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Cosmic Ray Observations in 1964-1965 with Mariner IV*

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ABSTRACT

The University of Iowa equipment on Mariner IV, which was launched towards Mars on 28 November 1964, consists in part of two thin window GM tubes sensitive to electrons of $E_e \gtrsim 40$ keV (Det B) and $E_e \gtrsim 45$ keV (Det A), and a shielded GM tube (Det C) sensitive to electrons of $E_e > 150$ keV and having a threshold of ~ 55 MeV for omnidirectional protons. Observations over the period 28 November 1964 to 30 September 1965 have shown the following: (a) Electrons in the energy range $0.40 \leq E_e < 150$ keV were present in the interplanetary medium prior to day 12, 1965 with intensities of ~ 0.5 $(cm^2 \text{ sec sr})^{-1}$. (b) The interplanetary cosmic ray gradient for protons of $E_p \gtrsim 430$ MeV was less than 3 per cent per AU and that the data are consistent with zero gradient. (c) There are large changes in the intensities of protons of $E_p \gtrsim 55$ MeV, but the direction and magnitude of the gradient for such protons were uncertain during solar minimum. The implications of these results are discussed.

Introduction

The Mariner IV spacecraft was launched on 28 November 1964 into an orbit calculated to produce a close approach to the planet Mars on 15 July 1965. The University of Iowa package of particle detectors on Mariner IV has previously been described in detail [Van Allen and Krimigis, 1965] [Krimigis and Armstrong, 1966]. Briefly, it consists in part of three end-window type GM tubes having electron energy thresholds of 40 keV (Detector B), 45 keV (Detector A), and 150 keV (Detector C) for particles entering through their collimators. The corresponding proton energy thresholds are 0.55 MeV, 0.67 MeV, and 3.1 MeV, respectively. Their omnidirectional characteristics are essentially identical with an effective threshold of ~ 55 MeV for protons. In addition to the GM tubes there is a thin (~ 35 microns) surface barrier solid state detector responding to protons in the energy ranges $0.50 \leq E_p \leq 11$ MeV (Detector D_1) and $0.88 \leq E_p \leq 4$ MeV (Detector D_2) and insensitive to electrons of any energy. Each of the five detectors has a conical collimator with a full vertex angle of 60°.

The detectors relevant to the present investigation are the three GM tubes, namely, A, B, and C. During the period of observations reported herein, detectors A and B responded to on day 8 and ended on day 12 [Krimigis and Van Allen, 1966]. Since the omnidirectional characteristics of detectors A, B, and C are identical, one must conclude that the decrease in the counting rates of A and B is due to the decrease in intensity of some component of radiation that can penetrate the thin windows of A and B, but not the shielded window of C. We are thus limited to the following types of radiation: (1) Protons in the energy range $0.55 \leq E_p < 3.1$ MeV; (2) x-rays in the range 2-12 Å; and (3) electrons in the energy range $0.40 \leq E_e < 150$ keV. We can eliminate (1) by noting that detector D_1, sensitive to protons in the interval $0.5 \leq E_p \leq 11$ MeV, did not show the presence of protons prior to day 8 [Krimigis and Van Allen, 1966]. Alternative (2) is unlikely, on the grounds that detectors A and B are pointing at different parts of the sky and, since the spacecraft roll is slow in celestial coordinates, could not both observe intensity fluctuations of some unknown x-ray source. We are thus led to alternative (3), namely that electrons in the range $0.40 \leq E_e < 150$ keV were present in the interplanetary medium prior to day 8, and the counting rates of detectors A and B decreased by 3% and 5%, respectively, after day 12. The change in the rate of detector B corresponds to an electron flux of 0.55 ± 0.05 $(cm^2 \text{ sec sr})^{-1}$ and that of detector A to 0.45 ± 0.05 $(cm^2 \text{ sec sr})^{-1}$. This apparent modulation of 40 keV electrons is reminiscent of the modulation of the 3 to 12 MeV electrons observed by Cline et al. [1964]. It is noted that on day 12 the component of the interplanetary spiral field changed its direction from negative (pointing towards the sun) to positive (pointing away from the sun) [Coleman et al., 1967], and that the intensity was modulated by the sector structure of the field since the appearance of electrons on day 340. Thus it appears that these electrons are of solar rather than galactic origin.

(b) Time Variations in Counting Rates of Detectors A and B.

The counting rates of A and B have shown short-term increases, corresponding to several proton and electron events, which have been discussed elsewhere [Krimigis and Van Allen, 1966; Van Allen and Krimigis, 1965]. In addition, there is a monotonic decrease in the background counting rate of detector A of ~ 15% from day 333, 1964 to day 374, 1965. This decrease was expected from the preflight temperature calibrations of A; the temperature of the instrument changed from approximately 29° C on day 334, to 9° C on day 374, 1965. It is noted that no monotonic decrease is observed in the counting rates of detectors B and C over the same period; this is also consistent with the preflight calibrations of these detectors, which show that the change in the counting rate over the temperature range quoted is less than one percent.

(c) Comparison of C and the Neutron Monitor.

The counting rate of detector C shows a correspondence in <u>detail</u> to the counting rate of the neutron monitor, from day 333, 1964 to approximately day 150, 1965. Beyond day 150, the correspondence in detail between the two detectors is not as pronounced. The ratio of the counting rate of C to that of the neutron monitor appears to be approximately constant up to day 150 and then gradually declines to a new constant value beyond day 200. In order to investigate the possible variation of the counting rate of C with heliocentric radial distance we show in Figure 2 the five day averages of the counting rates of C and the neutron monitor (the solar proton data have been excluded) along with the difference in heliocentric radial distance between the orbit of the earth and the position of Mariner IV. The observations have been divided into four periods as indicated in the figure. We observe the following.

(1) During period 1 the counting rates of C and the neutron monitor showed no change. The correlation coefficient between the respective rates is 0.65.

(2) During period 2 the counting rate of the neutron monitor increased by ~ 1.8%, while that of C increased by a maximum of 2.7% (shown by the dashed line of maximum slope consistent with the data). It is noted that a line with zero slope would also be consistent with the data. The correlation coefficient between the counting rates of C and the neutron monitor is 0.58.

(3) Period 3 shows a decrease of 7.5% in the counting rate of C and of 2.1% in the counting rate of the neutron

monitor. It is suggested that the proton energy spectrum may be changing during this period. The correlation coefficient was found to be 0.87.

(4) The counting rates of C and the neutron monitor showed no appreciable change during period 4. The correlation coefficient in this case was calculated to be 0.52.

The cutoff rigidity of the Deep River neutron monitor is 1.02 BV [Webber, 1962] corresponding to a proton energy of 430 Mev, whereas the omnidirectional threshold of detector C for protons is 55 MeV. Although the two detectors do not respond to particles of the same energy they may still be compared if the assumption is made that the energy spectrum stays constant or becomes softer during a given period of observation. Thus, detector C would be expected to see an equal or greater increase than the neutron monitor, if the above assumption is valid, as appears to be the case during period 2. We conclude from observation (2) above that the gradient for protons of $E_p \gtrsim 430$ MeV is less than 3 per cent per A.U. and that the data are consistent with a zero gradient. It is noted that this upper limit may be reduced even further by observing that a 1% increase in the neutron monitor counting rate corresponds to ~ 2.5% increase in the rate of Det C.

(d) Comparison of C with Injun IV.

A radiation detector with spectral sensitivity similar to that of C [Krimigis and Van Allen, 1967] was in operation on the

University of Iowa, polar-orbiting Injun IV satellite. The counting rate of the 112 GM tube was averaged over that period of time when the satellite passed over the earth's polar caps. The daily averages are shown in Figure 3. Data from two additional GM tubes with similar thersholds on the same satellite, a 302 and a 213 SpB, are shown for comparison. The counting rates of C and of the neutron monitor are also included. Neglecting the period when the satellite was tumbling irregularly, and carrying out an analysis similar to that in (c) above we find the following:

(1) The counting rate of the 112 GM tube increased by $\sim$ 15% from day 60 to day 130, while that of detector C increased by a maximum of 2.4%. The correlation coefficient during this period is found to be 0.23.

(2) The counting rate of the 112 decreased by $\sim$ 18% from day 130 to day 200, while that of detector C decreased by $\sim$ 7.5%. The correlation coefficient during this period was calculated to be 0.71.

We conclude from the above that for $E_p \gtrsim 55$ MeV, the period from day 60 to day 130 indicates a large (150 per cent/A.U.) negative gradient, while the period from day 130 to day 200 indicates an equally large positive gradient. It is noted that the counting rates of the Injun IV detectors have not as yet been corrected for the albedo contribution and thus the result for the gradient for protons of $E_p \gtrsim 55$ MeV is considered tentative and is not emphasized in the present study.

Conclusions

We have shown that

(a) Electrons in the energy range of $40 \leq E_e < 150$ keV were present in the interplanetary medium in intensities of the order 0.5 $(cm^2 \text{ sec sr})^{-1}$, prior to day 12, 1965.

(b) The interplanetary cosmic ray gradient for protons of $E_p \gtrsim 430$ MeV is < 3%/A.U. The data are consistent with zero gradient. This result is in apparent disagreement with the results of O'Gallagher and Simpson [1967].

(c) There are large changes in the intensities of protons of $E_p \gtrsim 55$ MeV, but the direction and magnitude of the gradient are uncertain during solar minimum.

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FIGURE CAPTIONS

Figure 1. The daily averages of the counting rates of the three GM tubes on Mariner IV. The Deep River neutron monitor rates have been included for comparison. Note the increase in solar activity beginning on day 144, as indicated by detectors A and B.

Figure 2. Five-day averages of the counting rates of detector C and the Deep River neutron monitor. ΔR represents the heliocentric radial distance between the orbit of earth and the Mariner IV spacecraft.

Figure 3. Similar to Figure 1 but with the Injun IV detectors included. The black dots indicate the counting rate of the SpB GM tube and the open triangles, the rate of the 302 GM tube.

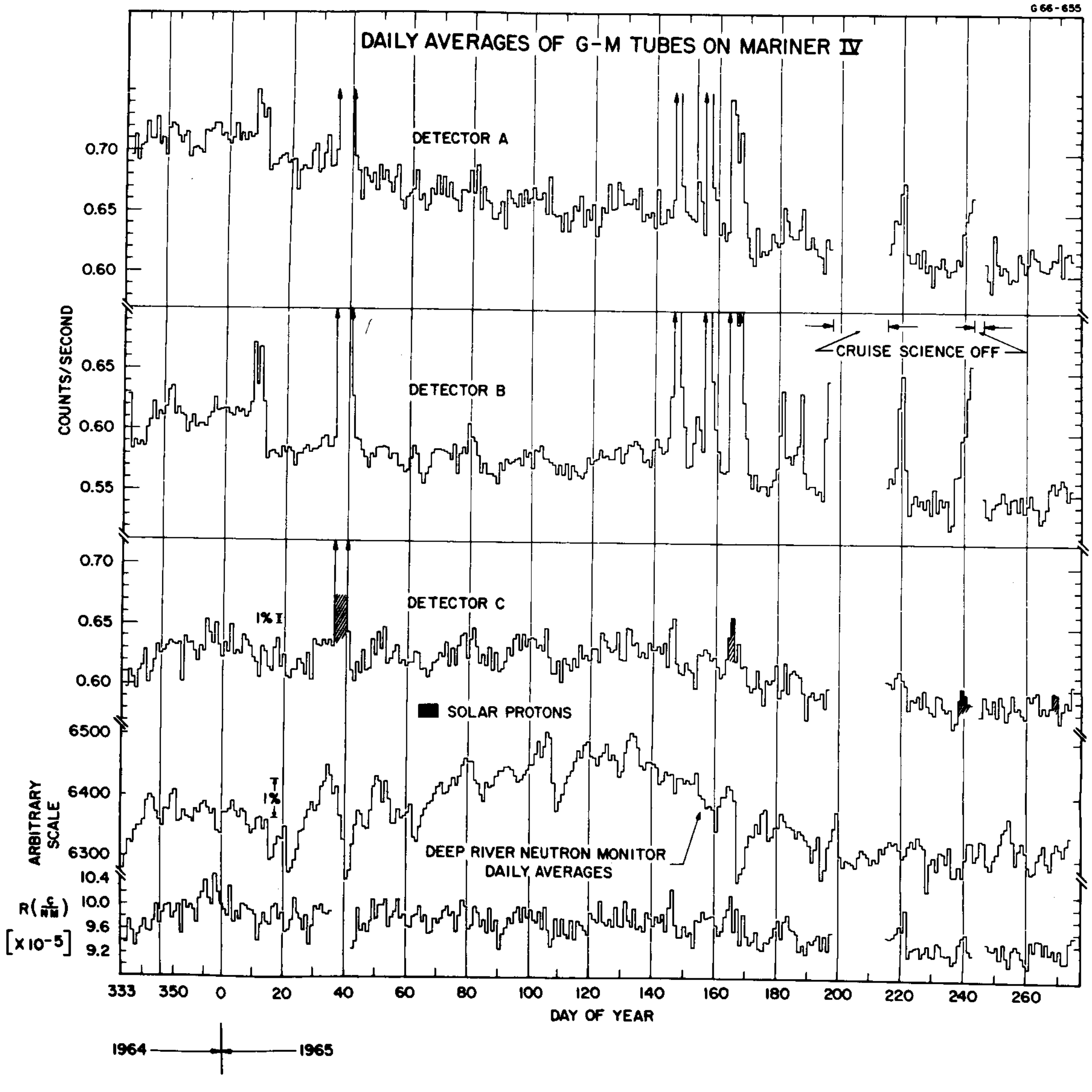
G66-655
DAILY AVERAGES OF G-M TUBES ON MARINER IV
DETECTOR A
DETECTOR B
DETECTOR C
CRUISE SCIENCE OFF
1% I
SOLAR PROTONS
DEEP RIVER NEUTRON MONITOR
DAILY AVERAGES
COUNTS/SECOND
ARBITRARY SCALE
R(C/NM)
[X10-5]
0.70
0.65
0.60
0.55
6500
6400
6300
10.4
10.0
9.6
9.2
333
350
0
20
40
60
80
100
120
140
160
180
200
220
240
260
DAY OF YEAR
1964
1965

Figure 1

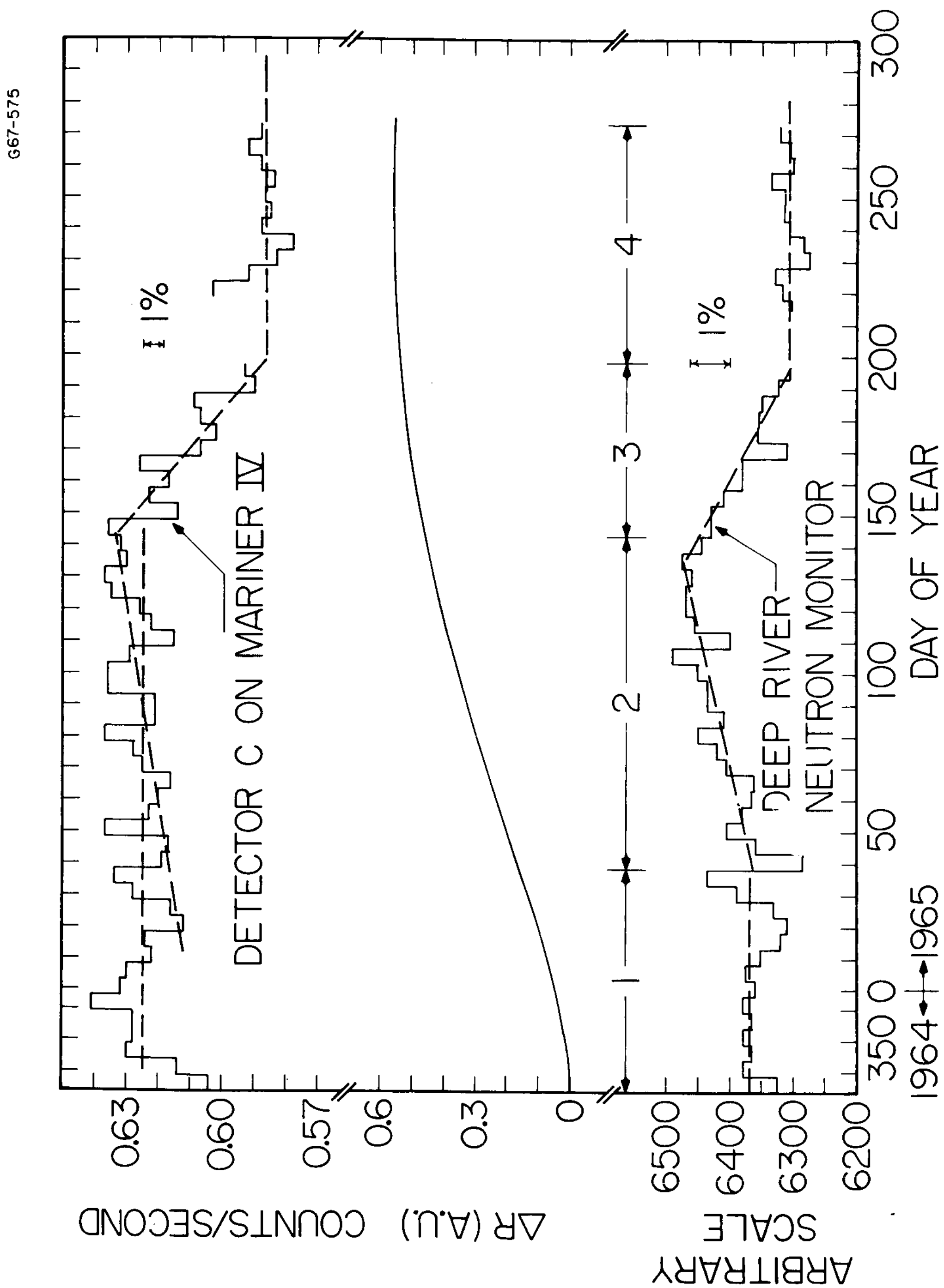
G67-575
DETECTOR C ON MARINER IV
DEEP RIVER
NEUTRON MONITOR
1%
1%
1
2
3
4
COUNTS/SECOND
ΔR (A.U.)
ARBITRARY SCALE
0.63
0.60
0.57
0.6
0.3
0
6500
6400
6300
6200
350
0
50
100
150
200
250
300
1964
1965
DAY OF YEAR

Figure 2

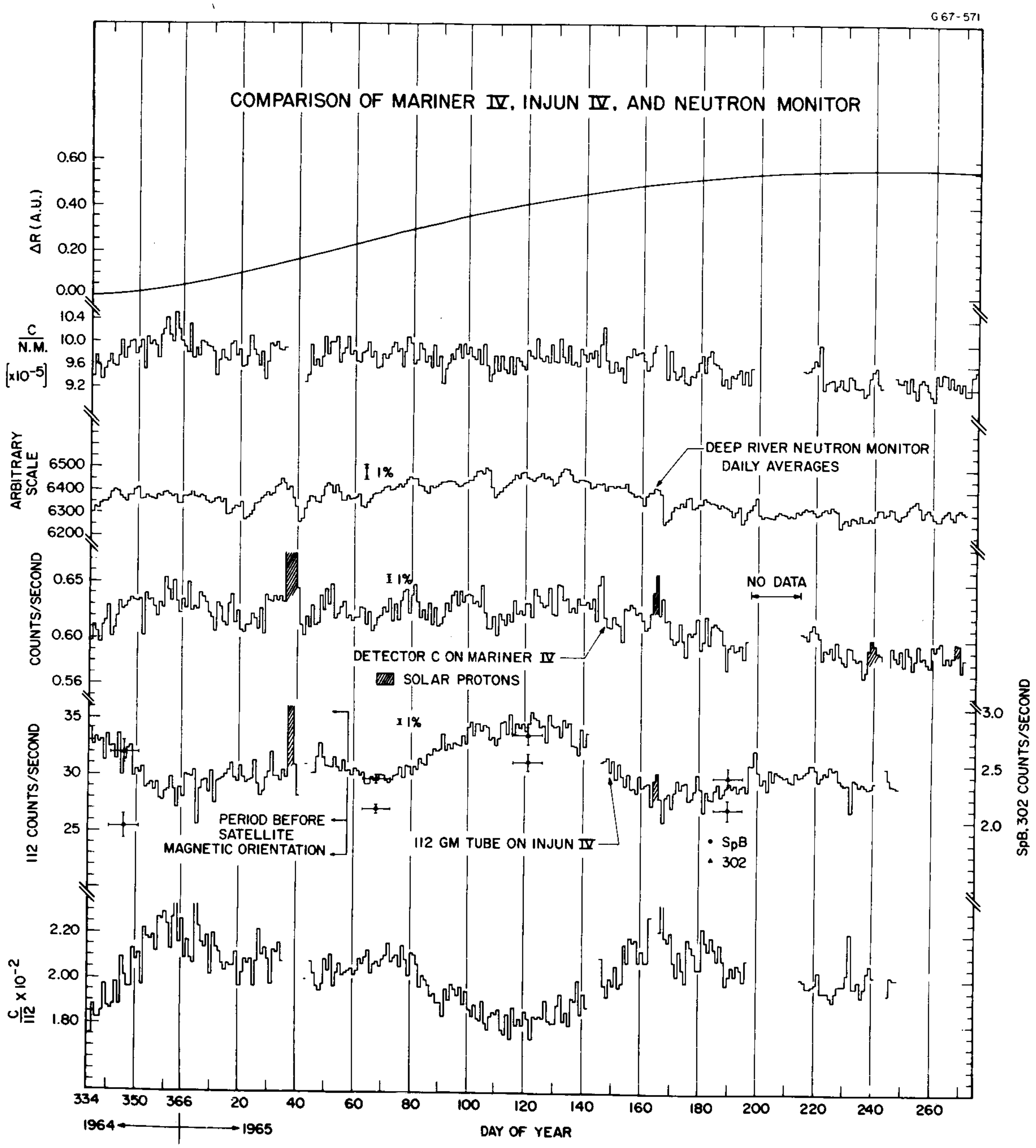
G 67-571
COMPARISON OF MARINER IV, INJUN IV, AND NEUTRON MONITOR
ΔR (A.U.)
0.60
0.40
0.20
0.00
C / N.M. [x10^-5]
10.4
10.0
9.6
9.2
ARBITRARY SCALE
6500
6400
6300
6200
DEEP RIVER NEUTRON MONITOR
DAILY AVERAGES
I 1%
COUNTS/SECOND
0.65
0.60
0.56
NO DATA
DETECTOR C ON MARINER IV
SOLAR PROTONS
112 COUNTS/SECOND
35
30
25
PERIOD BEFORE
SATELLITE
MAGNETIC ORIENTATION
112 GM TUBE ON INJUN IV
• SpB
▲ 302
SpB, 302 COUNTS/SECOND
3.0
2.5
2.0
C/112 x 10^-2
2.20
2.00
1.80
334 350 366 20 40 60 80 100 120 140 160 180 200 220 240 260
1964 ← → 1965
DAY OF YEAR

Figure 3