is at 8.97 MeV in ^{92}Nb, whereas 7.05-MeV deuterons on ^{90}Zr produce an excitation energy of 17.71 MeV in ^{92}Nb. If there were an analog resonance in ^{92}Nb at this excitation energy, its parent analog state in ^{92}Zr would be at the neutron separation energy. The deuteron-induced analog resonance reaction is isospin forbidden. This discussion of the compound nucleus does not preclude the (d,p) stripping mechanism to be described either as compound nucleus or direct. An explanation of these effects from a total flux conservation argument may be discounted on the grounds that the cross section of the (d,n) reaction to a particular state is very small when compared with the total cross section. This is further substantiated by the slowly varying elastic deuteron excitation curve. The (d,nn) reaction is energetically forbidden and the involvement of other reaction channels may be disregarded since their cross sections are negligible.

We conclude that it has been shown to be feasible to excite analog states by the (d,n) reaction. Further, we have by-passed the difficulties of neutron detection. Finally, we give evidence that the (d,p) and analogous (d,n) channel are strongly coupled. It is probable that this effect can be explained by a coupled channel calculation using an isospin-dependent potential.

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RECURRENT FORBUSH DECREASES ASSOCIATED WITH *M*-REGION MAGNETIC STORMS*

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The cosmic-radiation intensity near the orbit of Earth is observed to be under solar control, suffering frequent and transient depressions below a slowly varying level. A characteristic form of intensity depression is the "Forbush decrease," in which the intensity decreases to a minimum within 6 to 24 h, and then recovers to the pre-event level more slowly during the subsequent days. Previous studies have concluded that a Forbush decrease is observed throughout an extended volume of space, and is due to the screening effect of the interplanetary magnetic fields, which have been rearranged by a blast wave generated when a solar flare has occurred on the sun. That is, a solar flare is generally considered to be necessary to generate a Forbush decrease.

In this Letter we report the observation of a number of recurrent cosmic-ray modulation phenomena which have all the characteristics of Forbush decreases, but which were not preceded by solar flares. They were, however, intimately correlated with recurrent *M*-region magnetic storms, and we conclude that each recurrent series is the result of a shock wave initiated by a continuous emission of fast plasma by a restricted area of the sun. These shock waves would appear to be semipermanent features of the interplanetary medium.

The observations of relevance here were obtained by the cosmic-ray anisotropy detector on Pioneer VI,[1,2] which was launched into a heliocentric orbit of perihelion 0.8 A.U. on 16 December 1965. The information channel of interest is the counting rate of all pulses >7.5 MeV observed by a thallium-doped CsI scintillator, of cross-sectional area 38 cm^2, and depth 2.2 cm. The mean counting rate is 130 counts sec^{-1}, and data are accumulated for 14-sec intervals prior to transmission to earth. The data discussed herein are hourly and six-hourly average data.

The >7.5-MeV integral count-rate data for 2.5 solar rotations are displayed in Fig. 1, each graph corresponding to 27 days (i.e., one synodic solar rotation) of data. During the above period of time at least five solar-flare effects were evident in the >7.5-MeV data, the 7.5- to 45- and 45- to 90-MeV counting-rate data indicating that the enhancement of the >7.5-MeV counting rate was almost entirely due to cosmic rays of energy >45 MeV. Writing the observed >7.5- and 7.5- to 45-MeV counting rates as R and R_f, respectively, it would therefore be expected that a linear relationship should exist between R and R_f, an expectation borne out in detail by the observations. We have, therefore, applied a correction to the observed 7.5-MeV counting rate to remove the contribution of solar origin, the nonsolar (or galactic) counting rate being defined as $R-\beta R_f$, where β is determined by a least-squares analysis, and it is such data that are plotted in Fig. 1. Inspection shows that there is a pronounced tendency for depressions of the counting rate to recur after 27

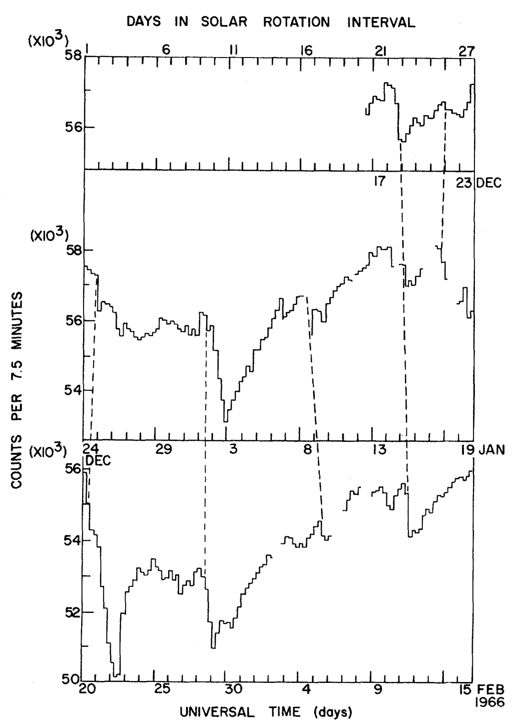

FIG. 1. The cosmic-radiation intensity as a function of time during the interval 16 December 1965 to 15 February 1966. Six-hour means are displayed.

days, five and possibly six separate recurrence series being apparent in this figure. It will be noticed that many of the recurrent depressions exhibit the rapid decrease and slow recovery typical of the Forbush-type decrease.

In Fig. 2, the Bartels planetary magnetic indices for the first five solar rotations subsequent to the launch of Pioneer VI are displayed. The galactic >7.5-MeV data from Pioneer VI (i.e., the species of data plotted in Fig. 1) have been examined for this period of time, and the times at which the counting rate has started to decrease have been identified and indicated upon the magnetic index diagram. A correction has been applied to allow for the distance between Pioneer VI and Earth, the times of onset of cosmic-ray decrease indicated on Fig. 2 being those which would have been observed by a detector identical to that on Pioneer VI located near the earth. The more pronounced cosmic-ray recurrence series have been indicated by the dotted lines. It will be noted that the four prominent recurrent cosmic-ray decreases tend to be associated with the onset of recurrent geomagnetic disturbances (M-region geomagnetic storms). The recurrent cosmic-ray and geomagnetic events in the vicinity of solar rotation day No. 22 (series D in Fig. 2) are good examples of this tendency.

The hourly cosmic-ray data for three members of one recurrence series (series D) are displayed in Fig. 3, along with concurrent interplanetary magnetic field data reported by Ness.[3] It will be observed that the time profiles of all three cosmic-ray events are similar to that associated with the typical Forbush decrease. Such is true of the other recurrence events in Fig. 1, and elsewhere in the Pioneer-VI data. We therefore conclude that the various events in the recurrence series in Fig. 1 are recurrent Forbush decreases, each being associated with an M-region recurrent magnetic disturbance.

Despite the evidence against such a situation,[4] we have, for completeness, considered the question of whether the magnetic and cosmic-ray events of any given recurrence series may have been due to the occurrence of solar flares in a long-lived sunspot group, flares occurring each time the group was near central meridian passage. We find that there is strong evidence within our data that this was not the case. For example, the largest observed recurrence

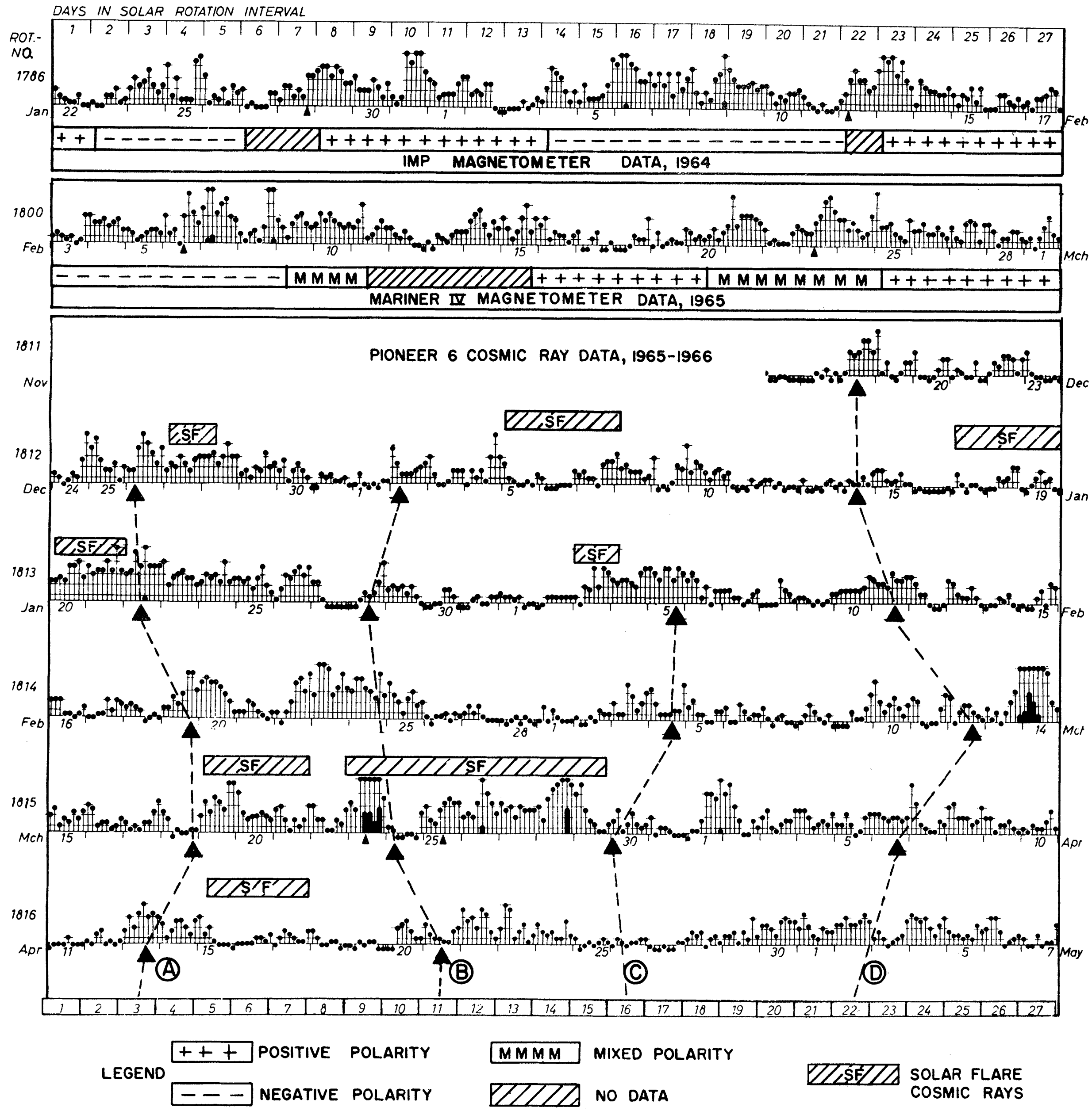

FIG. 2. The three-hourly *Kp* diagrams for the period of the Pioneer-VI flight, and for portions of the IMP-A and Mariner-IV flights. The onsets of the cosmic-ray decreases observed by Pioneer VI are indicated by the solid wedges.

event, which occurred on 12 March 1966 (Fig. 3), was preceded by a period of exceptionally minor solar activity, there having been only 9 subflares in the previous 4 days, and no flares of importance 1– or greater. There were no radio emission events in this period. A similar situation pertains prior to other recurrence events. Further, the periods during which solar cosmic rays were being detected by Pioneer VI are indicated in Fig. 2 which shows that the recurrence events in the series at solar rotation days No. 3 and No. 22 were never preceded by any solar cosmic-ray phenomena whatsoever.

We are therefore led to conclude that the disturbances of the interplanetary medium that

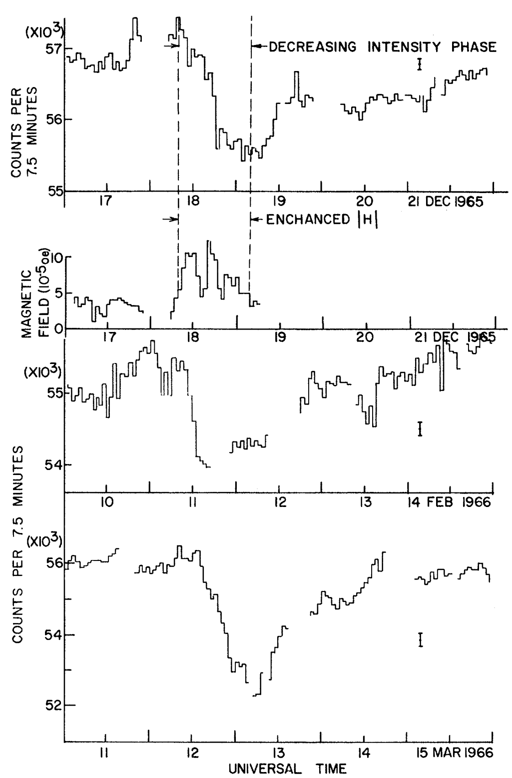

FIG. 3. The temporal changes in cosmic-ray intensity observed during three of the recurrent depressions in the vicinity of solar rotation day No. 22. The Pioneer magnetic observations for one recurrence event are presented.

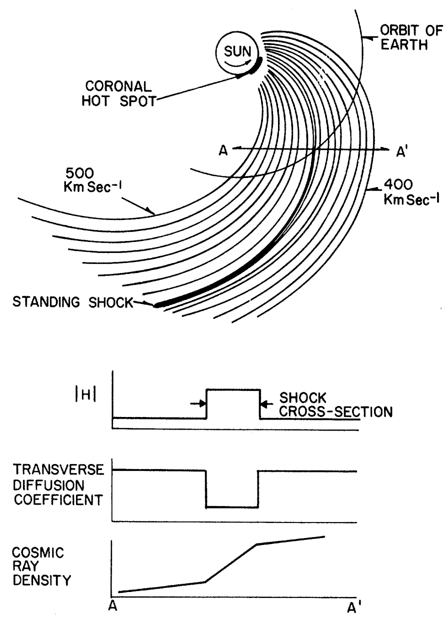

FIG. 4. The model of the standing shock wave generated by a single coronal hot spot.

generated the recurrent series of Forbush decreases in Figs. 1 and 2 were not initiated by solar flares. We suggest that the plasma disturbance responsible for an M-region storm is also responsible for a significant modulation of the galactic cosmic rays, there being a sharp boundary to the region of depressed cosmic-ray intensity. Such a situation would be created by a "hot spot" on the corona, the fast plasma from the "hot spot" creating a standing shock wave at its interface with the slower plasma from the remainder of the corona,[5,6] this situation being depicted in Fig. 4 for a single coronal hot spot. In this model, the enhanced plasma density in the shock (or incipient shock) would be responsible for the enhanced geomagnetic activity while the enhanced magnetic field strength within the shock would inhibit cosmic-ray diffusion across the magnetic lines of force, as summarized in Fig. 4. Note that this sketch applies to the instantaneous situation; with the passage of time, diffusion along the lines of force would cause the cosmic-ray density at a fixed point relative to the shock to increase in a montonic fashion. Consequently, as an observer crossed from outside to inside the shock, a steadily decreasing cosmic-ray intensity would be observed while passing through the shock, and then once inside the shock, it would steadily increase with time due to longitudinal diffusion. One characteristic of this model is that the decreasing phase of the Forbush decrease is associated with the inhibition of diffusion by the stronger magnetic fields within the shock; consequently, the model predicts that the decreasing-intensity phase terminates once the interplanetary magnetic field strength returns to its normal value. Comparison of the cosmic-ray and magnetic data in Fig. 3 indicates that this is, in fact, the case. The fact that the increase in the solar magnetic field intensity approximated the 4:1 value to be expected for a shock further substantiates the model.

Since a shock due to a persistent "hot spot" on the corona would remain stationary relative to a point on the rotating sun, the shock would appear to an observer elsewhere in the solar system to be corotating with the sun. Hence, an observer near Earth would observe the shock once every 27 days. To each "hot spot" on the corona, there would be a standing shock, hence there would be a number of interleaved, and independent, recurrence series evident in the cosmic-radiation data.

Bryant et al.,[7] the University of Chicago (as reported by Wilcox and Ness[8]), and the University of Iowa (Krimigis, private communication) have observed recurrent low-energy "solar" cosmic-ray enhancements, and in the cases which have been examined in detail, these enhancements appear to occur immediately after the observation of a sector boundary of the interplanetary magnetic field.[8] We have therefore carefully examined the 7.5- to 45-MeV data obtained from the cosmic-ray anisotropy detector on Pioneer VI for any enhancements before, during, or after the recurrent Forbush decreases. No such enhancements were observed except on those two occasions when an identified flare generated cosmic rays a few days previously. From examination of our daily mean 7.5- to 45-MeV data, we can set an upper limit of 0.001 particles cm^{-2} sec^{-1} for cosmic rays of solar origin of energy >7.5 MeV accompanying the recurrent Forbush decreases.

Wilcox and Ness[8] have disucussed the sectorial structure of the interplanetary magnetic field, the abrupt reversal of the interplanetary magnetic field vector being accompanied by marked enhancement of both the scalar field magnitude and the plasma density. Inspection of their Fig. 12 makes it clear that the sectorial reversals occurred concurrently with the initial onset of a recurrent or M-region geomagnetic storm. In Fig. 2 the Kp data for representative solar rotations during both the IMP-A and Mariner-IV flights are presented, along with an indication of the interplanetary field polarity. It will be noted that the recurrent Forbush decreases evident in 1966 appear to be closely correlated in solar rotation time with the sectorial boundaries observed in early 1964 and early 1965. For example, the well-developed Forbush-decrease recurrence series with its prototype on 18 December 1965 correlates well with the sectorial boundaries observed on 12 February 1964 and 25 February 1965. This would suggest that (a) the sectorial structure observed in the interplanetary field in early 1964 still existed essentially unchanged in early 1966; and (b) the standing shock waves invoked to explain the recurrent Forbush decreases define the edges of the sectors.

The continual presence of a number of standing shock waves "permanently" attached to and corotating with the sun would tend to expel galactic cosmic rays from the solar system. They would, in fact, act as the vanes of a centrifugal pump for cosmic rays, and thereby establish a radial cosmic-ray density gradient. Since the 11-year variation in solar activity would undoubtedly result in a variation in the number and intensity of the standing shocks, they would generate an 11-year modulation of the cosmic radiation in the solar system.

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