SOLAR PROTON EVENTS DURING THE RISING PHASE OF SOLAR CYCLE 22;†

T. E. Cayton, R. D. Belian, R. C. Reedy, G. D. Reeves, T. A. Fritz, and R. A. Christensen, Space Science & Technology Division, Los Alamos National Laboratory, Los Alamos, NM 87545.

Interest in solar energetic particles (SEPs), also called solar cosmic rays, comes mainly from three directions: (1) the concern about radiation hazards to humans [*1*] and electronics [*2*] in deep space (away from the protection of the Earth's magnetic field), (2) their effects on the Earth and the near-earth environment [*3*], and (3) studies of their fossil records in extraterrestrial matter [*4*]. Comparisons of the fluxes of energetic solar particles measured recently in space with those inferred from lunar data do not show any major differences between modern (last few decades) and ancient (last $\sim 10^4$–10^7 years) SEPs, although both data sets are far from complete [*5*]. Progress in improving the ancient record is discussed elsewhere at this conference [*6* – *8*]. We present new results for contemporary SEPs and discuss their implications.

The "modern" record goes back less than five decades for indirect measurements and since the early 1960s for direct measurements in space [*9*]. Since 1954 until now, the Sun has gone through only about 3.4 "11-year" cycles of solar activity, with solar cycle 19 starting in 1954 and the current cycle (22) commencing in October 1986. Compilations of the fluxes of solar protons are few. Only about 200 solar particle events since 1956 are in these compilations [*9*]. In comparing the fluences of solar protons as integrated over these events, there are some major disagreements. The solar-proton fluences during solar cycle 19 inferred from ^{22}Na and ^{55}Fe in lunar rocks [*10*] are much higher than those by other indirect methods [*9*, *11*]. More recent satellite measurements of solar proton fluxes often disagree, cf. [*2*], such as the event-integrated fluences of solar protons above 30 MeV usually being much higher in Feynman *et al.* [*11*] than those in Goswami *et al.* [*12*] during 1973–1986.

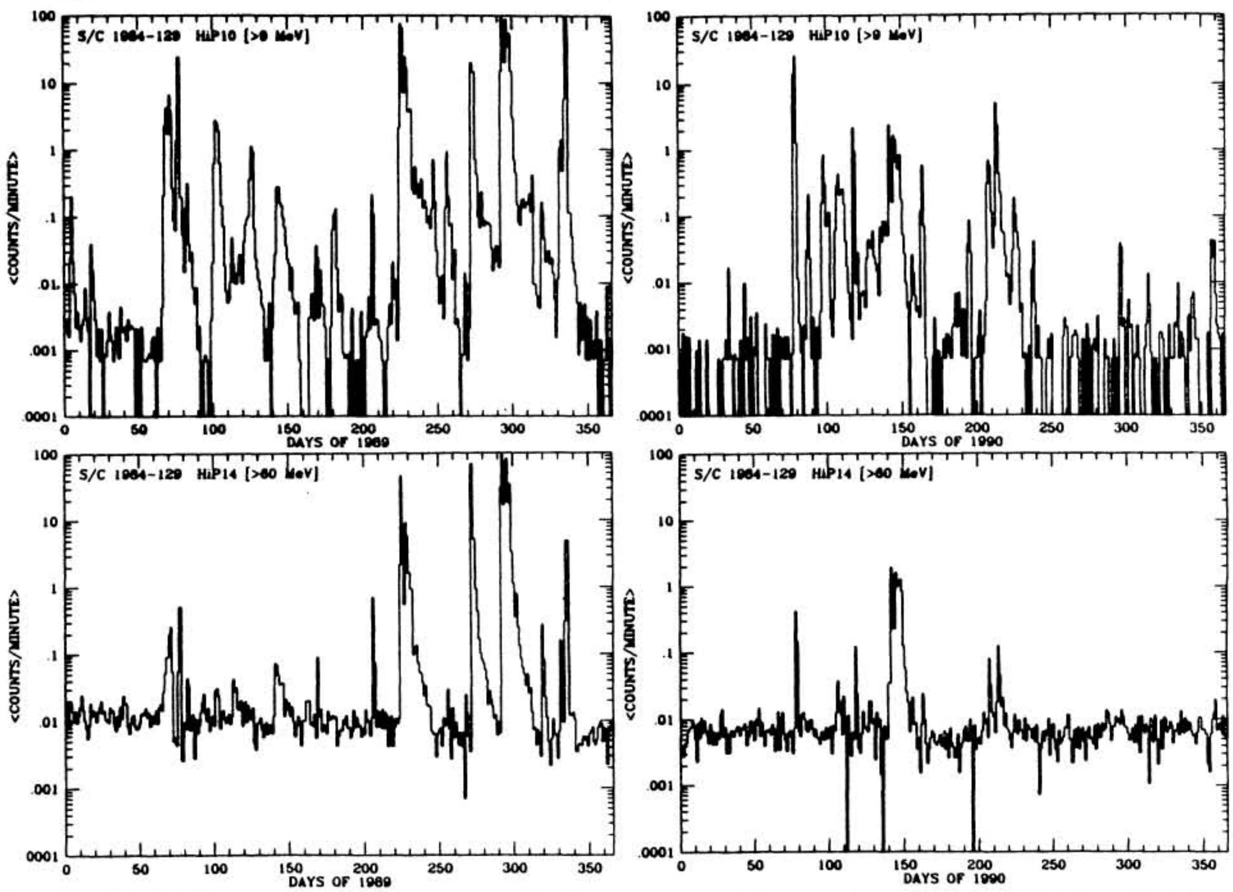
Few solar-proton-flux compilations have been published for events since 1987. The current solar cycle is of great interest as the Sun has been very active and there have been a large number of big solar particle events during the last two years, including six during the second half of 1989 with many particles $\gtrsim$0.5 GeV detected as ground level events (GLEs) with neutron monitors [*13*]. The GLE of 29 September 1989 was the largest since the huge one of 23 February 1956 [*13*]. It appears that the present solar cycle 22 will be like solar cycle 19, during which the Sun was very active and the fluxes of solar protons were very high [*5*, *6*].

We report results from the Los Alamos Charged Particle Analyzer (CPA) instrument on a satellite in geosynchronous orbit. Similar Los Alamos CPA instruments have made observations of energetic particles since 1976. The satellite's spin axis is normal to the Earth's surface, and protons are measured in the satellite's equatorial plane every 256 ms with two sets of detectors [*14*]. The LoP detector monitors protons with energies of $\approx$0.1–0.6 MeV. The HiP detector uses three detectors in a telescope configuration to measure protons from $\approx$0.4–160 MeV with 16 differential energy channels having energy thresholds nominally logarithmically spaced from 0.4 to 147 MeV. A magnet eliminates signals from electrons with energies below $\sim$1 MeV, and there is an active guard scintillator to reject signals from energetic particles that arrive from directions away from the telescope's front aperture, which has a half angle of $\sim 6.5°$. Numerical simulations are being done for the HiP detector to more accurately determine its response to protons of various energies from different directions. These calculations and other calibrations are not final, but preliminary results indicate for the HiP channel 10 (E>9 MeV) that $\approx$0.02 counts/minute is equivalent to a flux of 10 protons/(cm^2 s sr). We also plan to compare our measurements during 1976–1986 with those reported by others [*11*, *12*].

Measurements by the HiP detector on spacecraft 1984–129 since the beginning of solar cycle 22 (October 1986) have been compiled for protons with energies from 9 MeV to $\sim$160 MeV. (There are relatively very few solar protons with energies above 160 MeV.) The proton fluxes from daily averages for 1989 and 1990 are shown in Figs. 1–4 for energies >9 MeV and >60 MeV. The first two years of this cycle had low solar-proton fluxes, typical of other solar cycles [*11*]. The count rates in the >60 MeV channel during periods of no solar-particle events are due to the galactic cosmic rays and vary systematically with solar activity, diminishing with increasing solar activity. Adopting the threshold of 10 protons/(cm^2 s sr) used by Shea and Smart [*9*] for E_p>10 MeV in their compilation for earlier solar-proton events, there were no such events during the first 12 months of solar cycle 22 (October 1986 – September 1987), 4 during the next year, 24 during the third year, and 19 during the fourth year. There are many more solar-proton events above this proton-flux threshold during the first four years of the current solar cycle (47) than for the same period of any of the three previous cycles, which had 20–25 of such events [*9*].

The measurements show that the years 1989 and 1990 had much solar-energetic-particle activity. In 1989, the events in August through October (days 220–300) had many high-energy (>60 MeV) protons, consistent with the strong GLEs [*13*], while the events in March 1989 and most of those in 1990 were fairly soft. The total fluence of solar protons >10 MeV integrated over these two years is quite high, $\gtrsim 10^{10}$ protons/cm^2, similar to the integrals over all 11-years of solar cycles 20 or 21 [*5*, *6*]. We will report integral fluxes for >10, >30, and >60 MeV for these and other events observed by our CPA instruments after finishing the calibrations. It appears that solar cycle 22 is like cycle 19, with many intense, hard events. These recent SEP events with hard spectra will help to make the average modern spectral shape harder and thus more like that determined from the ancient record [*5*, *6*]. Such intense, hard events as seen in the second half of 1989, and which could possibly occur for another 6–7 years [*11*], could produce significant short-lived radioactivities in meteorites that fall during the next decade. New falls should be counted quickly to look for 78-day ^{56}Co made by ^{56}Fe(p,n)^{56}Co reactions, as was seen in the small Salem meteorite [*15*], which fell in May 1981 (near the time of maximum activity for solar cycle 21).

REFERENCES. [*1*] Letaw J. R. *et al.* (1987) *Nature* **330**, 709–710. [*2*] Normand E. and Stapor W. J. (1990) *IEEE Trans. Nucl. Sci.*, in press. [*3*] Gurney D. J. (1990) *Rev. Geophys.* **28**, 315–336. [*4*] Reedy R. C. *et al.* (1983) *Annu. Rev. Nucl. Part. Sci.* **33**, 505–537. [*5*] Reedy R. C. and Marti K. (1991) *The Sun in Time* (Univ. Arizona Press), in press. [*6*] Sisterson J. M. *et al.* (1991), this conference. [*7*] Jull A. J. T. *et al.* (1991), this conference. [*8*] Nishiizumi K. *et al.* (1991), this conference. [*9*] Shea M. A. and Smart D. F. (1990) *Solar Phys.* **127**, 297–320. [*10*] Reedy R. C. (1977) *Proc. Lunar Sci. Conf. 8th*, pp. 825–839. [*11*] Feynman J. *et al.* (1990) *J. Spacecraft & Rockets* **27**, 403–410. [*12*] Goswami J. N. *et al.* (1988) *J. Geophys. Res.* **93**, 7195–7205. [*13*] Mathews T. and Venkatesan D. (1990) *Nature* **345**, 600–602. [*14*] Baker D. N. *et al.* (1979) *J. Geophys. Res.* **84**, 7138–7154. [*15*] Evans J. C. *et al.* (1987) *Lunar Planet. Sci. XVIII*, pp. 271–272. † Work done under the auspices of the US DOE.



Figs. 1 – 4: Daily averaged count rates of solar protons with energies above 9 MeV for 1989 (top left) and 1990 (top right) and above 60 MeV for 1989 (bottom left) and 1990 (bottom right)