# NEUTRON MONITOR DATA ON THE 15 JUNE 1991 FLARE: NEUTRONS AS A TEST FOR PROTON ACCELERATION SCENARIO

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ABSTRACT. Response of Alma-Ata neutron monitor for solar neutrons from the 15 June 1991 was studied. We considered this response as a test for various scenarios of proton acceleration during the flare. The analysis of neutron monitor is an evidence in favour of the assumption of two acts of proton acceleration at impulsive and post-impulsive phases of the flare.

## 1.INTRODUCTION

High energy γ-ray emission of unusual long duration was observed by the GAMMA-1 telescope during the 15 June 1991 solar flare (Akimov et al.,1991; Leikov et al.,1993). This emission is considered as a signature of nuclear interaction of high energy protons in the solar atmosphere because π-decay is that which can be the source of such γ-rays. Unfortunately, the GAMMA-1 solar observations began about 20 minutes after the impulsive phase of the flare only (see Figure 1). There was no observation of γ-rays from the impulsive phase of this flare. This fact makes interpretation of the data quite difficult. Two possibilities were discussed. The first one is the only act of proton acceleration at the impulsive phase followed by long-time trapping of those protons in a magnetic loop (Kocharov et al., 1991; Mandzhavidze et al.,1993). Another possibility is that the observed γ-ray emission was originated from high energy proton accelerated at the post-impulsive phase of the flare (Kocharov *et al.*, 1994; Akimov *et al.*,1995). Prolonged microwave and other activities of this flare are considered as an evidence of the second scenario. At the same time, the fact that time profiles of microwave and high-energy γ-ray emission coincided at the post-impulsive phase could be an argument for electron bremsstrahlung origin of this flare γ-emission (such a possibility has been considered among a number of alternatives by Kocharov *et al.*, 1991). Thus, an additional independent information is necessary for reconstruction of high energy proton acceleration scenario for the 15 June 1991 flare. High-energy (>100 MeV) neutrons are produced simultaneously with π-decay originated γ-rays in the solar atmosphere during solar flares. Detection of such neutrons by means of ground-based neutron monitors could provide the necessary information on acceleration processes.

## 2.SOLAR NEUTRONS RECORDED BY ALMA-ATA NEUTRON MONITOR.

Response of a neutron monitor for solar neutrons is high for high monitor altitude and small solar zenith angle. Alma-Ata monitor (18NM64 at 3340 m above the sea-level) was in the best position (solar zenith angle of 28°) of all the neutron monitors for

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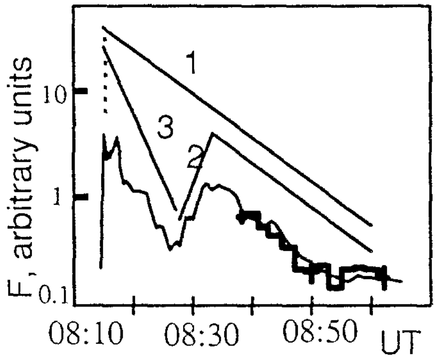


Fig.1. Time profiles of 9.1 GHz radio- (Curve) and high energy $\gamma$-ray emission (histogram) and suggested function of neutron production (lines) during the 15 June 1991 solar flare. Neutron production function: 1 - the only act of proton acceleration followed by trapping; 2 - proton acceleration at the post-impulsive phase of the flare; 3 - proton acceleration at the impulsive phase.

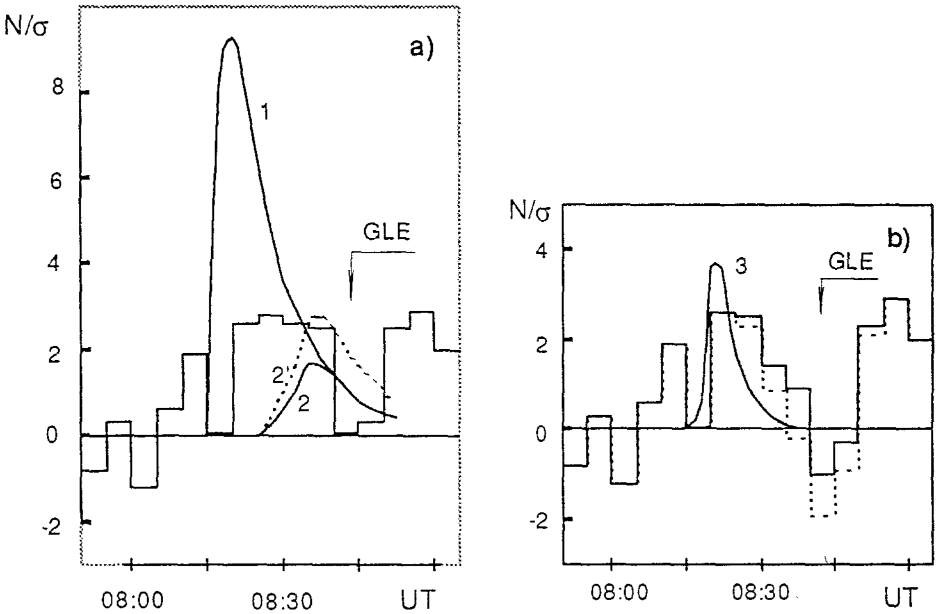


Fig.2. Detected ( the histogram a) ) and calculated (curves) response of Alma-Ata neutron monitor for neutrons from the 15 June 1991 solar flare. The histogram b) is the rest of the detected response when the calculated one (Curve 2 or 2' in Fig.2a) is subtracted. Numbers of curves correspond to numbers for the neutron production function in Fig.1.

detection of solar neutrons from the 15.06.1991 flare. High vertical geomagnetic cut-off rigidity of Alma-Ata monitor (6.7 GV) depresses significantly influence of solar cosmic rays which were the source of the GLE observed by the world neutron monitor network. Response (with background subtracted) of the neutron monitor during the flare is shown in Figure 2a. We made use of original Alma-Ata monitor count rate received from the World Data Center. The averaged over 07:00-08:00 UT time interval count rate was taken as the background. The response is given in units of standard deviation of cosmic ray count rate. According to the neutron monitor network data the onset of the GLE was not earlier than 08:42 UT (Shea M.A. and Smart D.F., private communication) which is shown in Figure 2 with the arrows. There are four 5-minutes increases in Alma-Ata monitor count rate before the GLE onset. Significance of each of them was of $\approx$2.5 standard deviations. The probability of statistical artifact of the whole 20 minutes increase is negligible. Thus, the increase at 08:20-08:40 UT could be caused by solar neutrons. In such a case the total number of neutrons (>300 MeV) injected from the Sun towards the Earth could be estimated as about $3\times10^{27}$ $sr^{-1}$ which is $\approx$6 times smaller then for well studied 3 June 1982 solar neutron event (Chupp *et al.*,1987). No one of neutron monitor but Alma-Ata could not detect neutrons from such a weak event at that time. Actually, data of other monitors did demonstrate absence of significant increase at due time. This fact is in accordance with the assumption of solar neutron origin of Alma-Ata monitor count rate increase.

## 3.DISCUSSION

We made use of Alma-Ata monitor data as a test for various scenarios of proton acceleration during the 15 June 1991 flare. We calculated the response of Alma-Ata monitor for solar neutrons by the technique described earlier (Kocharov *et al.*,1994a). Spectra of neutrons were calculated under the assumption of their isotropic generation at the Sun (see Gueglenko *et al.*, 1990). The spectrum of the primary protons in the flare site was taken as it was reconstructed from $\gamma$-ray observations at the post-impulsive phase by Kocharov *et al.* (1994) and by Mandzhavidze *et al.*(1993). There is some ambiguity of reported flux of $\gamma$-rays <100 MeV and that results in differences in the primary proton spectrum reconstructed by different authors. We took this fact into account.

We checked at first the assumption on the only act of proton acceleration at the impulsive phase of the flare followed by trapping. In this model the neutron production function must decay in time exponentially as it is shown in Figure 1 (Curve 1). The decay time corresponds to the observed $\gamma$-ray time profile. The spectral characteristics of the accelerated protons were extrapolated from the post-impulsive phase upon the whole duration of the flare. Curve 1 in Figure 2a is Alma-Ata response calculated under this assumption for the primary proton spectrum according to Mandzhavidze et al. (1993). One can see that it is dramatically higher than the observed one. Thus, we conclude that the trapping model contradicts the recorded data.

Next step was the suggestion that neutrons were produced at the post-impulsive phase only, and the time profile of their generation generally corresponded to time profiles of microwave and $\gamma$-ray emissions (see Curve 2 in Figure 1). Calculated response of the monitor is shown as Curves 2 and 2' in Figure 2a. Curves 2 and 2' were calculated for the primary proton spectra reconstructed by Mandzhavidze *et al.*(1993) and Kocharov *et al.* (1994). One can see that the calculated response is reasonable in comparison with the observed one at 08:30-08:40 UT for the primary proton spectrum obtained by Kocharov *et al.* (1994) as well as for one by Mandzhavidze *et al.* (1993). However, there is a rest of count rate at 08:20-08:30 UT (see Figure 2b).

We consider this rest to be caused by neutrons produced at the impulsive phase of the flare. We calculated expected response of the monitor for those neutrons under the assumption that the neutron spectrum was $N(E)\sim exp(-E/E_0)$. We suggested that the temporal behaviour of the neutron production function at the impulsive phase followed the time profile of microwave radio-emission (see Curve 3 in Figure 1). The calculated response fits the rest of recorded Alma-Ata count rate when the neutron spectrum is soft enough ( $E_0<100$ MeV ) because there was no significant response during 08:15-08:20 UT interval. The total number of the neutrons injected from the Sun during the impulsive phase was $N(>300\ \mathrm{MeV})=(0.5\div2.0)\times10^{27}\ \mathrm{sr}^{-1}$. For instance, Curve 3 in Figure 2b shows the calculated response for $E_0=50$ MeV and $N(>300\ \mathrm{MeV})=1.0\times10^{27}\ \mathrm{sr}^{-1}$.

## 4.CONCLUSION

The total response of Alma-Ata neutron monitor for solar neutrons (08:15-08:40 UT) from the 15 June 1991 solar flare can be explained under the assumption of two acts of neutron production at impulsive and post-impulsive phases of the flare. These acts correspond to two acts of proton acceleration. The first acceleration act took place at ≈08:15 UT and the spectrum of the primary protons was rather soft. The second acceleration act was at the post-impulsive phase of the flare as it was proposed earlier (Kocharov *et al.*,1994). It is interesting to note that the spectrum of protons accelerated during the impulsive phase of the 1991 June 15 flare turned out to be rather similar to the spectrum which was discovered recently (Kocharov *et al.* 1994a) for protons accelerated in the beginning of the 1990 May 24 flare. Thus, in comparison with the 24.05.1990 flare the 15.06.1991 flare demonstrated presence of additional acceleration of high-energy protons at the post-impulsive phase. This conclusion is in favour for the idea that a number of acceleration processes may take place. However their relative contribution varies with class of a flare.

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