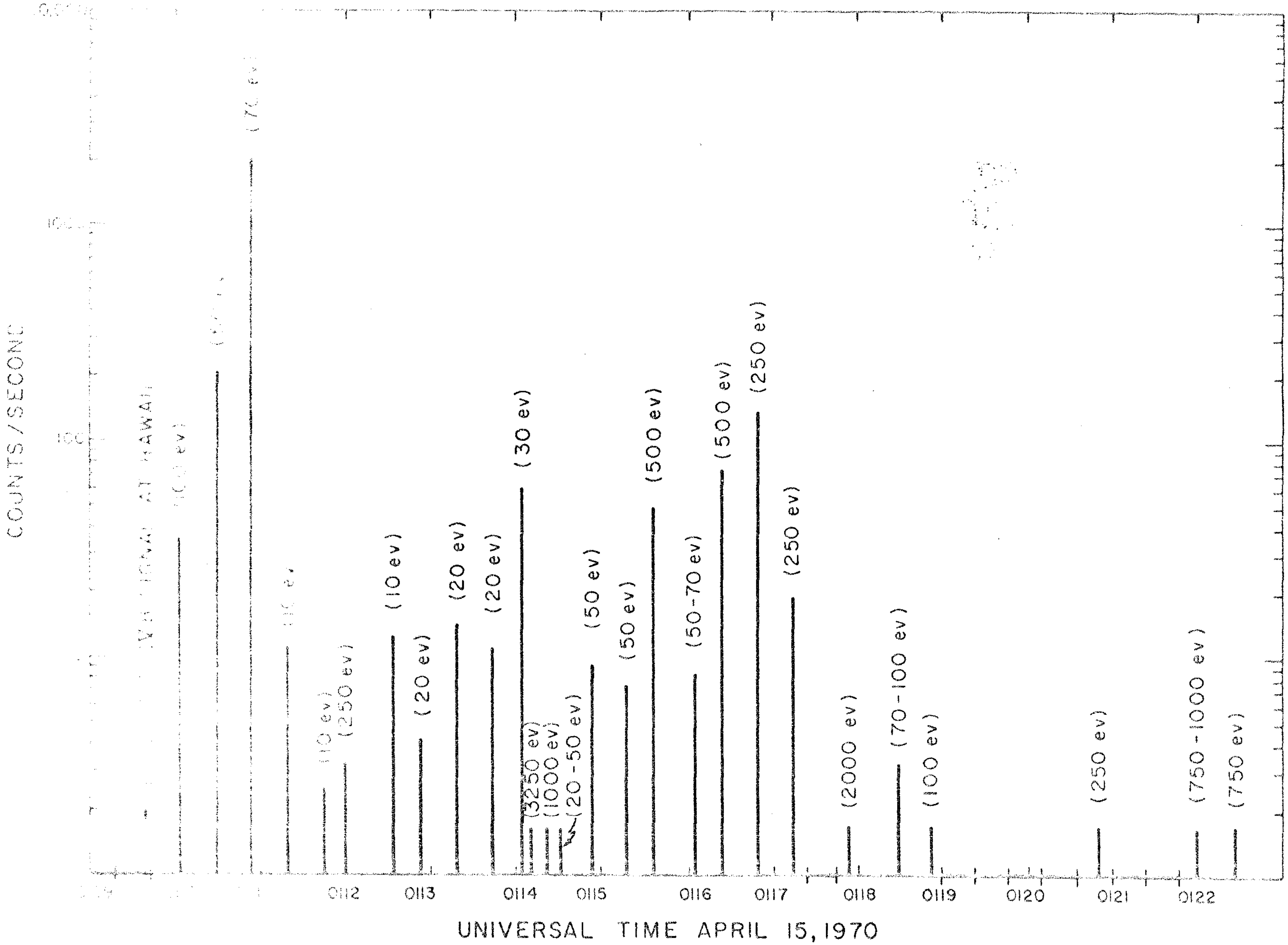
NO HIGHER ENERGY PEAKS

AVERAGE RATE AT SW ENERGIES 10^3 COUNTS

BOTH BRIEF AND EXTENDED LAPSES TO BACKGROUND RATES

HIGHER ENERGY PEAKS THROUGHOUT

FIGURE 3


COUNTS/SECOND
(10 ev)
(250 ev)
(10 ev)
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(20 ev)
(30 ev)
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(1000 ev)
(20-50 ev)
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(250 ev)
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0112
0113
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UNIVERSAL TIME APRIL 15, 1970
Figure 4

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ROUTING SLIP

MAIL CODE	NAME		
TM-5	W. K. Stephenson WKS	Action	
		Approval	
		Call Me	
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Attached is Dr. Hills, Rice U. input on the SIDE for the Apollo 12 ALSEP Final Report.

Circulate to all

NAME	TEL. NO. (or code) & EXT.
R. Mercer	5067
CODE (or other designation) TDX	DATE 10-30-70

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