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NEUTRON MONITOR AND PIONEER 6 AND 7 STUDIES OF THE JANUARY 28, 1967 SOLAR FLARE EVENT

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Abstract. A discussion of the January 28, 1967 solar flare event is presented. High energy data from several neutron monitor stations are supplemented by low energy data from the interplanetary space probes Pioneers 6 and 7. A study of the data obtained from these three observation stations widely separated in solar azimuth has shown (1) the most probable location for the responsible flare was $\approx 60°$ beyond the western solar limb, (2) other than the large emitted particle flux, the phenomena associated with the January 28 activity are not atypical of other solar flare effects, (3) both the $\gtrsim 0.5$ GeV and $\gtrsim 7.5$ MeV fluxes observed at the earth were isotropic, indicative of particle diffusion across the interplanetary magnetic field lines, (4) the spectral exponent of the differential rigidity spectrum at high energies was -4.8 ± 0.2, and (5) there was an indication of low energy solar injection prior to the high energy event of January 28.

A technique is also described for obtaining the differential rigidity spectral index for an isotropic flux as a function of the relative enhancements of any pair of neutron monitors sufficiently separated in latitude.

1. Introduction

Only upon very infrequent occasions ($< \approx 20$ times in the past 30 years) have solar flares generated cosmic ray particles of sufficient energy for their secondaries to be detected at the earth's surface. The solar flare time-profiles associated with these high energy events have been generally characterized by such salient features as (1) a relatively short duration, the entire flux enhancement usually vanishing in less than 12 h, (2) an initial anisotropic phase (with amplitudes as large, upon occasion, as $\approx 2000\%$ for high latitude stations), followed by a decreasing particle flux phase displaying a high degree of isotropy, and (3) a definite associated parent plage region on the visible solar disk. One of the most recent of these high energy solar events occurred on January 28, 1967. This solar flare event, which resulted in the generation of particles observable by high and mid-latitude neutron monitors, was unique in that neither the salient features (2) nor (3) were present. The fluxes of highly energetic particles at the earth's surface showed no preferred directions of arrival, and the event could not be related to any specific optical disturbance on the visible solar surface.

This communication presents a survey of data obtained during and subsequent to the high energy solar flare activity of January 28, 1967, obtained from three observa-

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tion stations widely separated in solar azimuth, these three observation stations being the earth (which through its world-wide network of neutron monitors provides information on particle fluxes more energetic than ≈ 0.5 GeV) and the two interplanetary deep-space probes Pioneers 6 and 7 (which provide information on low energy particle populations of energies > 7.5 MeV). The azimuthal separations of these three

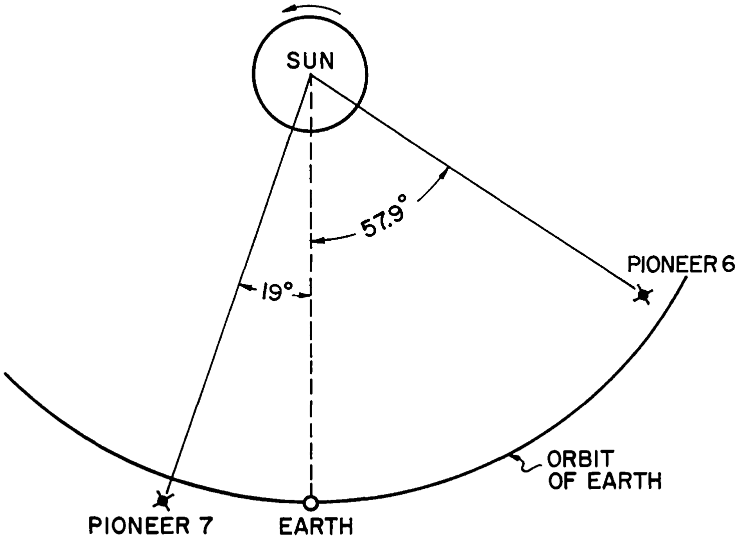

Fig. 1. Location in the plane of the ecliptic of Pioneers 6 and 7 relative to the earth-sun line at the time of the January 28, 1967 event.

observation stations on January 28, 1967 are indicated in Figure 1, wherein it is seen that Pioneer 6 was 57.9° west of the earth-sun line and Pioneer 7 was 19.0° east of the earth-sun line at the time of flare onset.

2. The January 28, 1967 Event as Observed from the Earth

Table I presents a summary of the ground-based neutron monitor coverage of the January event. It is seen that the flare onset at the recording stations occurred at 0833 ± 0003 UT. Figure 2 illustrates the enhanced counting rates above the pre-event value for twelve typical neutron monitor stations. Typical maximum enhancements range from 17.1% at high latitude stations such as Churchill, to 2.0% at mid-latitude stations such as Dallas. The enhancements observed from these two stations are depicted with better time-resolution in the five-minute counting rates of Figure 3. Excluding the high altitude stations (e.g., Sulphur Mountain and Mount Washington), it is seen that enhancements of $\approx 17\%$ occurred in all of the high latitude stations independent of their longitude. These equal enhancements, coupled with nearly identical onset times for stations widely separated in longitude, indicate that the particle flux associated with the January 28 neutron monitor enhancements displayed a very high degree of isotropy from the onset of the event.

The isotropic enhancement above the galactic counting rate $N_F^{(i)}$ $(R_C^{(i)})$ observed at station (i) due to a solar flare may be expressed as

$$N_F^{(i)}(R_C^{(i)}) = \int_{R_C^{(i)}}^{\infty} K R^{-\gamma} S^{(i)}(R)\, \mathrm{d}R \tag{1}$$

where the solar flare differential rigidity spectrum is assumed to be of the form $(\mathrm{d}J/\mathrm{d}R)_F = KR^{-\gamma}$, $S^{(i)}(R)$ is the proton specific yield function appropriately normalized for the particular detector, and $R_C^{(i)}$ is the cut-off rigidity at the location of station (i).

TABLE I

Summary of the neutron monitor coverage of the January event

Station	Geographic coordinates lat., long. (°E)	Vertical cutoff rigidity (GV)	Event onset (UT)	Percent enhancement
Sulphur Mt.	51.2, −115.6	1.14	08:(33 ± 3)	27.6 ± 0.1
Calgary	51.05, −114.08	1.09	08:(38 ± 3)	21.4 ± 0.1
Mt. Washington	44.28, − 71.3	1.24	08:(30 ± 30)	20.5 ± 0.1
Alert	82.50, − 62.33	1.0[a]	08:(38 ± 3)	17.3 ± 0.1
Churchill	58.75, − 94.09	1.0[a]	08:(33 ± 3)	17.1 ± 0.1
Deep River	46.10, − 77.50	1.02	08:(33 ± 3)	16.4 ± 0.1
Ottawa	45.4, − 75.6	1.08	08:(30 ± 30)	15.8 ± 0.1
Goose Bay	53.27, − 60.40	1.0[a]	08:(33 ± 3)	15.7 ± 0.1
Leeds	53.8, − 1.5	2.20	08:(48 ± 3)	7.2 ± 0.1
Kiel	54.3, − 10.1	2.29	08:(38 ± 3)	5.4 ± 0.1
Lindau	51.6, − 10.1	3.00	07:(30 ± 60)	4.2 ± 0.1
Dallas	32.98, − 96.74	4.35	08:(33 ± 5)	2.0 ± 0.1

[a] Atmospheric cutoff

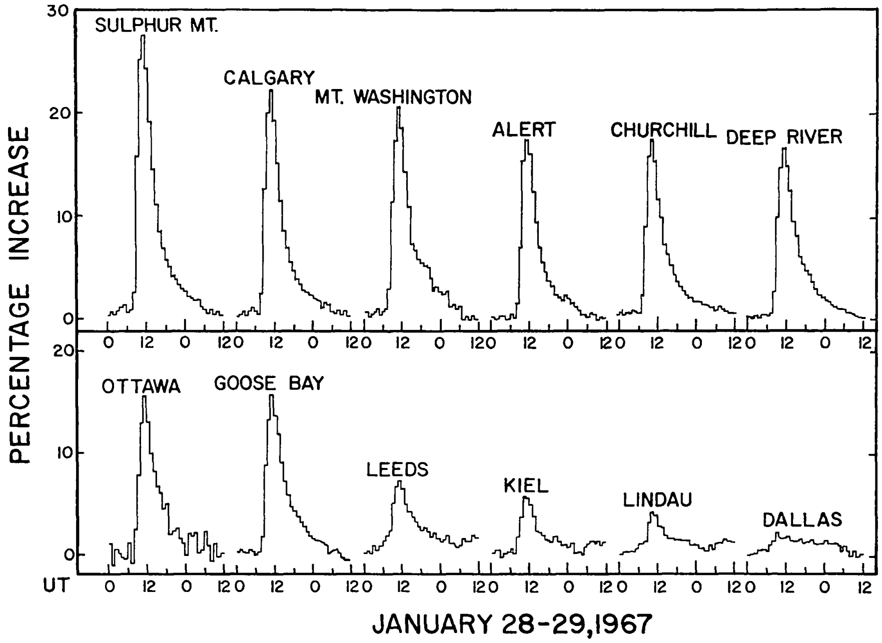

Fig. 2. Time profiles of the January 28, 1967 event as recorded by several typical neutron monitor stations.

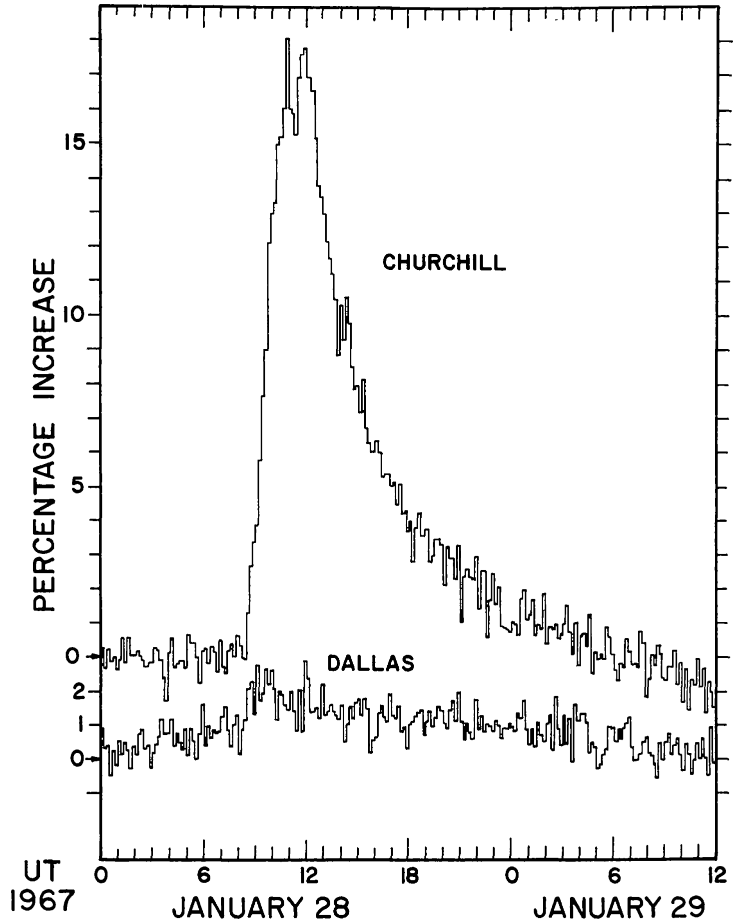

Fig. 3. Five-minute averaged percentage increases for the Churchill and Dallas neutron monitors during January 28–29, 1967.

Webber and Quenby (1959) and recently Lockwood and Webber (1967) have presented the proton specific yield function $S(R)$ in the rigidity range 2–50 GV calculated from the measurements of the primary cosmic ray spectrum and neutron monitor latitude surveys. Webber (1962) has extended this range down to 1 GV by using data obtained during the February 23, 1956, solar flare event where direct measurements of the solar particle rigidity spectrum were available. We will use in this work the values calculated by Lockwood and Webber (1967) based on a recent neutron monitor latitude survey by Carmichael *et al.* (1965). Designating, these values of the specific yield function $S(R)$, the normalization used by Lockwood and Webber was such that for a particular detector (i) we have

$$S^{(i)}(R) = S(R)\cdot \frac{\displaystyle\int_{15}^{\infty} \left(\frac{\mathrm{d}N}{\mathrm{d}R}\right)^{(i)} \mathrm{d}R}{\displaystyle\int_{15}^{\infty} \left(\frac{\mathrm{d}J}{\mathrm{d}R}\right)_{G} \mathrm{d}R} \qquad (2)$$

where $\int_{15}^{\infty} (\mathrm{d}N/\mathrm{d}R)^{(i)}\,\mathrm{d}R = N_G^{(i)}(15)$ represents the galactic counting rate that the neutron monitor (i) would record if situated at a location where the cut-off rigidity is 15 GV, and $\int_{15}^{\infty} (\mathrm{d}J/\mathrm{d}R)_G \mathrm{d}R$ is the integral primary proton rigidity spectrum above 15 GV. Thus the fractional enhancement $(\delta N/N)^{(i)}$ during a solar flare observed at station (i) with cut-off rigidity $R_C^{(i)}$ may then be given as

$$\left(\frac{\delta N}{N}\right)^{(i)} = \frac{K}{b} \cdot \frac{N_G^{(i)}(15)}{N_G^{(i)}(R_C^{(i)})} \cdot I(R_C^{(i)}, \gamma) \tag{3}$$

where

$$b = \int_{15}^{\infty} (\mathrm{d}J/\mathrm{d}R)_G \, \mathrm{d}R$$

and

$$I(R_C^{(i)}, \gamma) = \int_{R_C^{(i)}}^{\infty} R^{-\gamma} S(R)\, \mathrm{d}R .$$

Applying equation (3) to neutron monitor stations X and Y, and defining α_{XY} as the relative fractional enhancement of station X to station Y, yields the expression

$$\alpha_{XY} = \frac{N_G^{(X)}(15)}{N_G^{(X)}(R_C^{(X)})} \cdot \frac{N_G^{(Y)}(R_C^{(Y)})}{N_G^{(Y)}(15)} \cdot I_{XY}(R_C^{(X)}, R_C^{(Y)}, \gamma) \tag{4}$$

where

$$I_{XY}(R_C^{(X)}, R_C^{(Y)}, \gamma) = \frac{I(R_C^{(X)}, \gamma)}{I(R_C^{(Y)}, \gamma)} .$$

Since the ratio of the counting rates of the same neutron monitor at two different locations should be independent of the particular monitor, we have

$$\frac{N_G^{(X)}(15)}{N_G^{(X)}(R_C^{(X)})} \cdot \frac{N_G^{(Y)}(R_C^{(Y)})}{N_G^{(Y)}(15)} = \frac{N_G^{(Z)}(R_C^{(Y)})}{N_G^{(Z)}(R_C^{(X)})} \tag{5}$$

where $N_G^{(Z)}(R_C)$ is the counting rate of any monitor (Z) (e.g. a test monitor used in the latitude survey) at a location where the cut-off rigidity is R_C. Thus, the ratio

$$\lambda_{YX} \equiv \frac{N_G^{(Z)}(R_C^{(Y)})}{N_G^{(Z)}(R_C^{(X)})} \tag{6}$$

is dependent solely upon the cut-off rigidities at the locations of the measurements, and consequently, values of λ_{YX} may be obtained from latitude surveys such as that recently conducted by Carmichael *et al.* (1965). Equation (4) can now be written as

$$\alpha_{XY} = \lambda_{YX} \cdot I_{XY} . \tag{7}$$

Equation (7) indicates that for an isotropic primary cosmic ray flux, the relative enhancements of any two neutron monitor stations may be expressed as a function of the cut-off rigidities R_C of the stations considered, the proton specific yield functions $S(R)$, and γ, the exponent in the primary cosmic ray spectrum. Hence, assuming a fixed value for γ, and using the proton specific yield functions, one may evaluate the integrals in Equation (3) for any pair of neutron monitor stations, and thus the ratio I_{XY}. Then, calculating values of λ_{XY} using the results of the Carmichael *et al.* (1965) recent latitude survey, α_{XY} is readily available as a function of γ from Equation (7).

Figure 4 illustrates a plot of α_{CD} (relative solar flare enhancements as recorded by two neutron monitors) versus γ (differential rigidity spectral exponent of the solar flare particles) for the neutron monitor stations Churchill, Manitoba, and Dallas, Texas. Figure 4 then represents a universal curve for the stations Churchill and Dallas, which is independent of the solar flare considered. The sole criterion for the use of Figure 4 for determining the flare spectral exponent from the ratio of the percent enhancements observed at these two stations is that the high energy particle flux be isotropic. Hence, it may be confidently utilized in either an isotropic flare event such as the one currently under consideration or in the isotropic profile which high energy flares generally display in their decay phases. Figure 3 indicates that, during the maximum intensity phase of the January 28 activity, Churchill recorded a (17.1 ± 0.1)% increase above the 'quiescent' intensity, while Dallas recorded a corresponding (2.0 ± 0.1)% increase. Pressure correcting the maximum intensity phases of these two neutron monitor stations according to the dual attenuation length technique discussed

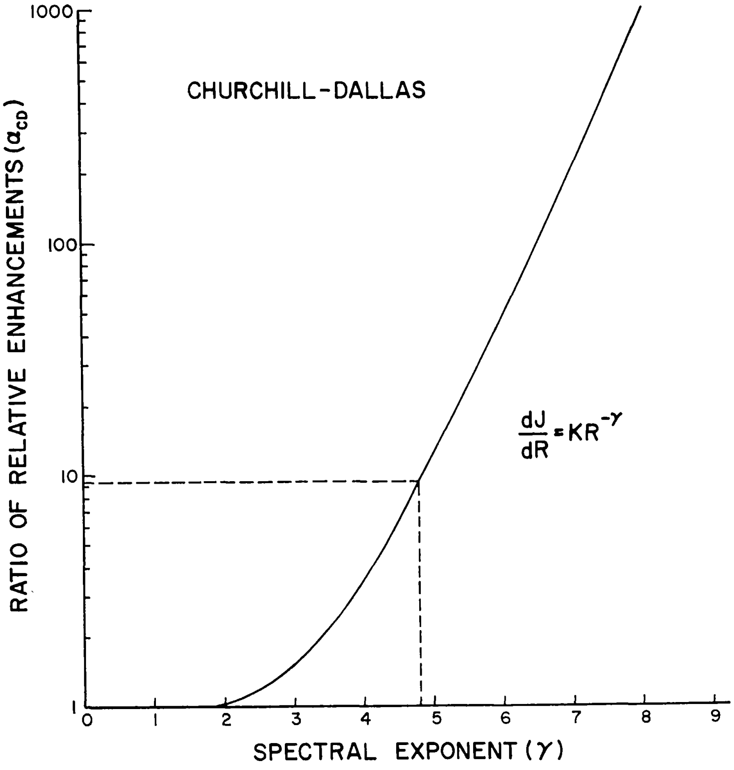

Fig. 4. Relative counting rate enhancements of the Churchill-Dallas neutron monitor pair α_{CD}, as a function of the spectral exponent γ.

by McCracken (1962), and utilizing the value of the attenuation length for the solar particles calculated by Wilson *et al.* (1967), yields maximum enhancements of (18.4 ± 0.1)% and (1.98 ± 0.1)% for Churchill and Dallas respectively. This results in an α_{CD} value of 9.3 ± 0.5. Hence Figure 4 suggests that the differential rigidity spectrum for the January 28, 1967, event was of the form $(\mathrm{d}J/\mathrm{d}R) \sim R^{-4.8 \pm 0.2}$ on the basis of the Lockwood and Webber (1967) specific yield functions.

Clearly universal curves such as that illustrated by Figure 4 may be generated for any pair of 'sea level' neutron monitor stations separated sufficiently in geomagnetic latitude that the α values are statistically meaningful. The rigidity spectrum was calculated using pairs of neutron monitor stations other than Churchill–Dallas. The results are given in Table II which shows the value of the spectral exponent for each pair of stations calculated using the WQ (Webber and Quenby, 1959) and the LW (Lockwood and Webber, 1967) proton specific yield functions. It can be seen that there is internal consistency among the different pairs of stations for each specific yield function. However, the use of the WQ function results in a somewhat steeper spectrum than the use of the LW function.

TABLE II

Spectral exponent for the January event

Station pair	Using LW yield function	Using WQ yield function
Churchill–Dallas	4.8 ± 0.2	5.9 ± 0.2
Leeds–Dallas	5.1 ± 0.2	5.5 ± 0.2
Kiel–Dallas	4.8 ± 0 2	5.1 ± 0.2
Churchill–Kiel	4.8 ± 0.2	6.8 ± 0.2
Deep River–Kiel	4.6 ± 0.2	6.5 ± 0.2
Calgary–Kiel	4.8 ± 0.2	6.8 ± 0.2
Average	4.8 ± 0.1	6.1 ± 0.1

3. The January 28, 1967, Event as Observed from Deep Space Probes

At the time of the January 28 solar flare onset, the deep space probes Pioneers 6 and 7 were situated in the plane of the ecliptic and separated by ≈ 77° in solar azimuth (see Figure 1). The on-board cosmic ray detectors have been extensively described elsewhere (see, for example, Bartley *et al.*, 1967; McCracken *et al.*, 1967). Suffice to say that the detectors possess the capability of obtaining information on the temporal variation, nature of the spectrum, and degree of anisotropy of the cosmic radiation of kinetic energies < 100 MeV/nucleon.

Figure 5 illustrates the counts per 7.5 min at hourly intervals of the non-directional cosmic-ray fluxes > 7.5 MeV recorded by Pioneers 6 and 7 for the time period January 25 to February 8, 1967. Pioneer 6 was launched in December, 1965, and by January, 1967, the satellite was $\approx 1.5 \times 10^8$ km distant from the earth. Data acquisition was only possible using a 210 ft paraboloid in California. Hence data acquisition was limi-

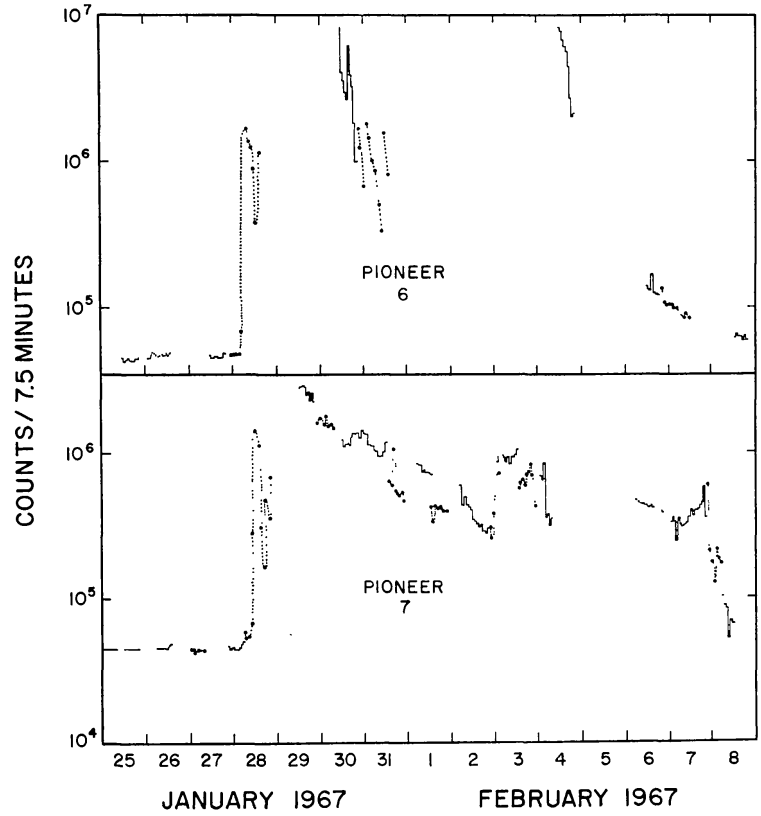

Fig. 5. Pioneers 6 and 7 data for the period January 25–February 8, 1967. The full circles represent data obtained during 'memory mode' operation (see text).

ted to only a few hours every week. Pioneer 7, however, was launched in August, 1966, and by January, 1967, was still close enough to the earth to permit much more extensive tracking coverage.

Figure 5 indicates the following salient features:

(a) At some time subsequent to $\approx$ 1200 UT on January 28, the inner solar system became densely populated with low energy ($>$ 7.5 MeV) cosmic radiation. Unfortunately, the onset phase of the event occurred during a time interval when no real-time data transmission was available. However, by January 29 the cosmic radiation appeared to be in a decay phase, at which time the particle flux as measured by Pioneer 7 was still nearly 2 orders of magnitude above its ambient value.

(b) Although the event as seen on the earth had a total time duration of $\approx$ 24 h, the inner solar system remained populated with low energy radiation for about two weeks.

(c) The Pioneer 6 data available to us are consistent with the recording of a higher particle flux at the position of Pioneer 6 than at the position of Pioneer 7. The meagre Pioneer 6 data suggest that the particle flux observed at Pioneer 6 was about 5 times the particle flux observed at Pioneer 7 throughout the early portions of the event. Since the cosmic ray detectors aboard Pioneers 6 and 7 have been calibrated and found to be directly comparable (within 5%) this ratio of observed counting rates is real and not instrumental in origin.

It is not possible to utilize the differential energy data of the Pioneer instruments to obtain definitive information on the nature of the spectrum or the degree of anisotropic particle propagation in the lowest energy channels since these channels were subject to counting rate saturation. However, in the very late stages of the event (≈ 10 days after its onset) the differential rigidity spectrum of the decreasing intensity phase can be represented in the form $(\mathrm{d}J/\mathrm{d}R) \sim R^{-6.2}$ which appears to be steeper than the differential rigidity spectrum observed for the high rigidity particle flux by the world-wide network of neutron monitors for the January 28 event.

However, this spectrum was obtained ≈ 10 days subsequent to the solar flare onset, and by that time the spectrum should have significantly steepened from the flare-onset value as calculated from neutron monitor data. Thus, the satellite spectral determination does not contradict the neutron monitor calculations.

The Pioneers 6 and 7 cosmic ray detectors have been designed to provide anisotropy measurements even during periods of large particle fluxes. Hence, although the data from the 65–81 MeV differential channel of Pioneer 7 could not be recovered sufficiently to provide definite values of the absolute particle flux, it could be used to provide realistic information on the degree of anisotropy present in that energy range during the maximum intensity interval January 29–31.

Although the data do indicate the presence of short term variations in the direction of particle arrival at the spacecraft, the magnitudes of the anisotropies in almost all of the cases were much less than ≈ 15%. That is, there were no indications of persistent anisotropies throughout the maximum intensity phase of the January activity. Similar conclusions may be made concerning the small amount of Pioneer 6 data available near the time of maximum intensity. Hence the high degree of isotropy noted by the neutron monitor stations for the high energy cosmic radiation appears to have been present also in the low energy cosmic radiation observed at the Pioneer spacecrafts.

4. Possible Solar Position of the Responsible Plage Region

Unique to the January 28 event is the fact that there is no possible visible flare to which it can be associated. The atypical isotropic nature of this event might suggest that the responsible solar flare occurred beyond the east limb of the sun and that the isotropy observed at the earth was due to particle diffusion across the interplanetary magnetic field lines.

Figure 6 illustrates the hourly counting rate (counts per 7.5 min at hourly intervals) of the > 7.5 MeV cosmic ray flux recorded by Pioneers 6 and 7 for the interval February 12–18, 1967. Shown also is the hourly counting rate of the Churchill neutron monitor during this same time interval. It is seen that the Pioneer 7 spacecraft recorded the onset of a solar flare at ≈ 2000 UT on February 13, 1967. This particle flux was undoubtedly associated with the intense activity displayed by McMath plage 8687. This plage region was responsible for several 3+ and one 4+ visible solar flare between ≈ 1800 and 2200 UT on February 13, and on this date was centered at the solar coordinates N22°, W10°. On the basis of preferential particle propagation through an undisturbed Archimedes spiral magnetic field configuration, Pioneer 7 was in a favorable position (see Figure 1) to record the solar induced flux. From the position of Pioneer 6, the February 13 event would be considered as having occurred on the normally unfavored eastern portion of the visible solar surface, and solar particles arriving at Pioneer 6 would have had to suffer diffusion across the interplanetary magnetic field lines. Fourier analysis of the 64–81 MeV data from Pioneer 7 indicates

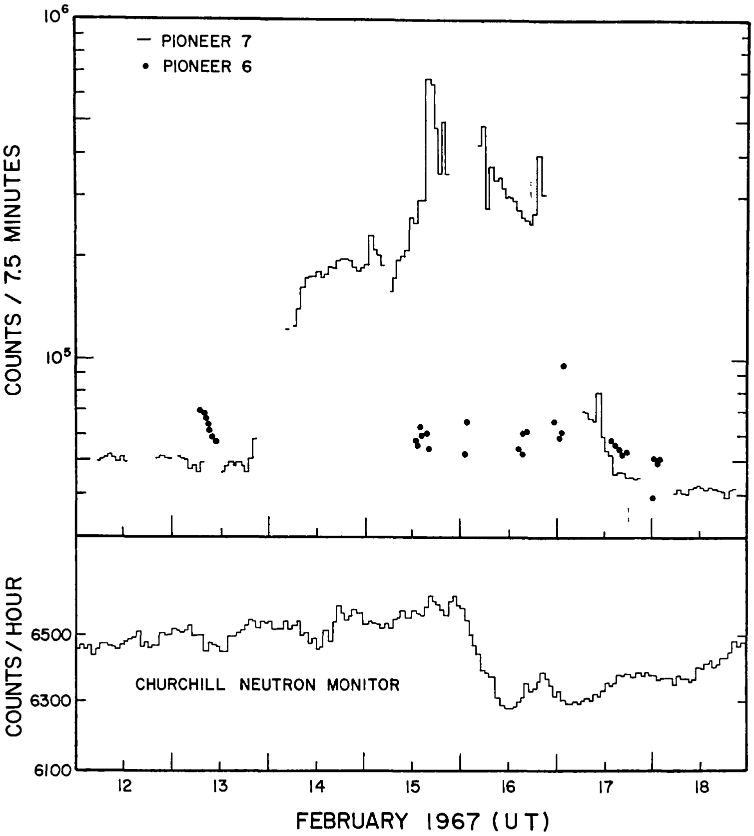

Fig. 6. Pioneers 6 and 7, and Churchill neutron monitor data for the period February 12–18, 1967.

that the observed anisotropy was consistent with normal particle propagation through an undisturbed Archimedes spiral configuration. During the onset of this solar flare, Pioneer 7 recorded anisotropies of 12–15% persistently from 45–90 °W of the satellite-sun line. Further, as seen from Figure 6, the counting rate of Pioneer 6 was at most minimally affected by the activity occurring in Plage Region 8687. This azimuthal gradient of the solar cosmic ray flux is consistent with the earlier report by McCracken *et al.* (1967) which implied the existence of gradients amounting to two orders of magnitude over 60° of solar longitudes for periods of time of about one day or more. On the basis of this azimuthal density gradient observed here, and elsewhere by McCracken *et al.* (1967) in other events, and the solar flare position suggested below, a conservative estimate of the 'guiding-center motion' particle flux (i.e., the particle flux as would be observed by a detector system suitably located to record the highly anisotropic propagation phase of the January 28 flare denied to the detector systems considered here) would be $> 2 \times 10^3$ particles $\text{cm}^{-2}\,\text{sec}^{-1}\,\text{ster}^{-1}$ above 7.5 MeV. This flux may be compared to the largest high-energy flare-initiated flux previously recorded, viz. 3×10^4 particles $\text{cm}^{-2}\,\text{sec}^{-1}\,\text{ster}^{-1}$ above 20 MeV, on February 23, 1956.

Plage region 8687 had an extended history of activity for several solar rotations both prior and subsequent to the January solar flare. Consequently we suggest that this region is a likely candidate for having injected the solar particles that were observable over a wide range of solar azimuths on January 28. The location of this plage region at solar longitude 10°W (as measured from the earth-sun line) on February 13 implies that its location on January 28 was (148.5 ± 10)°W, i.e. about 60° behind the western limb of the sun as seen from the earth. That this is a logical location for the responsible solar flare is borne out from the following set of observations pertaining to the January 28 event:

(a) There was no recorded solar flare occurring on the visible (from earth) solar disk, despite 100% flare patrol coverage on January 28. Also, the neutron monitor network failed to record the presence of an associated Forbush decrease. Thus the flare was probably located at more than 60° from Central Meridian Passage.

(b) Both the low energy particle fluxes recorded by the Pioneer spacecrafts and the high energy particle fluxes recorded by the world-wide network of neutron monitors were characterized by definite isotropy, indicating that the particles in each instance arrived at the detectors by diffusion rather than guiding center motion.

(c) The Pioneer 6 and 7 data available for inter-comparison indicate a greater intensity enhancement recorded at the location of Pioneer 6 than at Pioneer 7. For Pioneer 6 to be in a more favorable position to observe diffusive cosmic ray particles than Pioneer 7, the responsible flare must have been located within the quadrant of solar longitude immediately beyond the west limb (as seen from the earth).

(d) The plage region under consideration had a history of activity extending over several solar rotation periods.

Similar conclusions regarding the location of the flare responsible for this increase were reached by Baird *et al.* (1967) and Innanen *et al.* (1968). Lockwood (1968) has applied the predictions of the model of the diffusion of solar cosmic rays in the interplanetary field developed by Burlaga (1967) (referred to as the ADB model), to predict the particle injection time from the Deep River neutron monitor data. His estimate of 0730 ± 0015 UT for the injection time led him to conclude that the parent solar flare was located about 60° beyond the west limb. Applying the predictions of Burlaga's ADB model to the Churchill neutron monitor time profile we obtain an injection time of 0740 ± 0015 UT in good agreement with Lockwood's estimate.

5. Low Energy Activity Prior to the January 28 Event

Masley (1968) using riometer data, has reported the presence of low energy radiation (5–100 MeV) at the orbit of the earth before 0400 UT January 28. Although this author does not exclude the possibility of a low energy precursor related to the main event, he stresses the fact that some of its characteristics are consistent with its being due to a separate acceleration. The data from Pioneers 6 and 7 appear to support this latter possibility, viz. that two distinct solar flare events occurred on January 28, both generating particles that were detected over a large range of solar azimuths.

On January 28, the data from Pioneers 6 and 7 were collected under a 'memory store' mode of operation, wherein periodic samples of data were collected, stored within the spacecraft, and transmitted back to earth during the next data acquisition interval. Although less statistically significant than the continuous data stream, the recovered 'memory mode' data may be confidently utilized. Figure 7 illustrates this recovered data for the onset stage of the January 28 solar activity for Pioneers 6 and 7. It is evident that the average intensity recorded by Pioneer 6 increased significantly between 0300 and 0420 UT. At 0513 January 28, Pioneer 7 was recording a cosmic ray intensity which was ≈ 40% higher than the previous values recorded on January 27. This intensity appeared to decrease slightly, then rise drastically to large flux values sometime subsequent to 0800 UT. With the limited number of data samples available, it is difficult to discuss a detailed time profile of this activity. However, since both Pioneers 6 and 7 recorded measurable increases in the > 7.5 MeV fluxes prior to our estimate of the time of flare occurrence, these flux increases must be due to another solar injection which occurred before the solar flare effect observed by the neutron

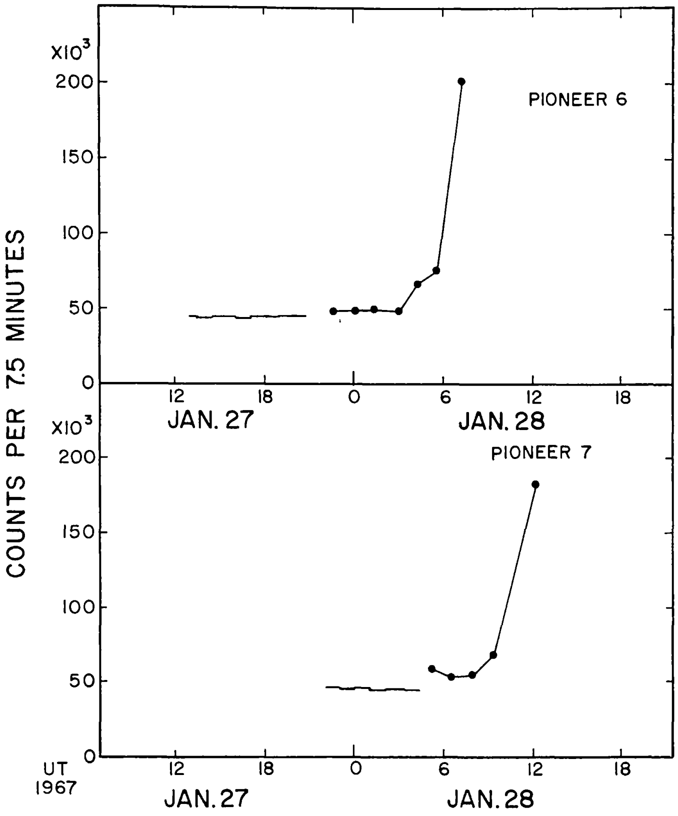

Fig. 7. The onset of the January 28, 1967 activity as recorded by Pioneers 6 and 7. The full circles represent data obtained during 'memory mode' operation (see text).

monitor network. Pioneer 6 recorded a much larger flux from this earlier event than did Pioneer 7, indicating that this solar flare also occurred on the back side of the sun as observed from the earth. The small flux increase detected by Pioneer 7 is consistent with the small increase in the 30 MHz absorption reported by Masley (1968).

6. Conclusions

From a study of the ground-based and deep space observations pertinent to the solar activity which commenced January 28, 1967 we conclude that even though the intensity profile as recorded by the world-wide network of neutron monitors was unusual in comparison to previously observed high energy solar flares, the solar flare responsible for the recorded fluxes was not at all unusual in nature, other than, perhaps, in the large production of cosmic ray particles. The salient features of the January 28 event may be summarized as follows:

(a) The probable location of the responsible solar flare was in McMath plage region 8687 located $\approx 60°$ beyond the west limb of the sun.

(b) The low energy particles ($\lesssim 100$ MeV) recorded at the Pioneer spacecrafts and the high energy particles ($\gtrsim 0.5$ GeV) recorded at earth had arrived after diffusion across the interplanetary magnetic field lines. Consistent with this particle diffusion, both species of particle fluxes displayed remarkable isotropy.

(c) On the basis of the azimuthal gradient observed here and elsewhere by McCracken *et al.* (1967) in other events, we estimate the flux that would have been observed by a detector ideally located in azimuth to be $> 2 \times 10^3$ particles cm^{-2} sec^{-1} ster^{-1} above 7.5 MeV.

(d) Both the particle fluxes observed at the deep-space probes and the earth were characterized by differential rigidity spectra of the form $dJ/dR \sim R^{-\gamma}$, with $\gamma \approx 5$ for the higher energies observed at the earth, and $\gamma \approx 6$ for the lower energies detected by the Pioneer deep-space probes later in the event.

(e) On the basis of Pioneer 6 and 7 observations, there are indications of a low energy solar injection several hours prior to the high energy main event.

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