Search for Solar Neutrons using the Bonner Ball Neutron Detector on the ISS

H. Matsumoto, K. Koga, H. Koshiishi, T. Goka, and Y. Muraki[1)]

Abstract— **The Bonner Ball Neutron Detector was launched on March 8, 2001 by the space shuttle STS-102 mission to measure the neutron environment inside the residential area of the International Space Station. The BBND measured conditions during large solar flares in April, August, and October of 2001. The authors sought the signal of solar neutrons. However on April 15, 2001, the ISS passed over the SAA during the arrival time of solar neutrons. Because of strong background radiation, the BBND did not detect a clear signal of neutrons in association with this flare. However, the BBND detected increased neutron flux in the space station in association with GLE that arrived 20 min after the impulsive flare.**

1. BONNER BALL NEUTRON DETECTOR

The Bonner Ball Neutron Detector (BBND) measures low-energy neutrons. The BBND is often used at beam extraction areas of accelerators for radiation monitoring the experimental hall. The BBND is a Bonner Ball-type detector with six ^{3}He-proportional counters covered with neutron moderators of various thicknesses. The ^{3}He proportional counter detects neutrons according to nuclear reactions between ^{3}He and thermal neutrons ($^3\mathrm{He} + \mathrm{n} \rightarrow {}^1\mathrm{H} + {}^3\mathrm{H} + 765$ keV).

2.BBND ONBAORD THE ISS

Bonner Ball Neutron Detectors of six different types were prepared for measurement of the radiation environment inside the International Space Station (ISS). They are presented in Figure 1. Sizes of the polyethylene spheres of the counters are the following: S1 has 51 mm diameter; S2 is 51 mm with the gadolinium shield; S3 is 81 mm with the gadolinium shield; S4 is 110 mm; S5 is 150 mm; and S6 is 230 mm. Detectors of six different types were used to provide uniform detection efficiency for a wide band of neutron energies. The energy resolution of each BBND is not sharp, but the detection of neutrons in a wide band of energy is guaranteed. For example, the S6 detector is the largest, with the highest sensitivity to neutrons, at around 2 MeV. Its high sensitivity extends almost uniformly throughout the energy range of 0.2–10 MeV.

The BBND system's total weight is about 40 kg. The system was launched by the space shuttle STS-102 on March 8, 2001. Data of the space environment were taken during March 23 – November 14, 2001 on this flight. Major results have been published elsewhere [1, 2]. Herein, we present additional results obtained through analysis of the effect of large solar flares on the ISS environment.

3. EFFECT OF SOLAR FLARES MEASURED BY THE BBND

Several large solar flares were observed during the flight [3]. Major flares were observed in April, August, and November of 2001. Especially for the flares of April 15 [4, 5] and August 25 [6] of 2001, solar neutrons were observed using ground level neutron detectors. Therefore, although we sought a signal of solar neutrons in the present data, no clear signal of solar neutrons coinciding with the observed signals by ground-based solar neutron detector was found in the data. For that reason, we first discuss why the BBND detected no clear signal of solar neutrons. Then we introduce an interesting new result.

On April 15, 2001, the neutron monitor located at Mt. Chacaltaya cosmic ray observatory in Bolivia (5,250 m altitude) detected 6,000 solar neutron events during 13:51UT–14:00UT [5]. The signal was detected by a 12 m^2 neutron monitor. Its detection efficiency was about 30% and its neutron intensity was reduced about one-third by absorption in the atmosphere. For that reason, we use a multiplicative factor of 10 when we convert it to the value at the top of the atmosphere. The solar neutron energy was $E_n \geq 100$ MeV. Therefore, the flux per unit area in a unit time at the top of the atmosphere over Chacaltaya with $E_n \geq 100$ MeV is about 0.055 events/s/cm^2 [= (6,000/9 min/12 m^2) × 10 = 550 events /s/m^2 = 5.5 × 10^{-2}/s/cm^2].

The BBND S6 counter has no sensitivity for solar neutrons with energy higher than $E_n \geq 100$ MeV [7]. However, the S6 counter has sensitivity for neutrons with E_n <50 MeV with low detection efficiency. On the other hand, low-energy neutrons of less than $E_n \leq 10$ MeV decay during their flight from the Sun to the Earth. Taking account of these effects, it seems appropriate to assume that the flux of solar neutrons at the top of the atmosphere with energy $E_n \geq 50$ MeV is about 0.11 events/s/cm^2 or 6.6 events/min/ cm^2.

On the other hand, the background is estimated using the actual data. Typical counting rates of the BBND S6 detector at higher latitudes, over the Equator, and above the South Atlantic

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Anomaly (SAA) were, respectively, 800 counts/min, 200 counts/min, and 10,000 counts/min as presented in Figure 2a. It is worthwhile to consider signals that are greater than three times the background fluctuation. Therefore, we set discriminating thresholds for signals to the counting rate of the BBND as 84 counts/min, 42 counts/min, and 300 counts/min, respectively. The acceptance of the BBND S6 detector has total area of 390 cm^2; however, the effective area can be estimated as 200 cm^2 for a region with sufficient thickness to incoming neutrons. Consequently, the expected counting rate of solar neutrons for the S6 detector in the flare of April 15, 2001 is approximately 22 events/s or 1,320 events/min. The detection efficiency of the BBND for a single neutron is not given, but it would be natural to use the value of the neutron monitor at lower energies. Here, we assumed it as 10%. The expected counting rate would then be 130 events/min for the S6 detector around the neutron arrival time, 13:51UT–14:00UT. Unfortunately, the BBND flew over the SAA at just that time. Consequently, the background is 2.3 times higher than the 3σ value of the background fluctuation. For that reason, the BBND was unable to identify the excess because of solar neutrons.

4. Excess of Events Immediately After the GLE

However, the BBND detected an excess of the counting rate after an impulsive flare occurred between 13:40UT to 13:51UT on April 15, 2001. The excess was detected neither in the region over the SAA nor over the Equator, but it was seen at high latitudes either near 52°N or near 52°S. The result is portrayed in Fig. 2. Figure 2a presents the counting rate of the BBND S6 detector during 11:00UT–16:00UT on April 15, 2001, although Fig. 2b represents the same plot for different observation times during 13:00–18:00 UT. The excess of 13:56UT was produced when the ISS passed through the SAA. Figure 3 depicts the trajectory of the ISS around the same duration. Figure 4 represents the arrival time distribution of Solar Energetic Particles (SEP) observed by the GOES satellite [8]. The flare occurred near the west limb so that the SEP arrived soon after the impulsive flare (about 20 min later than the impulsive flare) because the interplanetary magnetic field is connected with the Earth. These Solar Energetic Particles entered the polar region. Neutrons produced by the SEP were detected by the BBND onboard the ISS when the ISS passed over polar regions.

The effect of the increase was about twice that of the background. The background is made by the Galactic Cosmic Rays (GCR); its flux is usually about 800/min at this time. The duration of April–October, 2001 corresponds to the solar maximum. Therefore, the amount of GCR to the Earth is smaller than that of the solar quiet time. In general, in the case of the high activity of the Sun, a high intensity of neutrons (ratio produced by the SEP/produced by GCR) in the ISS is expected in comparison with the quiet time. Therefore, the detection of solar neutron events is expected to be easier during the high solar activity time.

5. Conclusion

We sought signals of solar neutrons in association with large solar flare that occurred on April 15, 2001 by the BBND on board the ISS residential area. However, the ISS passed over the SAA just during the solar neutrons' arrival time. Because of strong background, the BBND detected no clear signal of solar neutrons in association with this flare. Instead, the BBND detected an increase of neutron flux in the space station in association with the GLE that arrived 20 min after the impulsive flare. The flux of neutrons induced by these GLE particles was of about the same order as the background.

Acknowledgment

The authors thank all the members of Space Shuttle-Mir 8 (S/MM-8, STS-89), STS-102 and the mission operations teams of NASA and NASDA (former JAXA).

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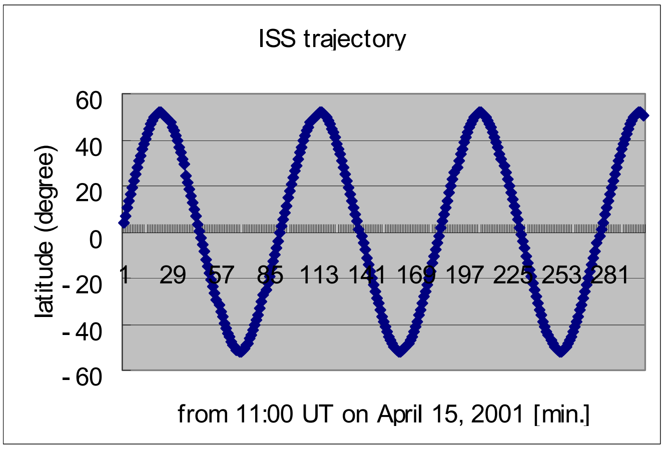
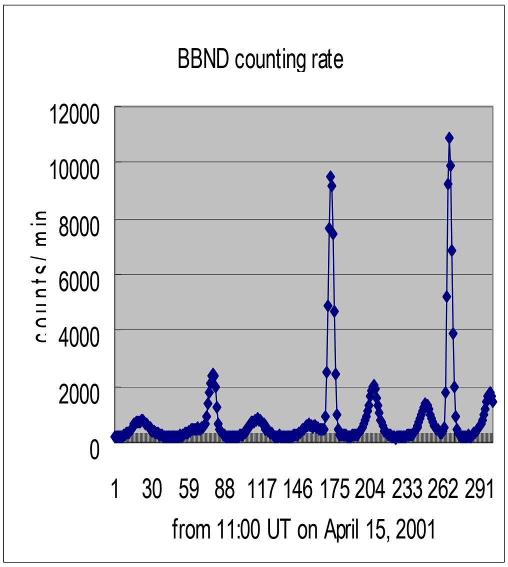


Figure. 3 The trajectory of the ISS is shown as the functions of the latitude and the flight time since 11:00UT of April 15, 2001. The duration 13:51-14:00UT corresponds to the minutes in the figure at 171-180



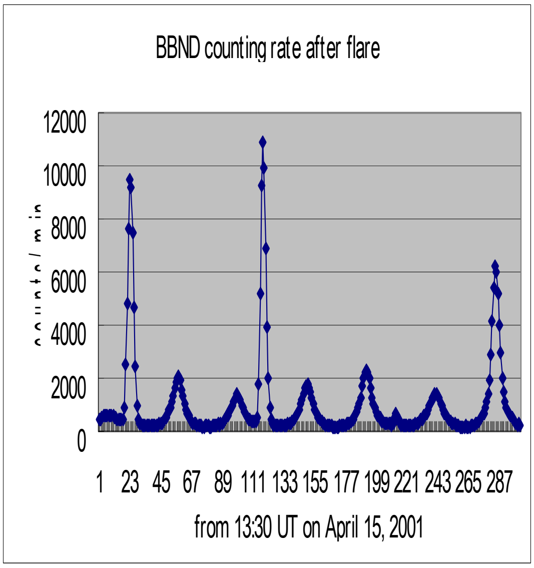


Figure 2a. The two sharp peaks at 175 and 262 were caused by the South Atlantic Anomaly. After the arrival of high energy solar particles (after 204), the intensity of neutrons increased when the ISS approached polar regions.

Figure 2b. The first peak from the left (at 23) was caused by the SAA. Around the time (20-30) solar neutrons were detected by the Chacaltaya neutron monitor.

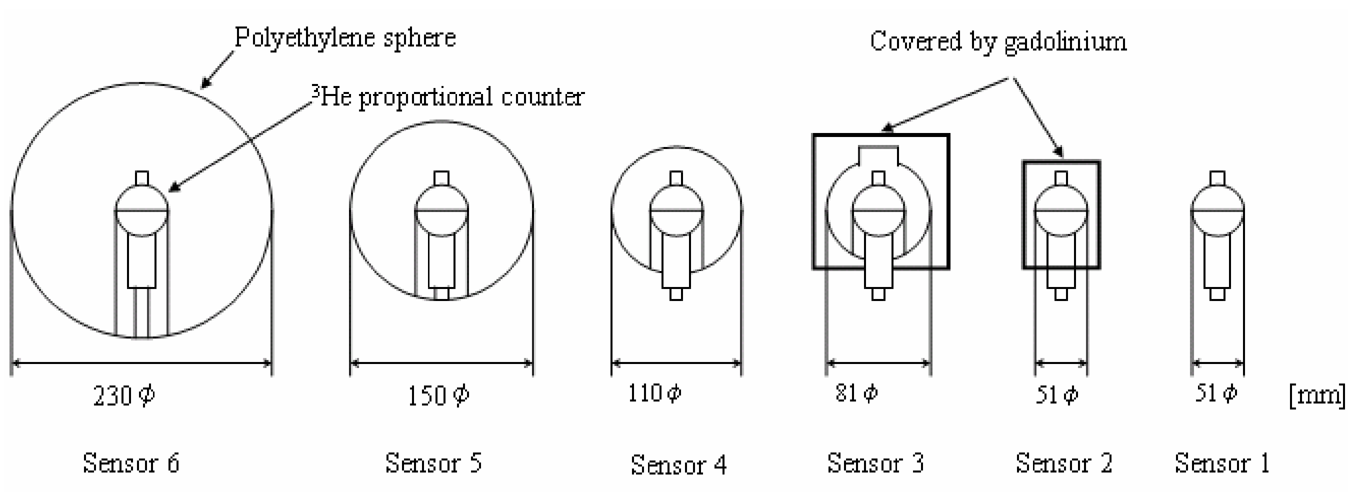


Figure 1. The six Bonner Ball Neutron Detectors were launched on the International Space Station. The sensor S6 is the largest detector, with the highest sensitivity to neutrons, at around 2 MeV. Its sensitivity extends almost uniformly throughout the energy range of 0.2–10 MeV.

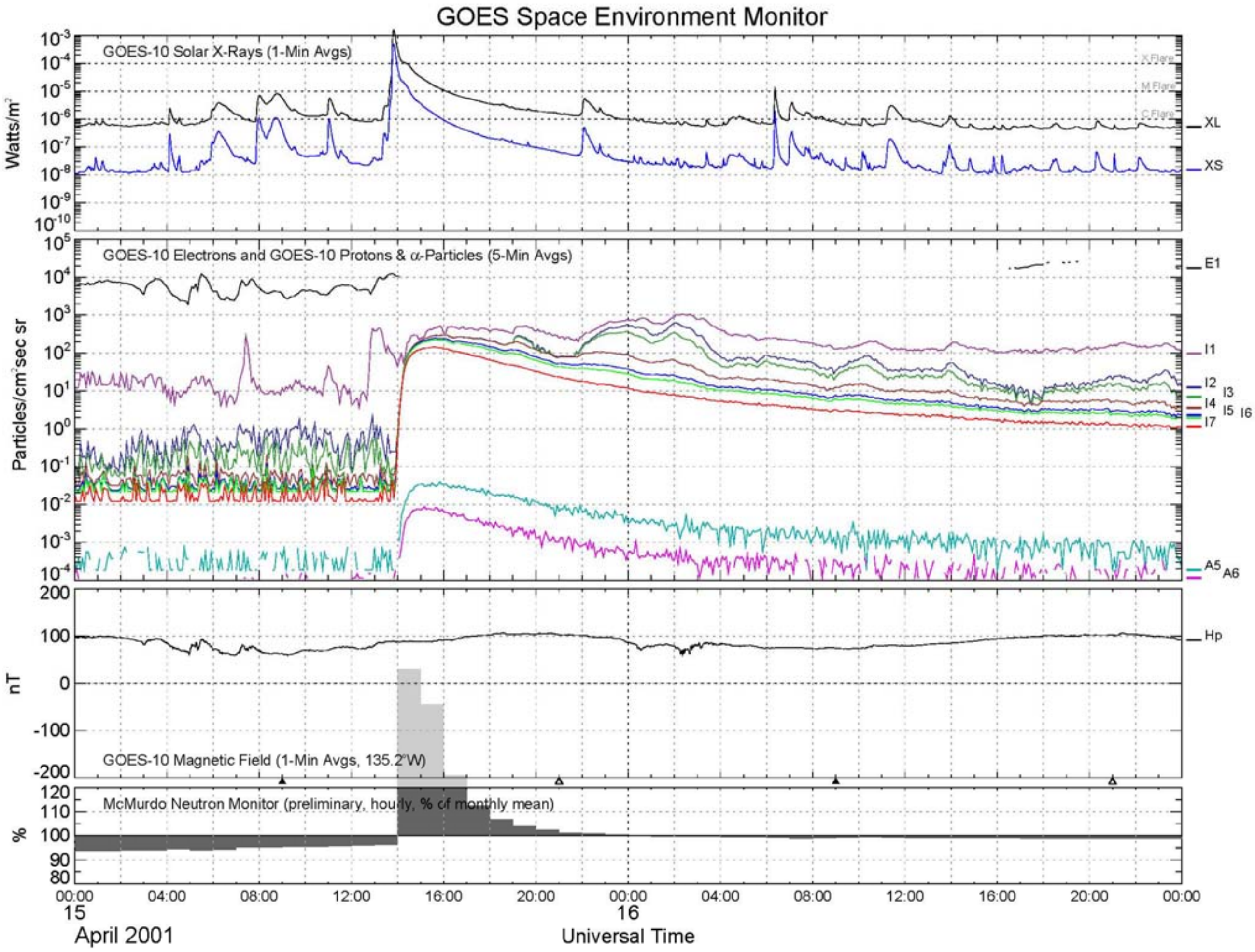


Figure 4. The GOES data of April 15-16, 2001.
The top panel shows the X-ray data. The impulsive gamma-ray flare was observed during 13:40-13:51UT by the Tohkoh satellite. Solar neutrons were detected at Chacaltaya during 13:51-14:00UT and Solar Energetic Particles arrived after 14:00UT (the second panel). The bottom panel shows the Ground Level Enhancement (GLE) was observed by the neutron monitor at McMurdo. (http://goes.ngdc.noaa.gov/data/plots/2001/GOES-200104.pdf)