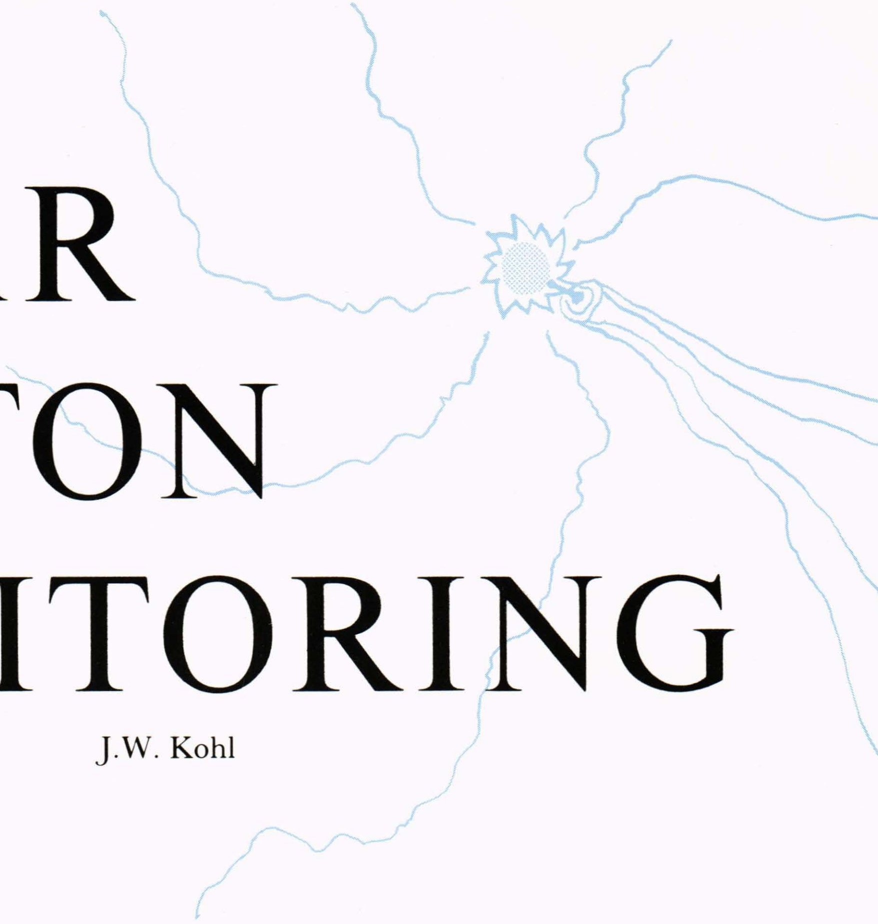


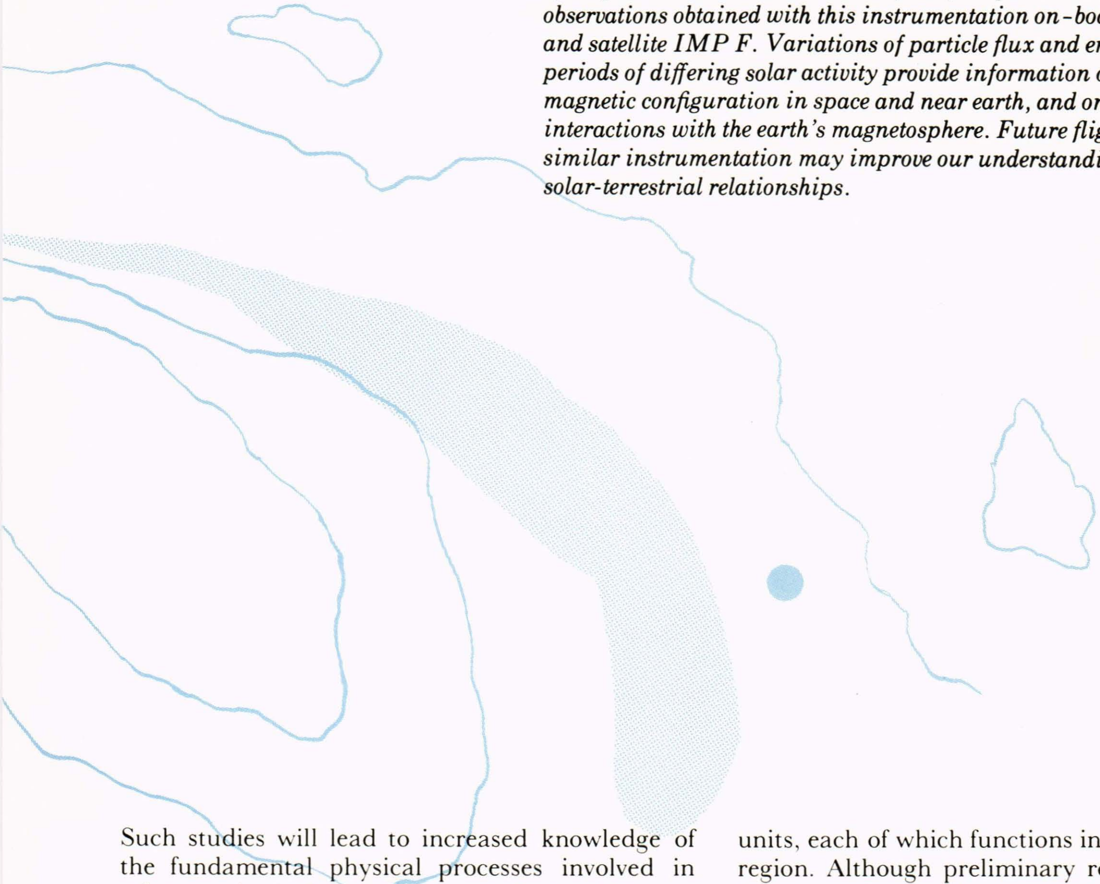
SOLAR PROTON MONITORING

J.W. Kohl

During recent years it has become obvious that solar conditions have a major influence on the near-earth environment. For this reason there has been an increasing effort in the study of the solar flare processes, from the solar flare mechanism to the various effects experienced in space and on earth. A solar flare, which has been defined as "a sudden short-lived brightening of a localized area of the chromosphere," now is recognized as a far more complex phenomenon. Solar flares occur in the solar chromosphere in the vicinity of complex sunspot groups. Models for the flare process have assumed the source of energy to be magnetic, thermal, kinetic, and some others, with new models appearing regularly. In any case, a flare is due to an instability leading to various phases of particle acceleration, storage, and release, accompanied by radiative emissions in a complex time sequence still comparatively uncertain. The study of the energy release in the form of X-rays, ultraviolet, visible light, radio noise bursts, and particles may someday evolve into a unified theory. In the meantime these separate disciplines involve many separate investigations by the scientific community in which most individual experiments are severely handicapped by a lack of spatial and/or temporal coverage. This results in much data in which the measuring conditions are so restricted that correlations become very difficult, if not impossible. What were, and are, needed are easily repeatable experiments to make similar measurements in different regions of space over a long period of time.

The Solar Proton Monitoring Experiment (SPME) is intended to provide continuous long-term monitoring of the energetic protons emitted by the sun. SPME was orignially conceived by C.O. Bostrom of APL and D.J. Williams, D.E. Hagge, and F.B. McDonald of Goddard Space Flight Center (GSFC). It consists of instrumentation suitable for measuring proton fluxes and spectra in an energy range associated with solar-activity changes, both near the earth and in interplanetary space during at least half of a solar cycle. Data from the radiation monitoring program is made available to scientists in related disciplines through the *Solar-Geophysical Data Bulletins* published monthly by the Environmental Science Services Administration (ESSA), Institute for Environmental Research for use in correlation studies.

Instrumentation has been developed to provide data over long periods of time on the radiation environment near earth and in interplanetary space. This article presents a description of the particle detectors used and a few of the preliminary observations obtained with this instrumentation on-board rockets and satellite IMP F. Variations of particle flux and energy during periods of differing solar activity provide information on the magnetic configuration in space and near earth, and on particle interactions with the earth's magnetosphere. Future flights of similar instrumentation may improve our understanding of solar-terrestrial relationships.



Such studies will lead to increased knowledge of the fundamental physical processes involved in solar-geophysical phenomena, such as: solar acceleration processes, interactions in the interplanetary medium, interplanetary magnetic configurations, and interactions with the earth's magnetic field.

Besides the strictly scientific, such a program has other uses, such as its ability to serve as a warning system of radiation hazards. With increased knowledge, it might be possible to predict both the probability and the effects of solar events with a greater reliability than exists at present. It can be appreciated how important both warning and prediction might be to manned spacecraft and to supersonic transports in high-altitude flights over the polar caps.

Description of Experiments

Since the purpose of the SPME is to provide a number of self-consistent packages for various spacecraft to allow monitoring of protons over a wide flux and spectral range, it was decided to keep the packages as simple as possible. This is accomplished by the use of four separate detector units, each of which functions in a different energy region. Although preliminary results from SPME have caused some changes, most of the basic units as used onboard SPICE rockets (the Solar Particle Intensity and Composition Experiment version of SPME) and satellite Explorer 34(IMP F) remained unchanged. The changes consist of more resolution in energy ranges and the addition of more detectors rather than actual detector changes. For this reason, a very brief description of each of the initial four detector units of SPME follows (see Fig. 1):

SPME—*Detector Unit 1:* This unit is a set of three 700-μ-thick, silicon surface-barrier detectors connected in parallel and mounted on orthogonal axes. The effective surface area of each individual detector is $0.8\ \text{cm}^2$, with the total providing a large area sensitive to incoming particles over a 2π steradian solid angle. The energy threshold is set by the 5.6-mm-thick hemispherical copper shield surrounding the detector to detect all protons with energy greater than 60 Mev.

Detector Unit 2: This unit is identical to Unit 1 except for the shielding thickness. In this case, the 1.6-mm-thick copper dome sets the threshold to measure protons with energy greater than 30 Mev.

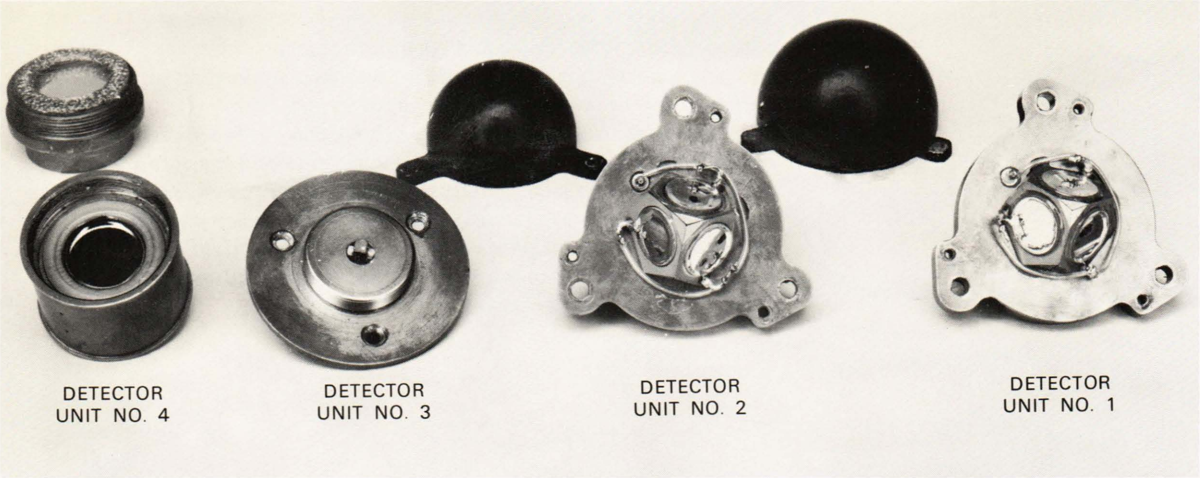


Fig. 1—The four particle-detector units of the IMP F version of SPME. The $E_p \geq 60$ Mev and the $E_p \geq 30$ Mev domes are shown with a black, protective coating which is removed before flight.

Detector Unit 3: This unit uses a cubic 3mm x 3mm x 3mm lithium-drifted solid-state detector. The look-angle is a 2π steradian hemisphere. The energy threshold for protons is set by the 0.63-mm-thick aluminum shield to measure protons of energy ≥ 10 Mev.

Detector Unit 4: This detector is a nominal 100-μ-thick silicon surface-barrier detector. The sensitive surface area is 200 mm^2. The only shielding on this unit is a 1/4 mil aluminized mylar film to provide an opaque shield over the light-sensitive detector. The detector housing incorporates a collimator which reduces the look-angle to a cone of 60° full angle. The electronic discrimination in this unit is so arranged that there are two channels of output information. One channel measures protons in an energy "window," $1.0 \leq E_p \leq 10$ Mev. The second channel of data is the "upper-level" of the 100-μ detector and measures particles depositing more than 3.6 Mev in the detector. A consequence of this scheme is that with the appropriate correction for the proton component (the spectral

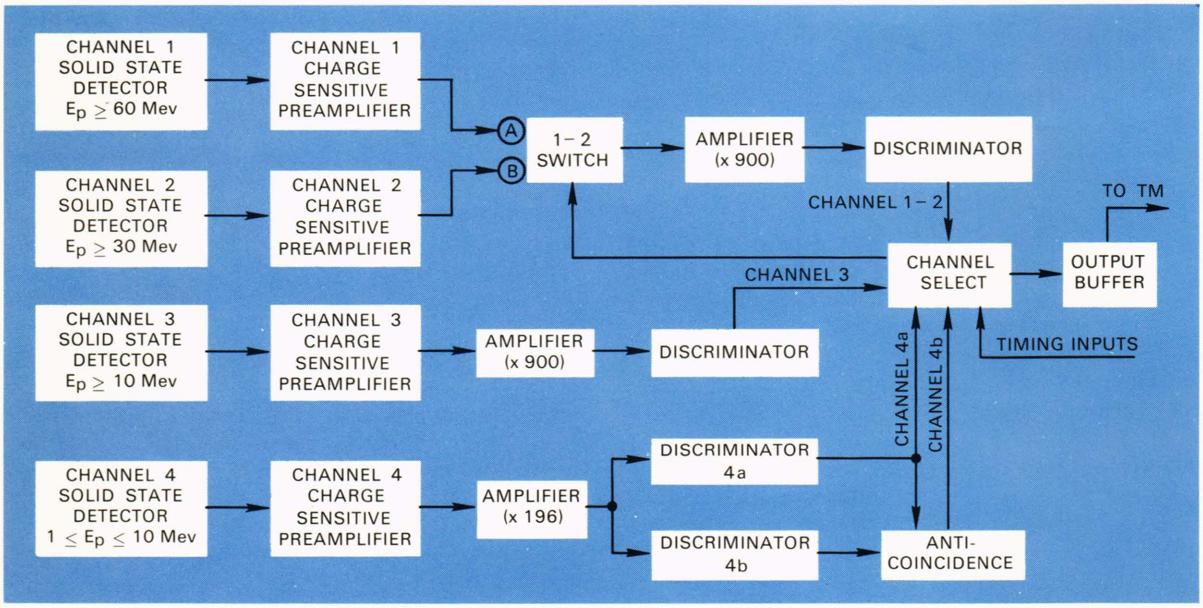


Fig. 2—Block diagram of the IMP F SPME electronics.

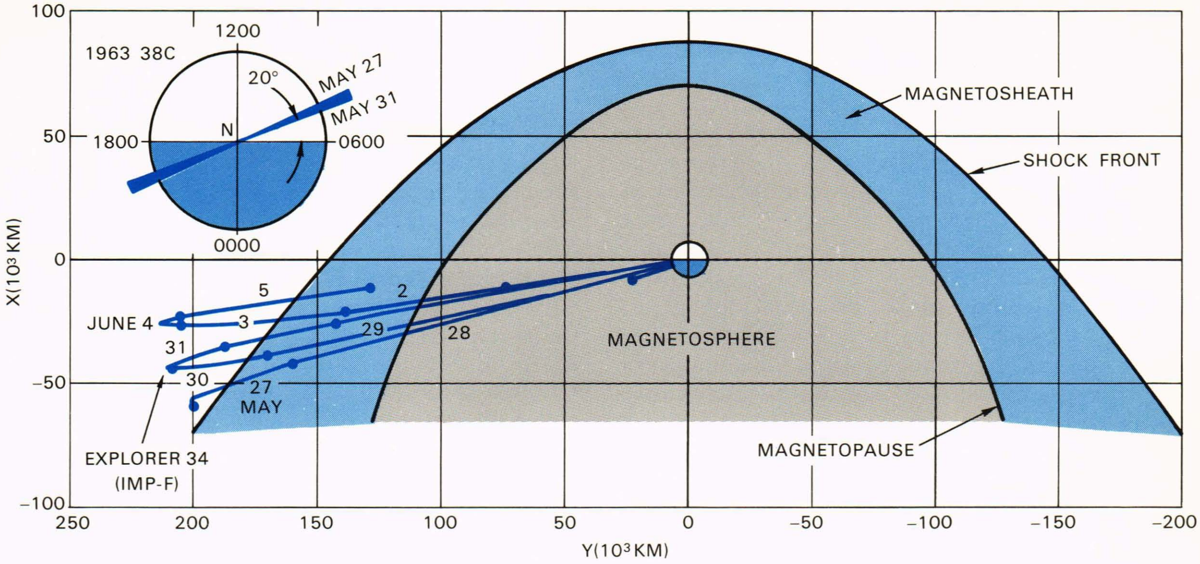


Fig. 3—Projection onto the ecliptic plane (as seen from the north ecliptic pole) of the IMP F orbit from May 27 through June 5, 1967. Also shown is the orbit of satellite 1963 38C, not to scale.

qualities of which can be calculated from the data in Units 1, 2, and 3), the "upper-level" channel may provide information on alpha particles.

Each of the four detector units described above has its own preamp-amplifier-discriminator, the outputs of which are sent to the data-processing electronics. A block diagram of the Explorer 34 (IMP F) version of the SPME package is shown in Fig. 2. It has been previously mentioned that SPME packages have been flown in SPICE rockets and satellite IMP F. Descriptions of these vehicles follow.

SPICE—The SPICE sounding rocket program was instituted to carry emulsions into the solar cosmic ray flux incident on the polar cap; it also served as a pre-satellite test for the SPME. As will be shown later, the flights provide important secondary information. Data have been obtained from three flights of Nike-Apache rockets launched from Ft. Churchill, Manitoba, Canada, at geomagnetic latitude 67°N, reaching altitudes of approximately 160 km. The nose cones were so constructed that they would provide no excess shielding material around the detectors while above the atmosphere. The detectors were oriented so that their axes of symmetry were perpendicular to the axis of the rocket (spin axis). Because the detectors would rotate several times during a data collection period, the resulting data are an integral measurement over all azimuth angles. It was assumed that the incident radiation would only come from the upper hemisphere necessitating a change in geometric factors from those of IMP F. The first flight was made during a solar quiet time to test the system, while the other two successful flights were made in the decay phase of the September 2, 1966 flare event.

Explorer 34 (IMP F)—IMP F, with its version of SPME, was launched on May 24, 1967 into a highly elliptical orbit perpendicular to the ecliptic plane. The orbit has an apogee of ~ 34 R_e (earth radii), a perigee of ~ 250 km, and an orbital period of ~ 4 days. At launch, the sun-earth-probe angle was approximately 104° and was changing at roughly 1° per day. The integral detector Units 1, 2, and 3, are mounted with their symmetry axes parallel to the satellite spin axis, which is perpendicular to the ecliptic plane. The differential flux detector, Unit 4, looks out perpendicular to the spin axis and undergoes several rotations in one data collection period integrating over all azimuth angles. Thus, no directional information is available. As mentioned previously, the IMP F data from detector Units 1, 2, and 3 are made available to the scientific community on a monthly basis—with a six-month lag time for data processing.

Observations

Analysis of the data from the SPME program is still in the preliminary stages. However, in this section, some observations of the very early data will be shown.[1, 2] Figure 3 shows the orbit of IMP F superimposed on the earth magnetic field

---

[1] C.O. Bostrom, J.W. Kohl, D.J. Williams, and J.F. Arens, "The Solar Cosmic-Ray Events in May 1967," *Trans. Am. Geophys. Union* **49**, Mar. 1968, 274.

[2] D.J. Williams, J.F. Arens, C.O. Bostrom, and J.W. Kohl, "Monitoring Observations of Solar Protons in the Interplanetary Medium," *Trans. Am. Geophys. Union* **49**, Mar. 1968, 274-275.

configuration as given by Ness.[3] In the same figure, for reference, is shown the orbit of satellite 1963 38C, not to scale, for the time period under consideration. The discussion itself is divided into time periods during which solar conditions were generally quiet and periods during which the interplanetary medium and the magnetosphere were in a disturbed state owing to recent solar flare activity.

Quiet Time—On July 20, 1966, a test flight in the SPICE sounding rocket program took place. Although this was a time of only moderate solar activity (monthly average Zurich solar index of 55.7), it was possible to obtain the galactic cosmic ray background from the $E_p \geq 60$ Mev detector. Since high-energy cosmic rays can penetrate the body of the rocket and enter the lower half-hemisphere of the detector from the back surface, it was necessary to modify the geometric factor for this effect. It was then calculated that the total cosmic ray flux at 67° north geomagnetic latitude is 0.573 ± 0.022 particle cm^{-2} sec^{-1} ster^{-1}. This is, in general, very near the total cosmic ray measurements made by Meredith et al[4] of 0.50 ± 0.05 particle cm^{-2} sec^{-1} ster^{-1} and Ginzburg et al[5] of 0.430 ± 0.016 particle cm^{-2} sec^{-1} ster^{-1}. After this test, the other SPICE flights took place during a polar cap absorption event.

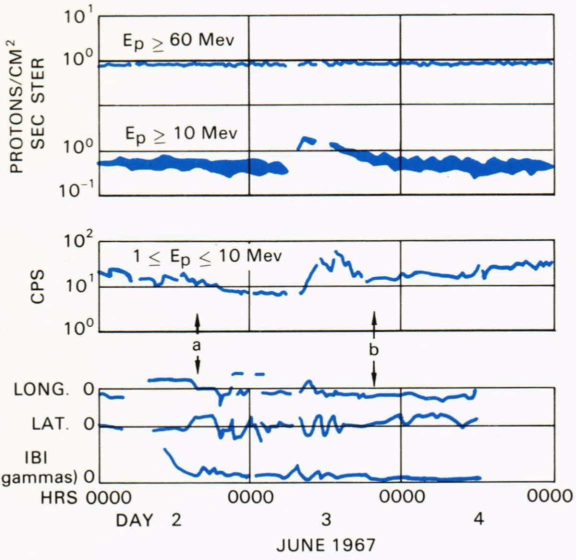


Fig. 4—IMP F SPME particle data and magnetometer data for the time period June 2 to 4, 1967.

Another example of relatively quiet time data from SPME can be seen in Fig. 4, which shows IMP F data from June 2 through June 4, 1967. The upper three curves are the particle fluxes from the respective detector units of SPME, while the lower three curves are the magnetometer data.* These latter show the longitude, latitude, and magnitude of the local magnetic field, respectively. Throughout the time period shown, the particle fluxes remained essentially constant, especially the $E_p \geq 60$ Mev detector. If this value is used to obtain a value of galactic cosmic ray background the result is a flux of 0.4 ± 0.1 particle cm^{-2} sec^{-1} ster^{-1}. Considering the change in solar cycle, this result is comparable to that of SPICE approximately one year earlier. The slight rise and decay of particle fluxes on June 3, 1967 was probably caused by a magnitude 3F solar flare at ~ 0300 UT, located at solar longitude E12°.

The magnetic data during the period June 2 to 4 is far from constant. At that time, the satellite was on its outbound leg. Probably, at time *a* the satellite crossed the magnetosphere into the magnetosheath, indicated by the turbulence of the magnetic field vectors. The fact that the particle fluxes remain constant (except for the flare increase) even though the field direction varies so rapidly, is suggestive of particle isotropy. At time *b*, the satellite passes the shock front and emerges into the interplanetary medium as evidenced by the smooth, small value of the field magnitude and the more uniform field directions. These data show that the magnetospheric boundaries at this time were not in the locations shown in Fig. 3. Information such as the above over a large portion of a solar cycle will provide interesting correlations between particle fluxes and field configuration.

Active Time—Two SPICE rockets were flown approximately 17 and 36 hours respectively, after a magnitude 3 solar flare on September 2, 1966 at 0541 UT. The raw count rate (for selected channels) versus time for the two flights is shown in Fig. 5. The shapes of the curves indicate the effect of atmospheric attenuation until the rocket trajectory carries the instrumentation above the atmosphere.

Above the atmosphere, the detectors measure an almost constant proton flux, (until reentry, where the atmosphere again plays an important role). As can be seen from Fig. 5, the count rates showed a decay of solar proton flux over the two day period, with the higher energies decaying faster.

---

[3] N.F. Ness, C.S. Scearce, and J.B. Seek, "Initial Results of the IMP-1 Magnetic Field Experiment," *J. Geophys. Res.* **69,** Sept. 1, 1964, 3531-3569.

[4] L.H. Meredith, J.A. Van Allen, and M.B. Gottlieb, "Cosmic-Ray Intensity above the Atmosphere at High Latitudes," *Phys. Res.* **99,** July 1, 1965, 198-209.

[5] V.L. Ginzburg, L.V. Kurnosova, V.I. Logachev, L.A. Rozarenov, I.A. Sirotkin, and M.I. Fradkin, "Investigation of Charged Particle Intensity during the Flights of the Second and Third Space-Ships," *Planetary and Space Sci.* **9,** November 1962, 845-854.

*Made available through the courtesy of D.H. Fairfield and N.F. Ness, both of whom are at Goddard Space Flight Center.

The primary experiment on-board the rockets was a set of nuclear emulsions furnished by the Particles and Field Group of GSFC, to supply information on both the proton and heavy nuclei components of solar flare emissions. The proton-to-helium ratios, i.e., their intensity and spectral variations, throughout an event provide clues to solar acceleration and propagation processes. Proton integral spectra were obtained from the emulsions and from SPME for the energy range 1 to 60 Mev. The spectral curves indicate very good agreement except for a seeming discrepancy for the low energy point of the 1727 UT, September 3, 1966, flight. If the 1 to 10 Mev data are adjusted for a possible spectral fold-over, the emulsion experiment and SPME show good agreement. This also seems to verify the results of McKibben and Englade that an OGO-III satellite pass at 0415 UT on September 3, 1966, indicates that the differential energy spectra of solar protons has a maximum at approximately 3 Mev, below which the flux decreases. The close correlation between the absolute fluxes as given by independent measurement, the nuclear emulsions, lend added weight to the future SPME data.

Another active time under investigation is the period of the solar proton events of May 1967. The IMP F SPME was launched at ~ 1430 UT on May 24, beginning its life by giving data on a flare event. Figure 6 shows a time history of the events as seen by the IMP F $E_p \geq 10$ Mev detector. Also shown in this figure are the polar cap average fluxes with $E_p \geq 8.4$ Mev as measured by the circular polar-orbiting, APL satellite 1963 38C at 1100 km (refer to Fig. 3 for 1963 38C orbit).[6,7,8] Although there is a discrepancy in the absolute flux magnitudes that has not yet been resolved, the relative changes in interplanetary space and near earth follow each other very well.

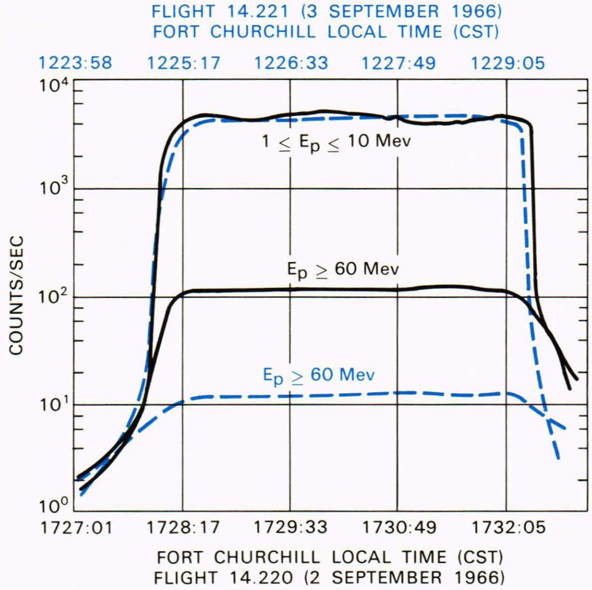


Fig. 5—Observed counting rates for channel 1 ($E_p \geq 60$ Mev) and channel 4 ($1.0 \leq E_p \leq 10$ Mev) for flight 14.220 (solid line) on September 2, 1966 and flight 14.221 (dashed line) on September 3, 1966 of the SPICE-SPME rocket program as a function of local time (CST) at Fort Churchill, Manitoba.

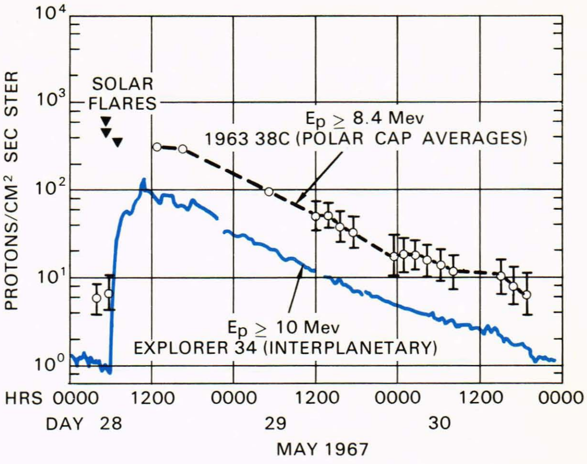


Fig. 6—Time history of proton fluxes during the May 28, 1967 flare event as seen by IMP F ($E_p \geq 10$ Mev) and 1963 38C ($E_p \geq 8.4$ Mev).

Another example of particle fluxes in space and near earth is shown in Fig. 7. In this figure, the time history of the IMP F $1 \leq E_p \leq 10$ Mev detector is compared with the sum of the 1963 38C polar cap averages from two particle detectors, $1.2 \leq E_p \leq 2.2$ and $2.2 \leq E_p \leq 8.4$ Mev. Although it is not shown, the individual components of the 1963 38C sum exhibit marked spectral changes throughout this event. It can be seen that the sum of the 1963 38C data, 1.2 to 8.4 Mev, compares very well with results for IMP F. The 1963 38C fluxes do show a difference from the interplanetary medium at times, as evidenced by the "drop-out" at ~ 0000 UT, May 30, 1967.

Another noticeable difference in fluxes between interplanetary space and the near-earth polar cap occurs with the 1963 38C pass at ~ 1500 UT, May 30, 1967. If the time scale is expanded, it can

---

[6] D.J. Williams and A.M. Smith, "Daytime Trapped Electron Intensities at High Latitudes at 1100 Kilometers," *J. Geophys. Res.* **70**, Feb. 1, 1965, 541-556.

[7] C.O. Bostrom, J.W. Kohl, and D.J. Williams, "The February 5, 1965 Solar Proton Event. 1. Time History and Spectrums Observed at 1100 Kilometers," *J. Geophys. Res.* **72**, Sept. 1, 1967, 4487-4495.

[8] D.S. Beall, C.O. Bostrom, and D.J. Williams, "Structure and Decay of the Starfish Radiation Belt, October 1963 to December 1965," *J. Geophys. Res.* **72**, July 1, 1967, 3403-3424.

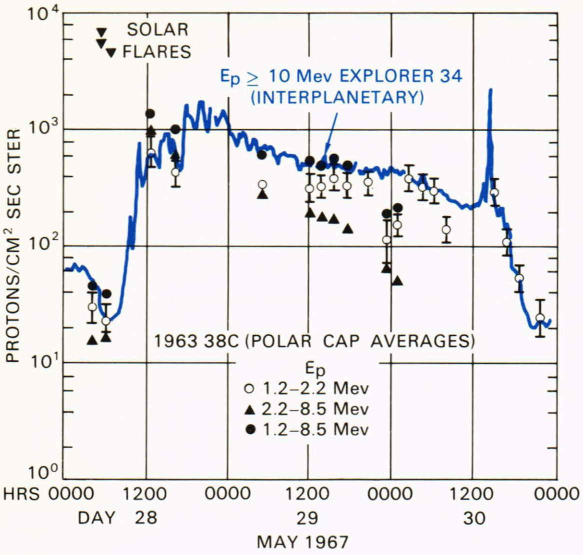


Fig. 7—Time history of proton fluxes during the May 28, 1967 flare event as seen by IMP F ($1.0 \leq E_p \leq 10$ Mev) and 1963 38C ($1.2 \leq E_p \leq 8.5$ Mev). The 1963 38C polar cap averages are shown as the sum of two channels ($1.2 \leq E_p \leq 2.2$ and $2.2 \leq E_p \leq 8.5$ Mev), to more nearly approximate the energy range of IMP F.

be seen that there is an increase by roughly a factor of 3 in the 1963 38C $1.2 \leq E_p \leq 2.2$ Mev proton detectors over a time interval of ~ 3 minutes, which is not present in the interplanetary fluxes obtained by IMP F. This indicates that for time periods greater than about one hour, the polar cap averages near the earth follow the interplanetary changes. But on a small time scale, the polar regions exhibit flux changes that point to selective accessibility by particles to certain limited latitudes.

During the May 1967 time period, a correlation of IMP F particle data and magnetometer data provided a picture of yet another phenomenon. The IMP F proton data for selected channels is shown in Fig. 8. The magnetometers indicated (private communication, D.H. Fairfield) that the satellite underwent multiple magnetopause crossings during the time period immediately prior to that shown in the figure. During the time periods marked *a* and *b* the satellite was in the magnetosheath. The lower energy particle detectors exhibit a sharp increase while in the magnetosheath. The higher energy detectors remain fairly constant, with just the hint of an increase in the $E_p \geq 10$ Mev detector. Then an interplanetary shock front followed by strong magnetic fields arrived at the satellite, after which the bow shock moved across the spacecraft leaving it in the interplanetary medium during the period indicated by *c*. Again the low-energy detectors exhibit a dependency on magnetic field not reflected by the high-energy detectors. Much more data of this form is necessary to obtain a consistent picture of the solar-terrestrial processes.

Future Solar Proton Monitoring Experiments

In keeping with the concept of SPME, plans are being made for similar packages to occupy places on future experimental and operational satellites. In particular, SPME units are intended to be used in IMP G, a series of TIROS satellites, and IMP I.

IMP G—The IMP G satellite is complete and will be launched early in 1969. The SPME package on IMP G is identical to that previously described for IMP F.

TIROS—A modified version of the SPME package will be used on a series of TIROS satellites. This effort is supported by the Environmental Science Services Administration and G.C. Reid and H. Sauer of ESSA are co-experimenters. The advantage of flying units on operational satellites is the assurance of continuous data for long periods of time, because operating satellites must be available to the system on a continuous basis. The higher energy detectors in the TIROS-SPME units remain the same. But since so much activity takes place in the lower energy detector—as seen in the "Observations" section—it seemed advantageous to observe this energy region in more detail. This is achieved by using a two-detector telescope array. With the utilization of appropriate coincidence and anti-coincidence schemes, the energy levels as

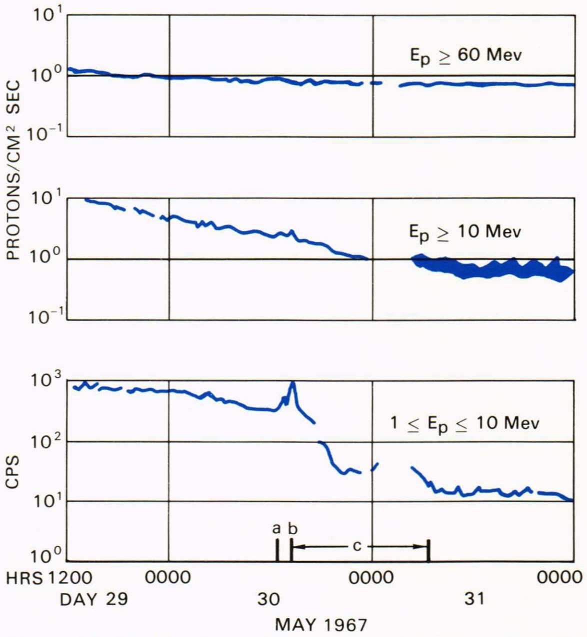


Fig. 8—IMP F SPME particle data for the period May 28 to 31, 1967.

TABLE I

TIROS-SPME DETECTOR CHARACTERISTICS

Detector Unit	*Energy Sensitivity*		*Comments*
	Protons (Mev)	*Alphas (Mev)*	
1	≥60	≥240	Omnidirectional
2	≥30	≥120	Omnidirectional
3	≥10	≥40	Omnidirectional
4	Electrons	≥250 kev	Directional: 15° full angle. Oriented perpendicular to field line.
5	0.27 - 0.56	0.48 - 0.78	Directional:
	0.56 - 1.05	0.78 - 1.28	40° full angle.
	1.05 - 3.05	1.28 - 4.1	Oriented along
	3.2 - 60	> 12.5	field line.
	———	12.5 - 32	
	High Energy Background	———	
6	0.27 - 0.56	0.48 - 0.78	Directional:
	0.56 - 1.05	0.78 - 1.28	40° full angle.
	1.05 - 3.05	1.28 - 4.1	Oriented perpendicular to field line.
	3.2 - 60	> 12.5	
	———	12.5 - 32	
	High Energy Background	———	

shown in Table I can be obtained. In the TIROS package, two such telescopes are used, one at right angles to the magnetic field line and one looking up the field line.

TIROS-SPME also incorporates an electron detector. This detector is oriented to observe the trapped energetic electron component. The data provide information on the locations of the trapped radiation zones, and possible electron contamination on the proton detectors.

IMP I—The IMP I package will be a cross between the IMP F and G package and the TIROS package. That is, the $E_p \geq 60$, 30, 10 Mev detector units will remain the same, the 1 to 10 Mev unit will be replaced by a telescope as described in "TIROS", and a low-energy ($E_p >$ 100 kev, $E_e \geq$ 10 kev) experimental avalanche detector may be added. The telescope will be mounted perpendicular to the satellite spin axis, which is perpendicular to the ecliptic plane. Unlike IMP F and G, the detector unit will not integrate over all azimuth angles as the satellite rotates, but will provide eight-sector directional information in the ecliptic plane.

Discussion and Summary

The Solar Proton Monitoring Experiment was designed to provide information on particle fluxes and spectra in an energy range influenced by solar activity, over a period of many years, and in different regions of space, with sets of self-consistent instrumentation. Preliminary analysis of the resulting data, such as has been outlined in the "Observations" section, has already supplied a number of clues to particle behavior in interplanetary space and near earth.

Since the quiet time data in all SPME detectors is essentially galactic cosmic ray background, analysis over a large portion of a solar cycle would give information towards understanding the solar modulation of galactic cosmic rays, including any energy dependence. It is an interesting point to note that as particle detectors extend their searches into the lower energy regions, the quiet sun is not really very quiet. The SPME lower energy detectors indicate that there usually exists a highly variable flux, well above background. The higher energy particles usually remain at the level of cosmic ray background with discrete increases and decay only during times of solar flare activity.

Correlations of particle data with magnetic field information are also interesting studies. One such preliminary study seems to indicate a high degree of isotropy at almost all times except for short periods during solar flare events, even though the magnetic field directions change over a wide range. The temporal behavior and energy dependence of this isotropy condition are clues to particle diffusion processes and magnetic irregularities in interplanetary space.

When near-earth particle data are involved in these correlations, the view is toward obtaining an understanding of particle interaction with the earth's magnetosphere. There exists the possibility of determining how solar particles of different energies enter the earth's magnetosphere. The next step would be to determine a mathematical model for this interaction with the magnetosphere and the trajectories of the particles once they have entered.

As a final restatement of the purpose of SPME, let it be said that the object of the program is to establish correlations between solar activity and terrestrial effects with a view towards increasing basic scientific knowledge and providing a prediction or warning service of possible radiation effects.

Acknowledgements

The author wishes to express his gratitude to his co-workers in the SPME program for their many discussions in interpretation of the data. Thanks are also due D.H. Fairfield and N.F. Ness for the use of their magnetometer data. Special thanks go to C.O. Bostrom for his many valuable discussions and for the use of his results from the SPICE-SPME project. The author also wishes to thank Rosa Lee McQuiney for processing the large quantities of data involved in a program of this magnitude.