REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1999	Final Report

4. TITLE AND SUBTITLE

Monitoring and Investigation of Ground Level Solar Cosmic Ray Enhancements by Means of High Altitude Neutron Monitor

5. FUNDING NUMBERS

F617089-98-WE064

6. AUTHOR(S)

Dr. Anatoly V. Belov

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

IZMIRAN
Russian Academy of Sciences (RAS)
Troitsk,P/o 142092, Moscow region
Russia

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SPC 98-4035

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking IZMIRAN as follows: The contractor will investigate high-energy solar neutrons which are produced at solar flare sites. He will improve the registration system of the Alma-Ata neutron monitor and develop methods of reliable selection of the solar neutron events, as well as methods to study high energy solar proton events and calculate their spectra. He will supplement the GLE database existing at the Space Vehicles Directorate of AFRL with the GLE data files from Russian and Kazakh stations.

14. SUBJECT TERMS

EOARD, Solar Physics, Space Science, Cosmic Rays

15. NUMBER OF PAGES

11

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

AQF99-09-1574

FINAL REPORT
for the EOARD/AFMC Contract F617089-98-WE064

"MONITORING AND INVESTIGATION OF GROUND LEVEL SOLAR COSMIC RAY ENHANCEMENTS BY MEANS OF HIGH ALTITUDE NEUTRON MONITOR"

ABSTRACT

This project was directed toward the theoretical and experimental study of the ground-level solar cosmic ray enhancements by neutron monitors. This includes the observation at Earth of high-energy protons and direct relativistic solar neutrons, generated during powerful solar flares. The cosmic ray groups from IZMIRAN (Russia) and Institute of Ionosphere (Kazakhstan) conducted the work. The Alma-Ata high altitude neutron monitor has a favorable location and good data statistics for observations of different cosmic ray effects. However, its registration system did not satisfy modern demands in the year of 1997. Registration system of the Alma-Ata high-altitude neutron monitor was improved. Methods for reliable selection of the solar neutron events among the solar ground-level enhancements as well as a method to study high-energy solar proton events and calculate their spectra were developed. These methods were used for retrospective and current analysis of neutron monitor data. To search the possible solar neutron events we used as a reference frame the catalog of x-ray events registered by the GOES satellites and the available information on the hard x-ray and gamma solar emission obtained aboard the SMM and CGRO satellites. Some particular candidates and the statistics of NM count rate close to onset of energetic solar events are discussed in this report. Besides, we supplemented the extensive GLE data presently existing at the Space Vehicles Directorate of the Air Force Research Laboratory with the GLE data files from Russian and Kazakhstan stations.

1. INTRODUCTION

The observation at the Earth of solar protons and direct relativistic solar neutrons, generated during powerful solar flares (in combination with X-ray and gamma-ray data) allows us to obtain unique information on the Sun's flare process and particle acceleration mechanisms. Solar neutron measurements provide more direct information about the source of acceleration, than proton and electron observations do, and it give the crucial information to test the models of particle acceleration. For instance, solar neutron observations gave the decisive argument for multi-step acceleration mechanisms during the solar flare event. Neutrons may be produced in several episodes of charged particle acceleration, between which particles are mostly trapped.
The special behavior of the neutrons and close tie between the neutrons and gamma radiation allows relatively easy to identify the onset of ground-level neutron events among of the other solar events, observed by neutron monitor network. Relativistic neutrons appear to be generated in majority or perhaps into all powerful solar flares. Thus, relativistic protons (>1 GeV) are generated in powerful flares more often than they are observed at the Earth. High-energy neutrons possible can be detected in many events, which show no measurable proton increase. Sometimes these protons do not pass through the interplanetary medium in the vicinity of the Earth; sometimes they don't leave the area of acceleration. In these cases solar neutron observations are the only source of information about the protons accelerated at the Sun. The identification of the solar neutron enhancement is often difficult, since the galactic cosmic ray variations and solar proton enhancements can overlay them. Therefore, an important part of this work is devoted to developing and improving of reliable methods to discriminate proton and neutron ground-level enhancements. For this purpose a complex database for events under consideration was arranged.

The detection of solar neutrons is mostly probable near local noon at mid- and low-latitude mountain neutron monitors. There are only a few such cosmic ray stations in the world network (about 10), and high mountain (3340 m) neutron monitor at Alma-Ata (Institute of Ionosphere, MN-ANRK) is among those detectors with the best capability to record direct solar neutrons. Table 1 illustrates this fact. In addition, it is the only station with such capability in this longitudinal region. Besides of this unique mountain site and longitudinal location, another major geophysical property make Alma-Ata mostly desirable for these studies. The combination of its geomagnetic cutoff rigidity (6.7 GV) and high altitude makes this station enable to record ground-level enhancements for all those events where maximal rigidity of the protons exceeds the geomagnetic cutoff rigidity. The most relativistic solar proton events have maximal energy of particles close to this cutoff value, so the Alma-Ata station is ideal for detecting upper energy limit in many relativistic proton events. Although recorded magnitudes of ground-level enhancements (GLE) are usually very small at these geomagnetic latitudes the high statistical accuracy of the 18-tube NM-64 Alma-Ata neutron monitor, located at 3340 m altitude, make possible detection of these events at this point. It is very important to estimate the upper energy of particles accelerated in the flare for the studying solar particle spectra and anisotropy. The geomagnetic field does not affect solar neutrons. Solar neutrons with sufficient energy to penetrate through the Earth atmosphere to the detector location will be recorded as a solar neutron event. With the high altitude of the Alma-Ata station, solar neutrons of the energy order of 300 MeV can be detected. Thus, the Alma-Ata station is an essential station to study of the relativistic solar neutron and proton production and transport in the interplanetary medium. Addition of high altitude Alma-Ata station on the world network of solar neutron patrol will greatly assist to scientific community in the study of such events during this solar cycle.

As mentioned above, Alma-Ata cosmic ray observations are the integral part of the solar cosmic ray monitoring. Data from Alma-Ata station, due to its unique location and high statistical accuracy, are of great value for investigation of both solar neutron and solar proton events. However, registration system on this station did not satisfy modern demands in the year of 1997 to obtain and provide the high quality data. So, some modernization of registration system based on the modern computer techniques was essential for Alma-Ata station.

The following technical and research activities were carried out in the frame of the contract:

- Modernization of the registration system at the high mountain Alma-Ata station to provide the continuous monitoring of cosmic ray fluxes in one minute regime of accumulation; modification of the Alma-Ata neutron monitor to measure the distribution of the neutron multiplicity as a function of time.

- Preparation of the new GLE files from Russian and former Soviet Union neutron monitors to augment current data to GLE Database maintained by the Air Force Research Laboratory VSBS personnel.
- Creation of the complex database for selected events, which involves cosmic ray, X- and gamma-ray data; improvement the method for selecting solar neutron and proton events from the background cosmic ray variations and determining of their time profiles by means of this complex database.
- Retrospective and current analysis of the events and relevant data by the improved method.

2. THE ALMA-ATA NM AND ITS NEW REGISTRATION SYSTEM

Our co-investigators from Alma-Ata (Institute of Ionosphere) started modernization of the registration system at the high mountain Alma-Ata station just from the beginning of the contract to provide the continuous monitoring of cosmic ray fluxes in one minute regime of accumulation and to present data in the standard NM format. The modernization includes modification of NM electronics to measure the distribution of the neutron multiplicity as a function of time. At the same time the old system on the mountain Alma-Ata station operated continuously, so the long data set from this neutron monitor was not broken and there was a possibility to record any new ground level enhancement at this point.

During the second step of our Contract the optimal configuration of devices for modernization of the registration system at the high mountain Alma-Ata was developed and accepted. The necessity to protect equipment (in particular, for connection with Internet) against the thunderstorms, which are very strong and frequent at the altitude 3340m, needs a special care. The new registration system will account this problem.

The INTERNET line is now available at the altitude of 3340 m in mountains near Alma-Ata. The server with output to the Internet was equipped and installed there in January 1999. Another computer for the new registration system was installed in the NM building. A cable was buried between the main server and the computer of the registration system. So, the cosmic ray station

Alma-Ata 3340 m is included into the Internet. Data of the Alma-Ata NM are available now by ftp upon request.
The address is: ftp://tien-shan.uni.sci.kz .
Therefore, when the new registration system will operate, it would be possible to present the Alma-Ata NM data on the INTERNET in near real time.
Manufacturing of the special devices for the new registration system is finished and at present time it goes trough attenuation, checking and adjusting to the main detector. Special software is developing to transfer current data from the new registration system to the main server. We do hope, this summer we shall look in the Internet Alma-Ata NM data in near real time. As a whole, we got more in this area than it was planned.

3. DATA BASE OF POSSIBLE GLE

At least two GLE were registered in the new solar cycle, on November 6, 1997 (GLE 55) and May 2, 1998 (GLE 56). The data files in standard format from 14 Russian and former Soviet Union neutron monitors for GLE55 and from 10 stations for GLE56 have been prepared to augment the current data GLE Database maintained by the Air Force Research Laboratory VSBS personnel. Additionally the data were gathered for problematic event on August 24, 1998. These files, accordingly to the agreement with the AF Research Laboratory, are on the IZMIRAN server and may be taken at any moment by anonymous ftp (ftp.izmiran.troitsk.ru directories C055, C056, and CP58) for GLE Database in Boston (partly they are already taken). Below is the listing of the corresponding files:
C055aatb5 - 5-min.data
C055aatb - 1-min. data
C055apty, C055caps, C055ervn, C055irk2, C055irk3, C055irkt, C055kiel, C055mgdn, C055mosc, C055mos5, C055nvbk, C055txby, C055yktk, C055lmks;
C056aatb, C056apty, C056oulu, C056mos5, C056mosc, C056txby, C056yktk C056irkt.dat, C056irk2.dat, C056irk3.dat
CP58atb5 - 5-min.data CP58atb1 - 1-min. data
CP58apty, CP58cap1, CP58cap5, CP58irk2, CP58irk3, CP58kil1, CP58kil5,
CP58mos1, CP58mos5, CP58txby, CP58oulu

4. POSSIBLE NEUTRON ENCHANCEMENTS AND THEIR RETROSPECTIVE ANALYSIS

NM registers solar neutrons, if their intensity is sufficient at the Earth orbit and the NM looks in the right direction. We created two catalogues of major x-ray and gamma-ray events when the Alma-Ata NM might observe possible solar neutrons. One, based on the GOES satellite data, accounts 776 events over the period of 1974-1999 when all flares >M1 importance and all proton flares followed by optical flare >2 class and/or with >1 hour duration. Second one used the data of hard x-ray and gamma-ray solar emission obtained by the BATSE detector aboard the CGRO satellite (1991-1999) with magnitude >1000imp/s and accounts 341 events might be effective for detecting at Alma-Ata. The lists of possible neutron events by both catalogues are presented on our anonymous ftp-server ftp://ftp.izmiran.troitsk.ru in the directory EOARD (file aatb_XR.txt and file aatb_ba.txt correspondingly)

A complex database was created on the basis of these catalogues and corresponding data from Alma-Ata neutron monitor. A special computer program was elaborated to work with this database. It allows to sort data by date, by the magnitude of expected or oserved effect, by the amplitude of X-ray flare. It allows selecting data by the X-ray flare magnitude, by date, by expected effect, by the magnitude of variations near the onset and so on. The program calculates possible response of the Alma-Ata neutron monitor in percents above background to the neutron flux of the prominent neutron event of June,3 1982 (the parameter Np in our notations), what can be observed if a flux of solar neutrons near the Earth is like on June 3, 1982. Choosing as a threshold response Np equal to 0.03, more than 750 events in CR intensity mostly favorable for observation in Alma-Ata were selected. Therefore, we assume that the flux of solar neutrons can be about 100 times greater than that observed on June3, 1982. On the beginning of our work Alma-Ata NM data were not available in standard GLE format for all selected events. Now 5-min data of all selected events and 1-min data of last years are transformed in this form. These standard files were tested for possible instrumental errors. Analyzing variations of real NM count rate and comparing them with expectations we may select possible neutron enhancements among of other cosmic ray effects of magnetosphere and interplanetary origin. As additional

information we used in our analysis data obtained aboard the SMM and CGRO satellites concerning hard x-ray and gamma-ray solar emission. The considered effects, in general, are not clear and large; however, it looks very interesting and promising in some cases. Below is the listing of events, which are the most probably candidates registered solar neutrons.

Date	onset time
80.04.07	05:18
82.08.09	06:37
89.09.04	06:25
89.09.09	04:37
89.09.14	06:59
89.10.02	08:41
90.09.17	07:50
91.06.01	04:00
91.06.06	07:05
91.06.12	07:00
91.06.15	06:33
91.06.17	08:09
91.07.11	08:35
91.07.14	08:27
91.07.22	09:36
91.08.05	05:24
91.10.27	05:36
98.05.08	05:53

Let us discuss some particular events from the list.

91.06.15 The only one event over the considered period of the Alma-Ata NM on June 15, 1991 was reported previously as caused by solar neutrons (see Kocharov, et al., 1997). It is well known event when both protons and neutrons supposed to be generated The Np parameter is 4.2% and the real maximum is about 1% at 08:30 UT. Besides, another, a little bigger increase at 06:33 UT has to be marked as associated with possible coming solar neutrons (see figure 1).

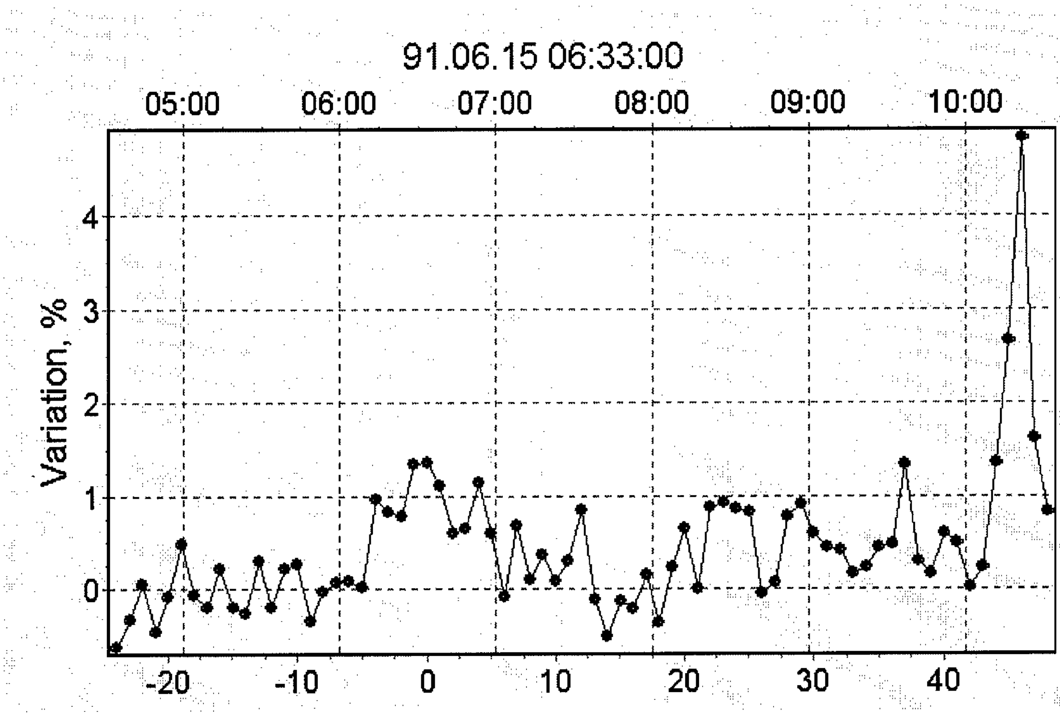
91.06.15 06:33:00
05:00
06:00
07:00
08:00
09:00
10:00
Variation, %
4
3
2
1
0
-20
-10
0
10
20
30
40

Fig. 1

98.05.08. The effect observed on May 8, 1998 (see figure 2) is very interesting from many points of view. Counting rate increase occured on Alma-Ata NM at the moment coinciding with the X-Ray flare onset (05:53 UT) . It had not great amplitude (~1.5%) and was detected only due to the high statistic (~1200 imp/s) and good time resolution (1 min data) of Alma-Ata neutron monitor. This event appeared to be a result of the flare activity from the same active region that lead 6 days ago (on 2-nd May) to the small and very anisotropic GLE (C056 in our dataset). On the 8-th of May this region was on the western limb. At the moment of X-ray flare a significant brightening in UV and radio emission (Nobeyama) has been observed on the western lymb. At the same time BATSE recorded long-durated gamma–flare of the complicated time profile. This set of measurements shows that we have a great solar flare and only its top part was observed in X-Ray.

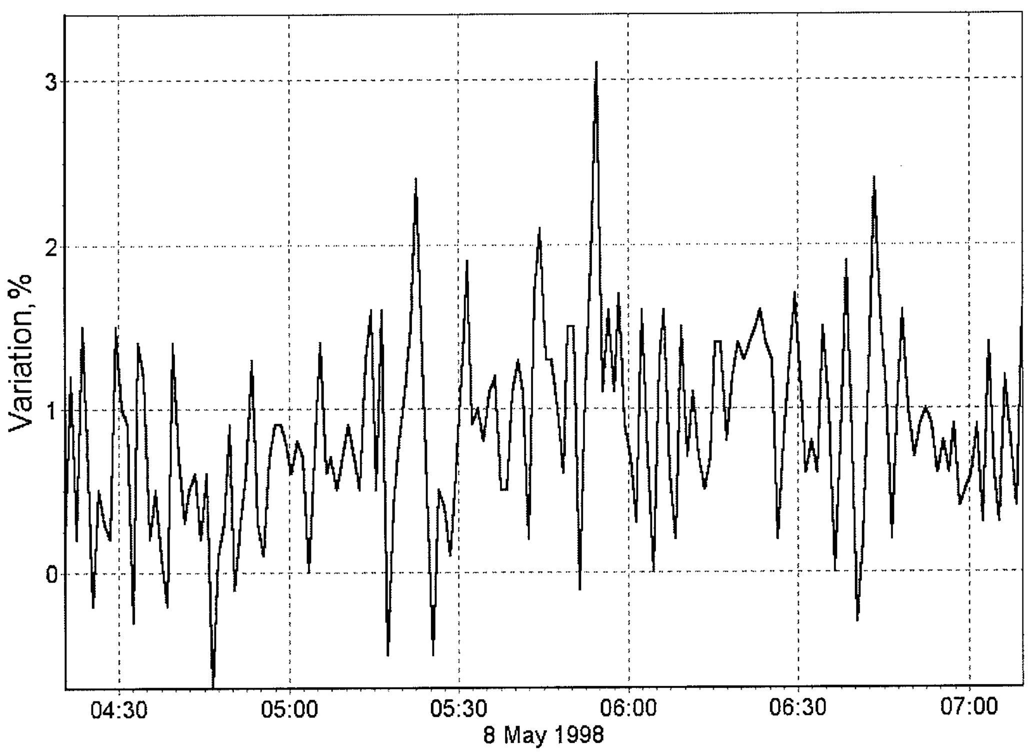

Fig. 2

82.08.09. A rather small variation of NM count rate comparable with statistical variation was observed on August 9, 1982 close to the x-ray onset. The Np parameter is about 9% and the effect duration is characteristic for arriving of solar neutrons, so we believe that this is a good candidate for solar neutron event.

78.05.07. Contrary, the relatively large enhancement observed on May 7, 1978 we attribute to solar protons but not neutrons. The Np parameter for this event was small and GLE 31, occurred at that time, was recorded on many other NMs. Although it was not big (about 2%), but in 5-minute data both isotropic and anisotropic parts are pronounced very clearly (Figure 3).

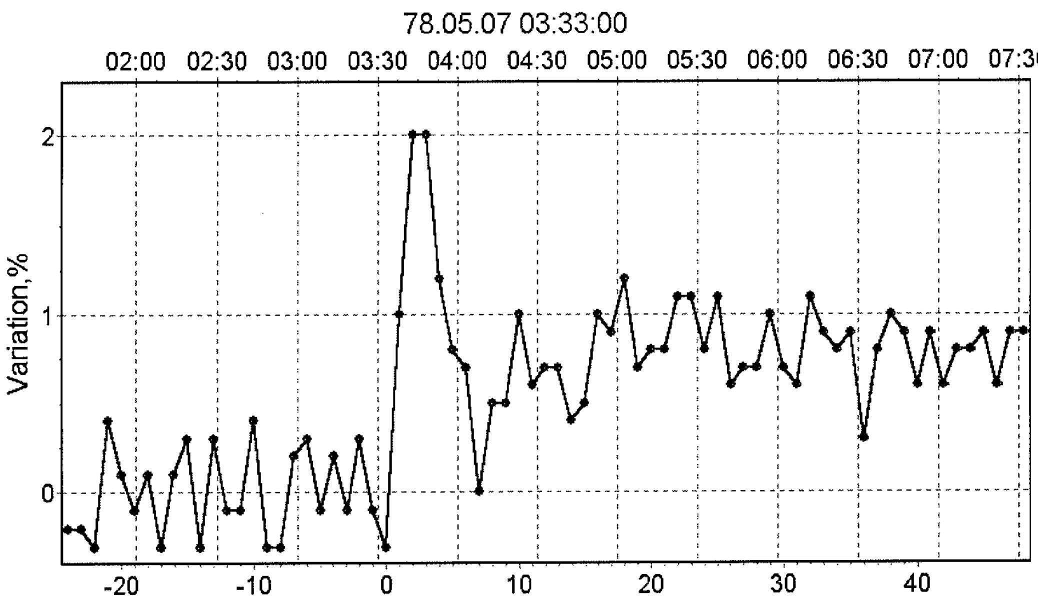

Fig. 3

79.07.24. Another example of possible neutron enhancement, which amplitude is much more than statistical variations, is the event on July 7, 1979 (Figure 4).

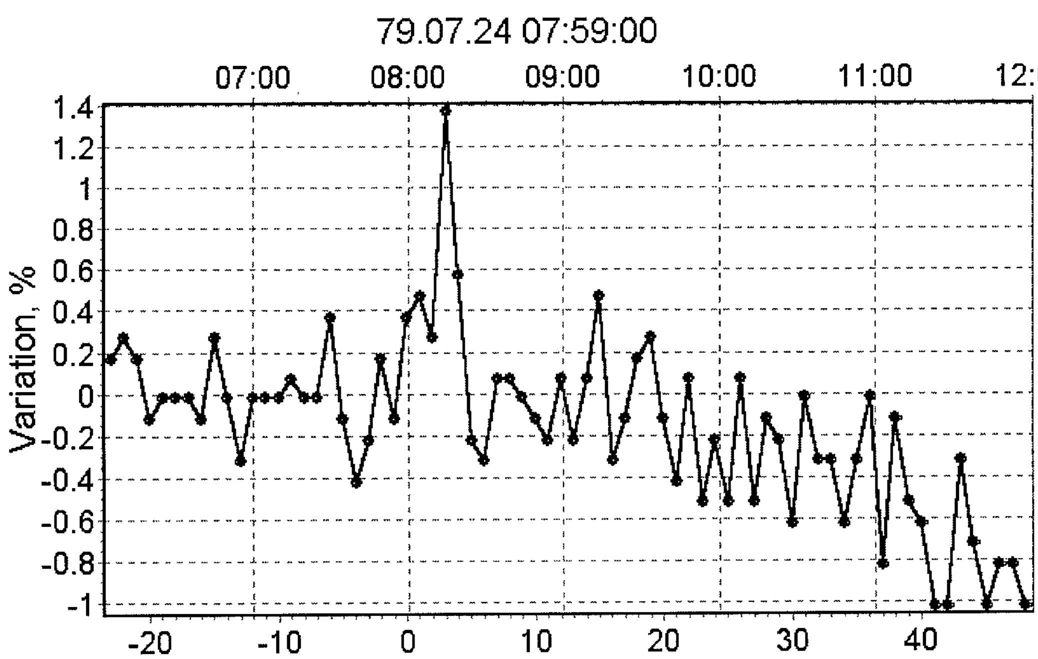

Fig. 4

91.06.17. Here we see two effect. First increase in the time of solar flare onset (8:27 UT) is possible solar neutron effect and second increase followed by decrease is shock wave effect (SSC was in 10: UT) and beginning of Forbush-decrease. (Figure 5)

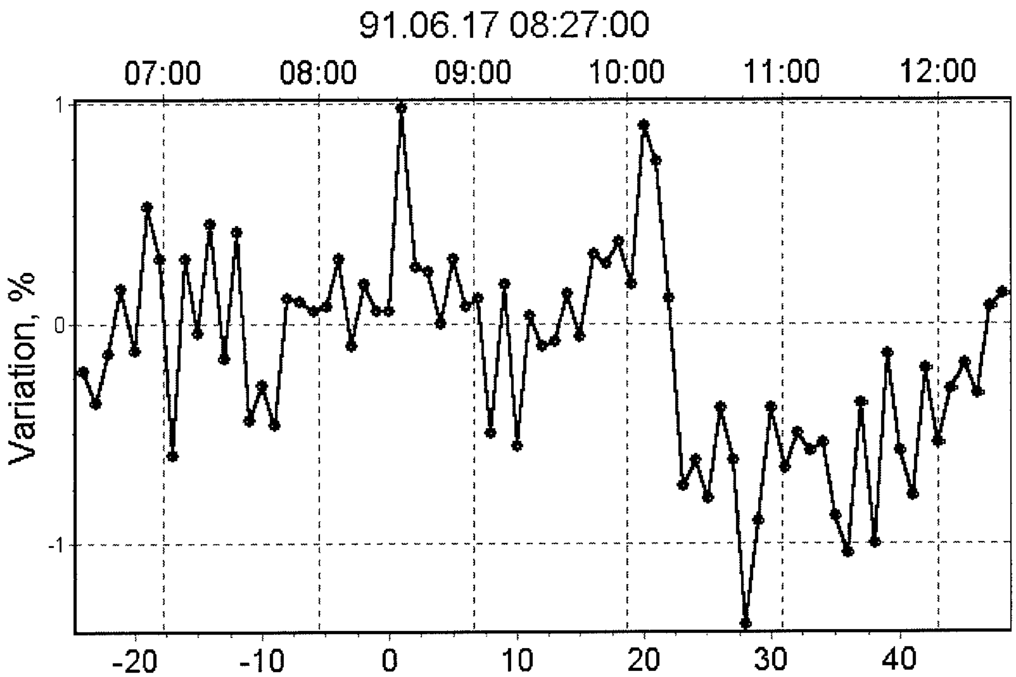

Fig. 5

80.04.07. Another example of possible neutron enhancement, which amplitude is comparable with statistical variations, is the event on April 7, 1980. Definite identification of variation origin is impossible in this case..

Mean effect. The statistical analysis of data may provide an additional information. For instance, our database allows to calculate an average enhancement for any data set. In our preliminary statistical analysis by the epoch lay on method we used data without instrument variations and well pronounced trends (more than 2%). We applied this method in two sets of data: one with the whole number (739) of events, another group where expected effect exceeded 1 % (286 events). Data of all events within of each dataset were centered around the x-ray onset of parent solar event and then were averaged. Figure 6 presents results of averaging in group 1, and Figure 7 illustrates results from group 2. Corridor around of the main curve in each figure corresponds to 2 standard statistical error. One can see the clear enhancement close to the x-ray event onset, although of not big magnitude: for all events it is around of 0.05% and for second group it is close to 0.07% and better pronounced. It is interesting and gives some reasons for speculations that maximums of averaged variations are observed at the x-ray onset and about 30 minutes later. However, we should mention that GLEs and small Forbush effects were not removed from the data used to plot this picture and 5-minute data of the 89-91 years were not corrected for pressure variations, although it can't change the result significantly.

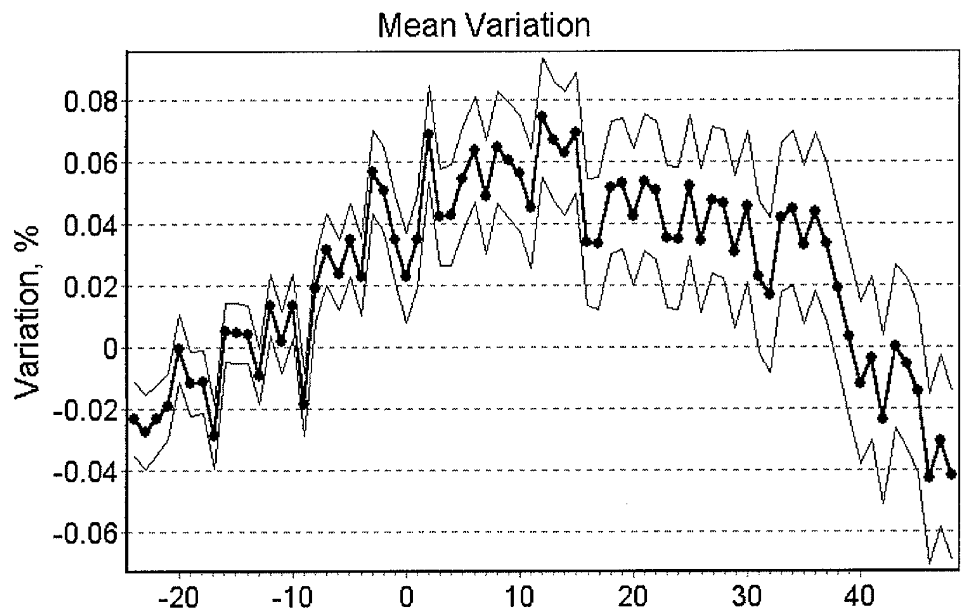

Fig. 6

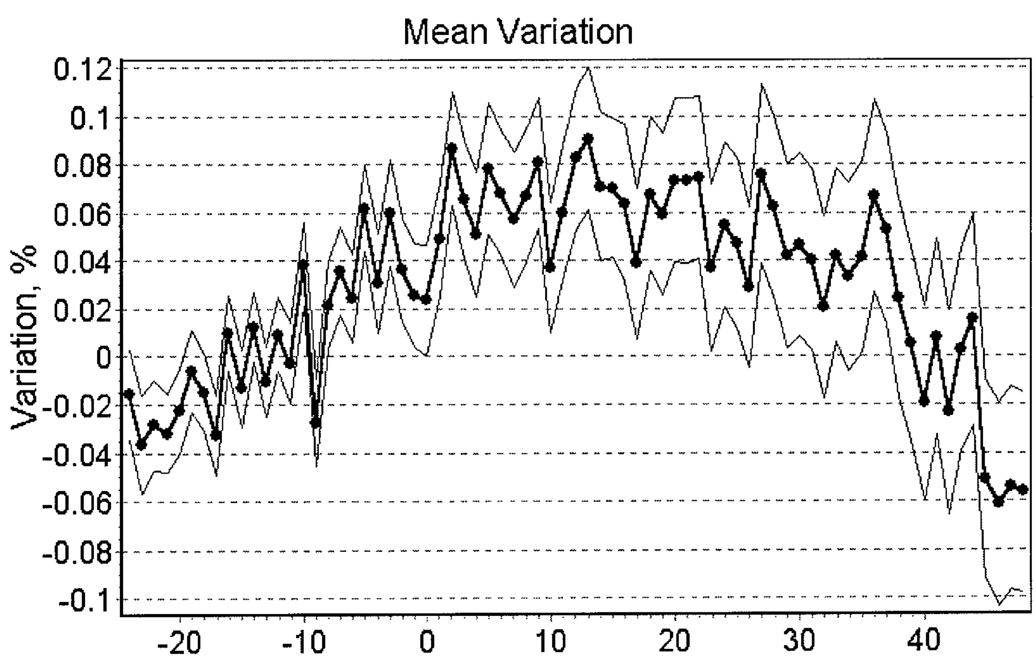

Fig. 7

CONCLUSION

The results of our work under this project can be presented as following in a whole:

1. A verification and presentation in standard form convenient for the further investigations of the great capacity of 1- and 5-minute data from Alma-Ata neutron monitor has been done;
2. We understood better special possibilities of the high-altitudinal 18-counter NM of Alma-Ata stations for various studying of cosmic ray effects.
3. Quite extensive archive of NM data in standard GLE format is created on the basis of Alma-Ata NM observations.
4. Two databases were built up on the basis of lists X-ray and gamma-ray flares, which allows to comfortable and fruitful study the possible cases of solar neutron coming.
5. A set of new events was selected where detecting of solar neutron on the Alma-Ata stations seems to be highly probable.
6. A big amount attendant phenomena was revealed for which study the data from high mountain Alma-Ata station may have a crucial importance.
7. A complete modernisation of NM registration system at Alma-Ata station and output in the Internet were provided.

List of operating neutron monitors sorted by (solar neutron effect)/(statistical noise) ratio.

Station		Lat	Long	Alt	H0	Rc	counts	Hmin	Csn
ALMA ATA B	aatb	43.1	76.6	3340	680	6.61	1205	746	12.1
JUNGFRAUJOCH_2	jun2	46.5	8.0	3475	646	4.61	331	725	7.3
JUNGFRAUJOCH	jung	46.5	8.0	3570	639	4.61	141	717	5.0
EREVAN	ervn	40.2	44.3	2000	815	7.58	1100	879	4.2
CLIMAX	clmx	39.4	-106.2	3400	685	2.99	97	736	3.8
LOMNICKY STIT	lmks	49.2	20.2	2634	748	3.98	420	857	2.9
IRKUTSK_3	irk3	51.3	100.6	3000	715	3.64	239	835	2.5
EMILIO SEGRE	esoi	33.3	35.8	2025	797	10.80	160	836	2.3
TSUMEB	tsmb	-19.1	17.4	1240	880	9.21	314	909	1.8
IRKUTSK_2	irk2	51.4	100.6	2000	800	3.64	207	935	1.1
POTCHEFSTROOM	ptfm	-26.4	27.1	1351	870	7.00	53	900	0.8
HAFELEKAR	hflk	47.3	11.4	2290	830	4.38	81	937	0.7
CALGARY	calg	51.1	-114.1	1128	883	1.08	272	1029	0.6
TBILISI	tbls	41.7	44.8	510	965	6.73	146	1049	0.4
MT.WELLINGTON	mtwl	-42.9	147.3	725	950	1.89	108	1040	0.4
HERMANUS	hrms	-34.4	19.2	26	1015	4.58	110	1068	0.3
BEIJING	bjng	40.1	116.3	48	1000	9.56	135	1078	0.3
ALMA ATA A	aata	43.3	76.9	775	920	6.61	45	1010	0.3
ROME	rome	41.9	12.5	60	1030	6.32	153	1121	0.2
NEWARK	nwrk	39.7	-75.8	50	1013	2.09	83	1090	0.2
MEXICO CITY	mxco	19.3	-99.2	2274	779	8.61	136	804	0.2
HALEAKALA	hlea	20.7	-156.3	3030	724	12.91	60	748	0.2
KERGUELEN	kerg	-49.4	70.3	33	1020	1.14	191	1171	0.2
IRKUTSK	irkt	52.5	104.0	433	984	3.64	156	1162	0.2
KIEV	kiev	50.7	30.3	120	1000	3.57	128	1161	0.2
KIEL	kiel	54.3	10.1	54	1008	2.36	152	1213	0.1
NOVOSIBIRSK	nvbk	54.8	83.0	163	1000	2.87	162	1209	0.1
MOSCOW	mosc	55.5	37.3	200	1000	2.43	199	1217	0.1
GOOSE BAY	gsby	53.3	-60.4	46	1030	0.64	161	1226	0.1
MAGADAN	mgdn	60.1	151.0	220	1000	2.09	144	1287	0.1
YAKUTSK	yktk	62.0	129.4	105	1000	1.65	142	1320	0.0
OULU	oulu	65.1	25.5	0	1020	0.78	92	1408	0.0
APATITY	apty	67.6	33.3	177	1000	0.57	151	1437	0.0
INUVIK	invk	68.3	-133.7	21	1030	0.17	165	1500	0.0
TERRE ADELIE	tera	-66.7	140.0	45	1007	0.02	101	1426	0.0
CAPE SCHMIDT	caps	68.9	180.5	0	1000	0.55	101	1471	0.0
TIXIE Bay	txby	71.4	128.5	15	1000	0.45	122	1539	0.0
SANAE	snae	-70.3	-2.4	52	987	0.86	70	1489	0.0
MCMURDO	mcmd	-77.8	166.7	48	1007	0.00	234	1784	0.0
THULE	thul	76.5	-68.7	260	1005	0.00	108	1725	0.0
SOUTH POLE	sopo	-88.0	210.0	2820	680	0.09	255	1630	0.0

Explanation:

Lat,long,alt - latitude(°), longitude(°), altitude(m) of station.
Rc(GV) - geomagnetic rigidity cut-off.
H0(mb) - standard atmospheric pressure.

Hmin(g/cm2) - minimal atmospheric depth along solar direction.
counts(1/s) - counting rate.
Cns - (solar neutron effect)/(statistical noise) ratio.