RESULTS OF MEASUREMENTS OBTAINED IN THE FIRST PHASE OF THE RADIATION MONITORING SYSTEM DEPLOYMENT ON THE RUSSIAN SEGMENT OF THE INTERNATIONAL SPACE STATION

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Radiation monitoring system (RMS) /1-3/, being deployed on the International Space Station, is a part of radiation safety implementation system of the station. The purpose of the RMS is to provide information for assessment of radiation doses absorbed by the crews during space flights. An additional purpose of the system is to assess radiation situation automatically and to inform the crew in case of its worsening. The block diagram of the system is illustrated in Fig.1.
The installation of fixed part of radiation monitoring equipment was scheduled in the first phase of RMS deployment, the mobile part, on the basis of dosimeters "Liulin" and "Pille", will be installed in the next phase /4, 5/.

The R-16 device has been operating on the ISS since summer, 2000. The daily reports on radiation doses of the ISS crews are produced on the basis of the R-16 data. «Progress M 1-6» delivered next six packs of the system equipment to the ISS on May 23, 2001. These packs included:
- Four DB-8 sets of dosimeters with semiconductor radiation detectors;
- Utility Unit (UU) and Data Collection Unit (DCU) made for processing and analysis of the data obtained;

Block scheme of the Radiation Monitoring System and accompanying on board devices

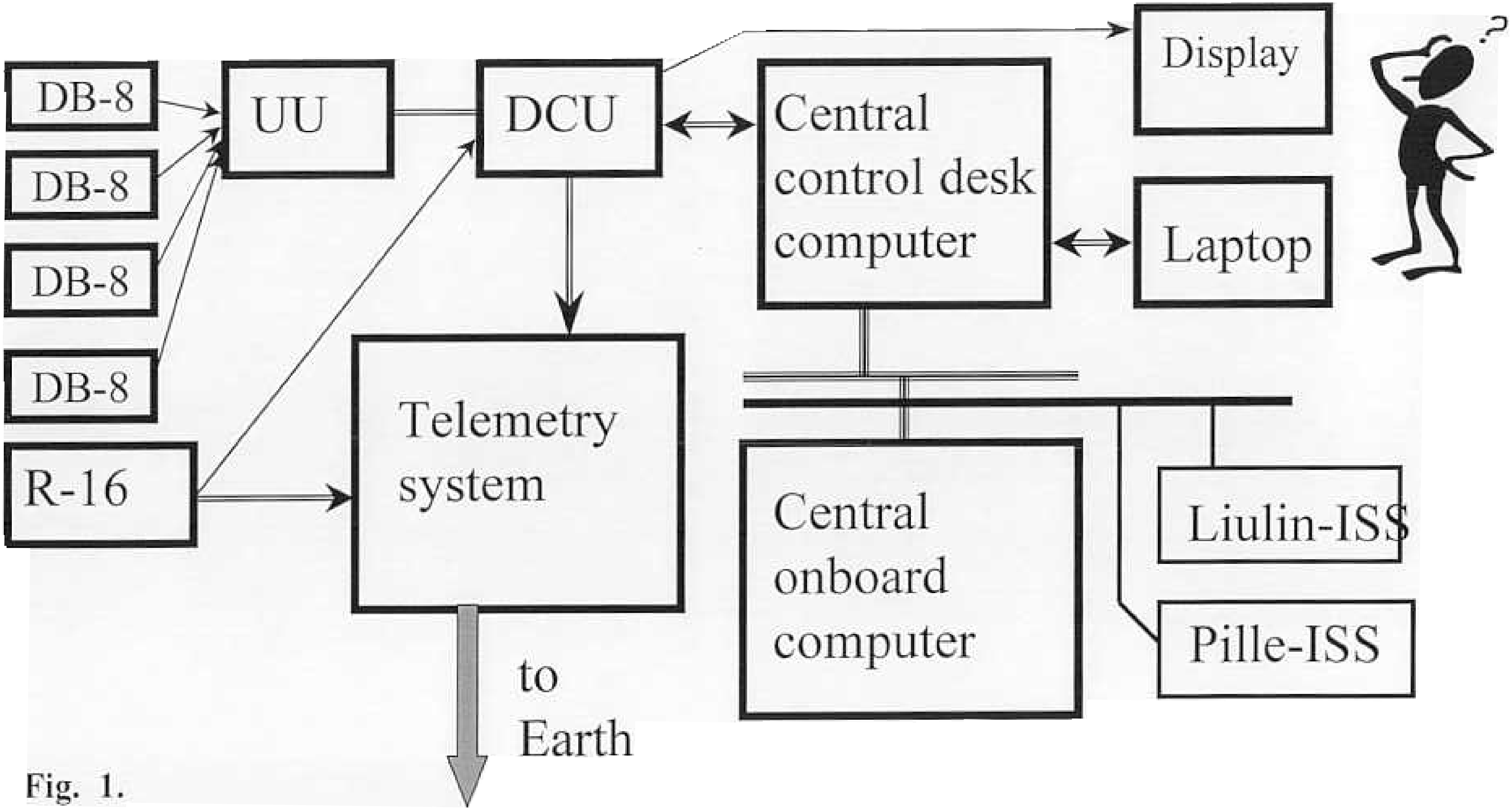


Fig. 1.

On the 27th July 2001 the crew of the 2nd ISS mission mounted the packs on board of the station and connected up all the cables except the Central control desk computer (CCDC) cable. Having passed a series of tests the RMS has been operating since August 1, 2001.

Since the CCDC cable is not connected, the RMS is operating in a restricted mode (not communicated with the crew). This restriction is due to the fact that the CCDC software does not support communication with the RMS now. After a newer version of the software being installed, the appropriate cable will be attached, and RMS-crew communication will be available.

A brief description of the equipment

Sensitive components of the system are disposed in DB-8 units. All the 4 units are similar. Each of them has 2 fully independent channels consisting of a semiconductor detector, preamplifier, scaling amplifier, analog-digital converter and digital signal-processing scheme. The sensitive component is a silicon semiconductor detector NP300 with a 300 μm sensitive layer covering an area of 1 cm^2. The difference between the two channels is that one of the detectors has additional lead shielding. The shielding is a sphere surrounding the detector. The sphere wall thickness is 3 g/cm^2 Pb that is equivalent 1.52 g/cm^2 of water.

The UU and DCU are designed for digital processing of measurements and communication with ISS systems.

When developing the RMS a close attention was devoted to the onboard location of DB-8 inits. Locations of the units were selected so that the RMS detectors were in various conditions of shielding by the station equipment. The information on the units' location is given in Table 1.

Table

Block	Location
DB-8 №1	Starboard side, behind board № 410
DB-8 №2	Port side, behind board № 244 (cabin)
DB-8 №3	Starboard side, behind board № 447 (cabin)
DB-8 №4	Starboard side, behind board № 435
R-16	Ceiling of Big diameter bay, behind board № 327
UU	Starboard side, behind board № 447 (cabin)
DCU	Starboard side, behind board № 447 (cabin)

Dose measurement in DB-8 units of RMS

Since semiconductor detectors are distinguished by a high linearity of transformation of absorbed energy into electric charge /6, 7/. Absorbed energy is linearly correlated to the charge, formed in the sensitive volume of the detector under the radiation influence.

Electrons generated by traversing particles are accumulated on the NP-detector electrodes and then come to the charge-sensitive preamplifier input. Then the amplified signal comes to:

- the scaling amplifier input,
- the discriminator input.

The scaling amplifier provides a proper adjustment of the signal to be transmitted to the analog-digital converter (ADC) input.

The discriminator output signal comes to the ADC trigger and to a separate impulse counter.

If to neglect the system noise and rounding off errors then the absorbed dose is related to the sum of the ADC output signal as:

$$D = \frac{E}{m} = \frac{\omega_i \times \frac{q}{e}}{m} = \frac{\omega_i \times \Delta U \times C}{m \times e \times \eta} \times \sum K = V \times \sum K \qquad (1)$$

where	D	is the absorbed dose;
	E	is the energy absorbed by the sensitive volume
	m	is the sensitive volume mass;
	ω_i	is the NP pair formation energy;
	e	is the electron's charge
	q	is the electric charge formed in the detector;
	K	is the analog-digital converter output signal;
	q	is the charge generated in the detector sensitive volume;
	C	is the input capacitance of the detector-preamplifier system;
	η	overall multiplication factor of signal before the ADC;
	ΔU	is the quantization step of the ADC;
	V	is calibration factor

Thus, in order to determine the value of absorbed dose it is necessary to count correctly a sum of output signals coming from the ADC and to know constant factor V, standing before this sum.

The factor V was determined during calibration of the equipment, and Σ K was counted by two independent methods.

Output signal from the ADC was added to the total dose counter. After power-up of the RMS this 32-bit counter resets and then accumulates signals until overflow after which the cycle loops.

Besides, amplitude pulse spectrum of the detector is recorded. Energy boundary distribution of the recorded spectrum is presented in Fig. 2. The second way of Σ K determination is based on summing up the number of particles in spectrum channels with respective weighting factors. This way allows increasing of the dynamical range of measurements based on the correction of the calculating error caused by the dead time of the discriminator and ADC.

The formulae for dose calculations has the following form:

$$D = \frac{V}{1 - \frac{N_p \times \tau}{T}} \times \frac{N_p}{\sum_{j=1}^{19} n} \times \sum_{j=1}^{19} (u_j \bullet n_j) \qquad (2)$$

Where D is the absorbed dose;
- V is calibration factor
- N_p is a number in the of particle counts
- τ is a dead time of the discriminator
- T is a duration of the interval of measurement
- j is a number of spectrum channel
- n_j is a number of particle counts in the channel j
- u_i is the weighting coefficient for the channel j

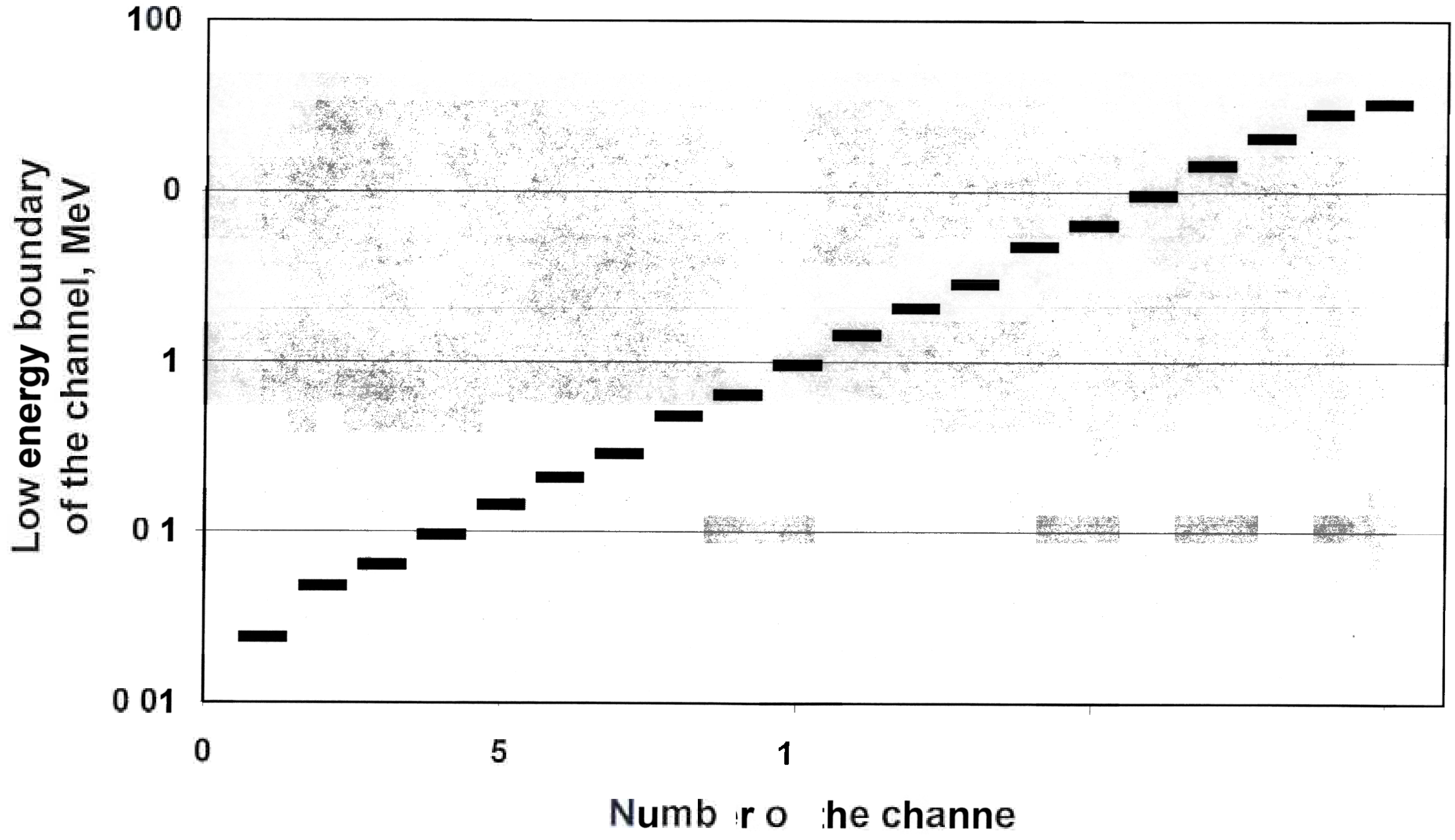
The first factor provides a correction of miscounts caused by the dead time of the discriminator; the second factor is to do this correction for the ADC dead time. Dose calculation in accordance with the formulae (2) is realized in the DCU.

The values of total dose counter, flux and spectrum are transmitted to the UU every 10 seconds, then flux and spectrum values reset.

The UU receives data from the 8 independent measuring channels (2 channels in each of the four DB-8 units), and then transmits them to the DCU for further processing and analysis.

At present time the software version of the DCU provides accumulation in internal memory and then transmission of data by means of telemetry during communication sessions.

D :ribut on o energy bordarie fo :he channe o :he DB-8 un



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Results

Figure 3 illustrates the dynamics of total dose accumulation of DB-8 blocks for the first 18 days of the RMS operation, since August 1, 2001. Figure 4 presents similar data for particle fluxes. It is interesting to note that solar proton event occurred on August 16, 2001 did not contribute significantly to the dynamics of dose accumulation on board of the station.

Table 2 summarizes doses recorded by the DB-8 sets of RMS for the first two weeks of its operation.

Table 2

Detector	Dose for two weeks, mGy	Mean dose rate, mGy/day
Block № 1, not shielded	4.02	0.29
Block № 1, shielded	3.65	0.26
Block № 2, not shielded	3.08	0.22
Block № 2, shielded	2.91	0.21
Block № 3, not shielded	3.31	0.24
Block № 3, shielded	3.24	0.23
Block № 4, not shielded	1.93	0.14
Block № 4, shielded	2.35	0.17

It can be seen that there is more than 2-fold difference between values measured with various detectors. This fact does not contradict previous measurements with the use of passive detectors on MIR station /8, 9/ and shows that the task of placement of the DB-8 blocks in various shielding conditions is successfully accomplished.

Hardware-controlled spectrum of energy deposited in the detectors of the first DB-8 block recorded for that 2-week period is given in Fig. 5. Figure 6 illustrates similar data for all the 8 detectors. It should be mentioned that doses calculated in terms of energy deposition spectra agree with those determined by the data from total dose counters of the DB-8 blocks with accuracy of no worse than 4%. Figure 7 presents the same data normalized by the width of energy range of each channel.

The RMS makes it possible to obtain not only integral dose profiles but also a detailed dynamics of dose rate. Figures 8 and 9 illustrate dose rate and flux measured with 2 out of 8 detectors while passing through the area of the South-Atlantic anomaly. It can be noted that there was about a four-fold difference between the dose rates of detectors in the anomaly zone. As it was expected, the dose difference measured in the SAA is essentially higher then that per day. This difference can be even higher during solar particle event. That is why, for correct prediction of crew

Time dependence of the counts measured with the internal dose counters of the DB-8 units.

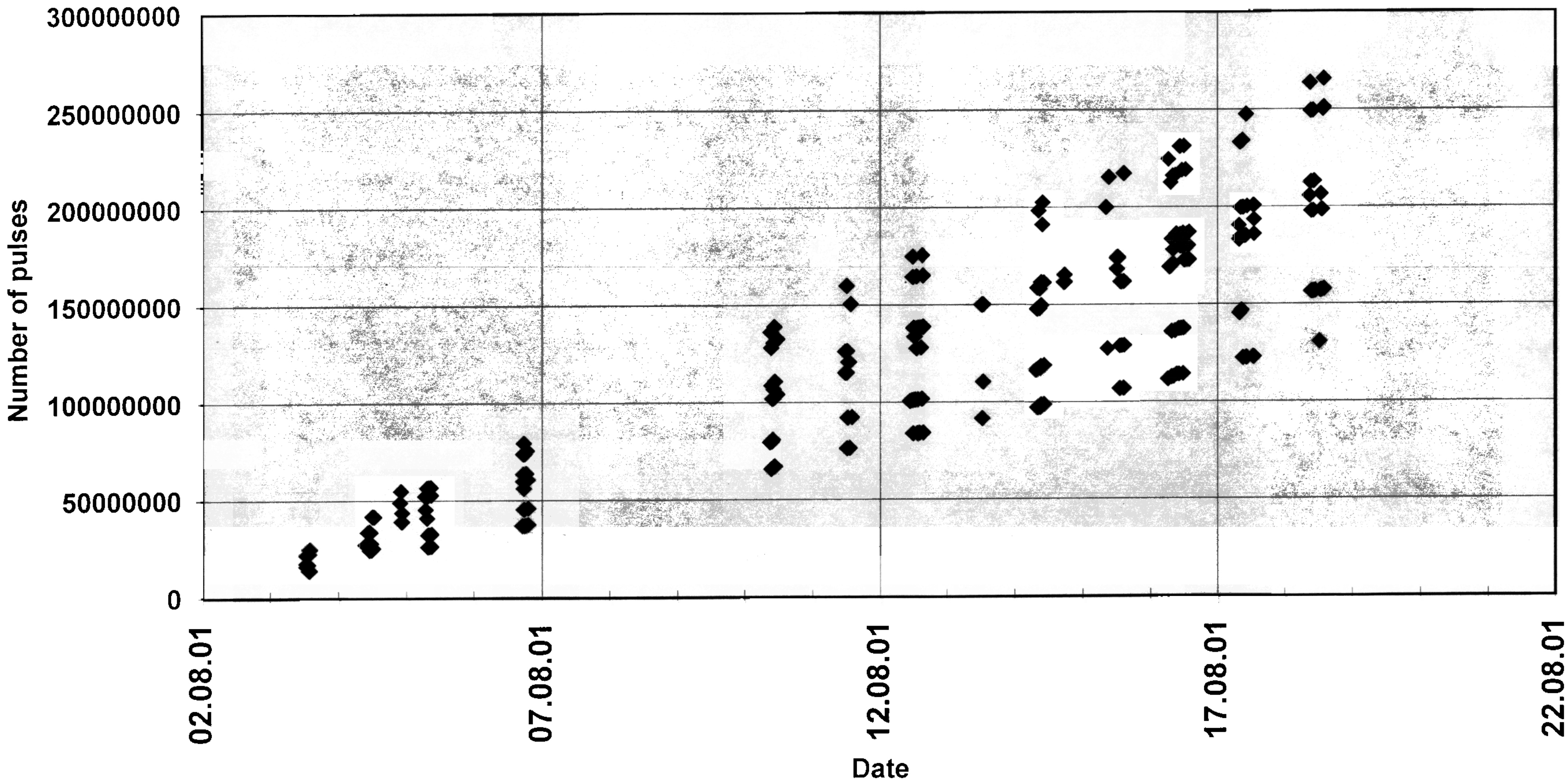


Fig. 3.

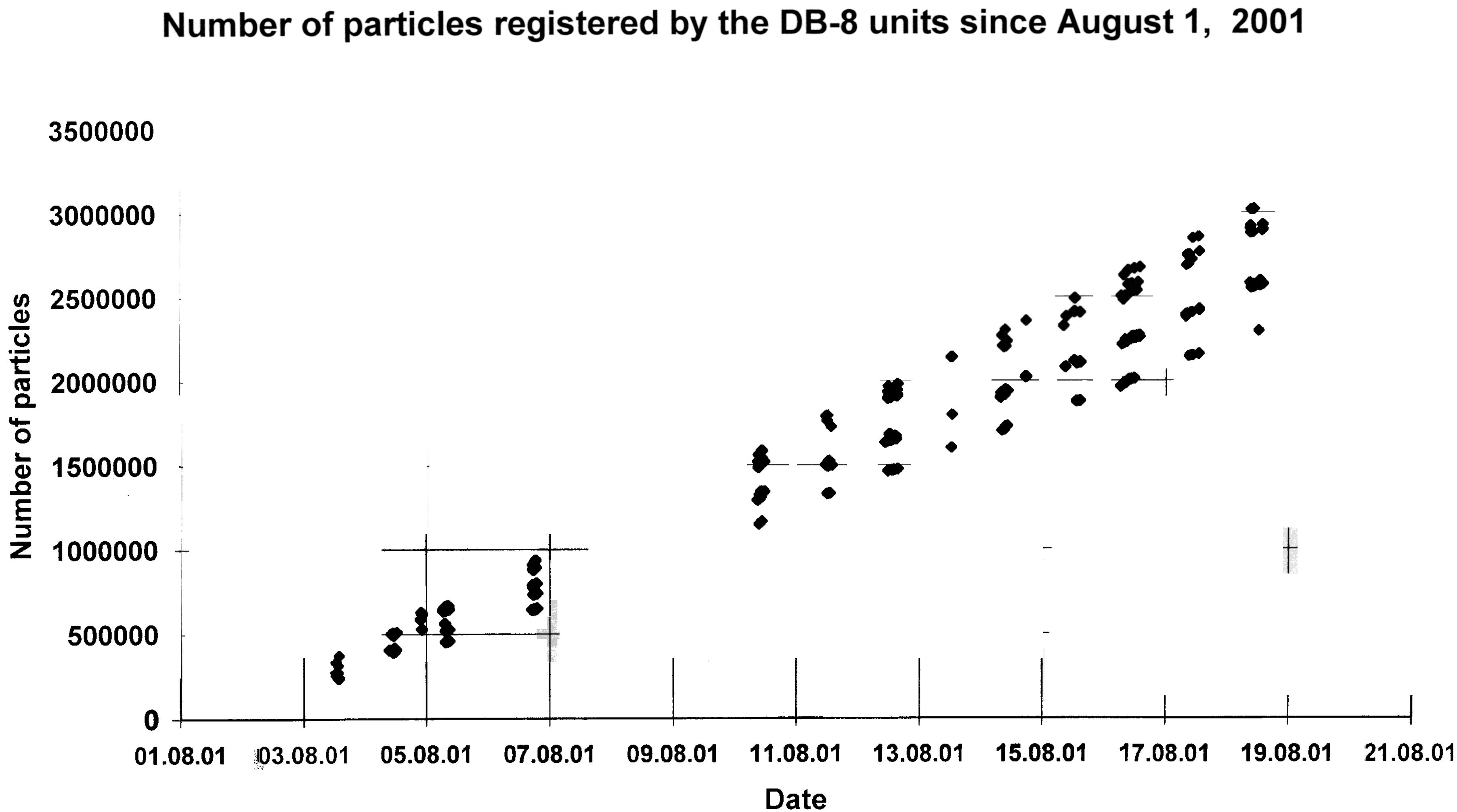
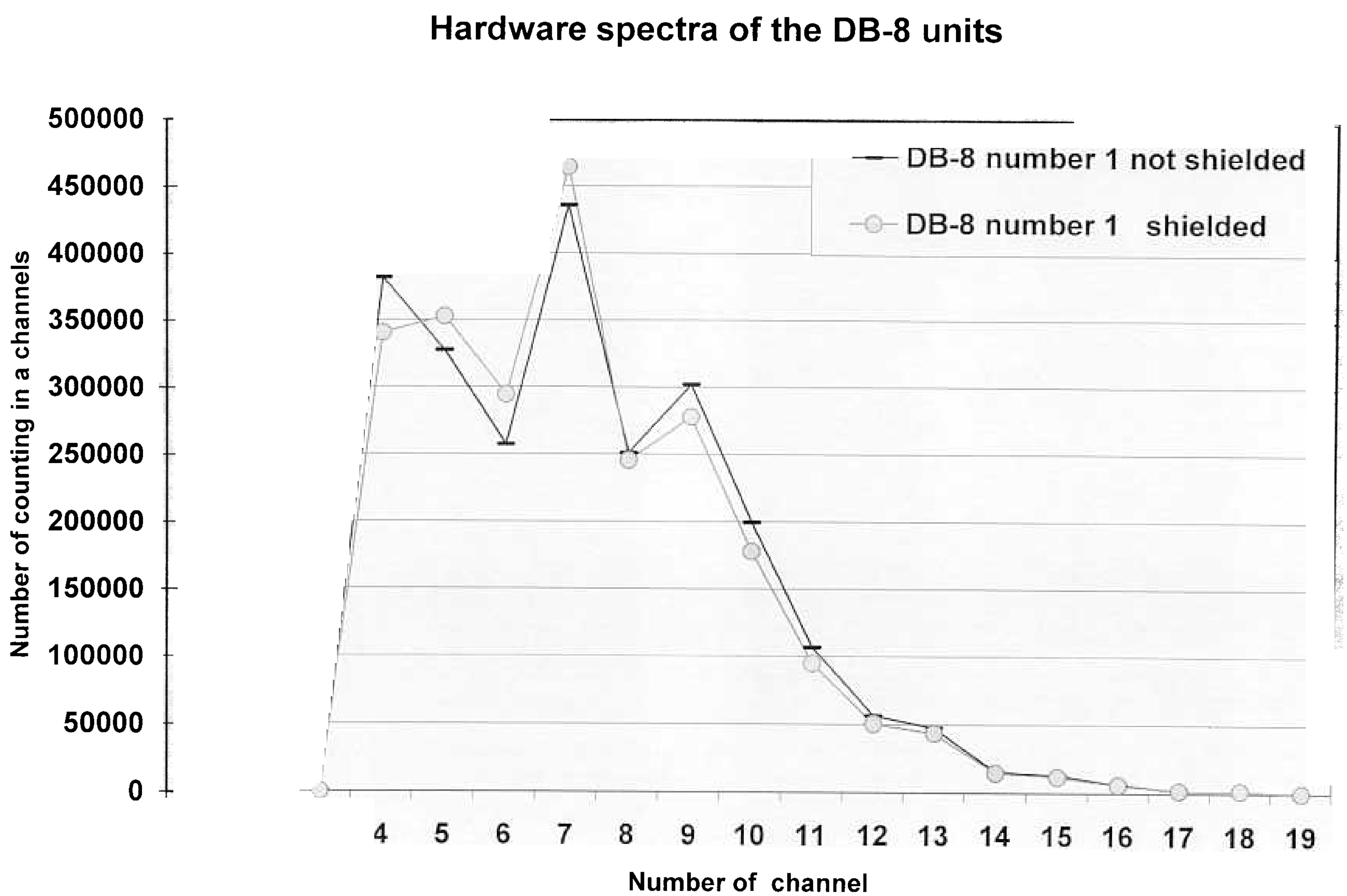
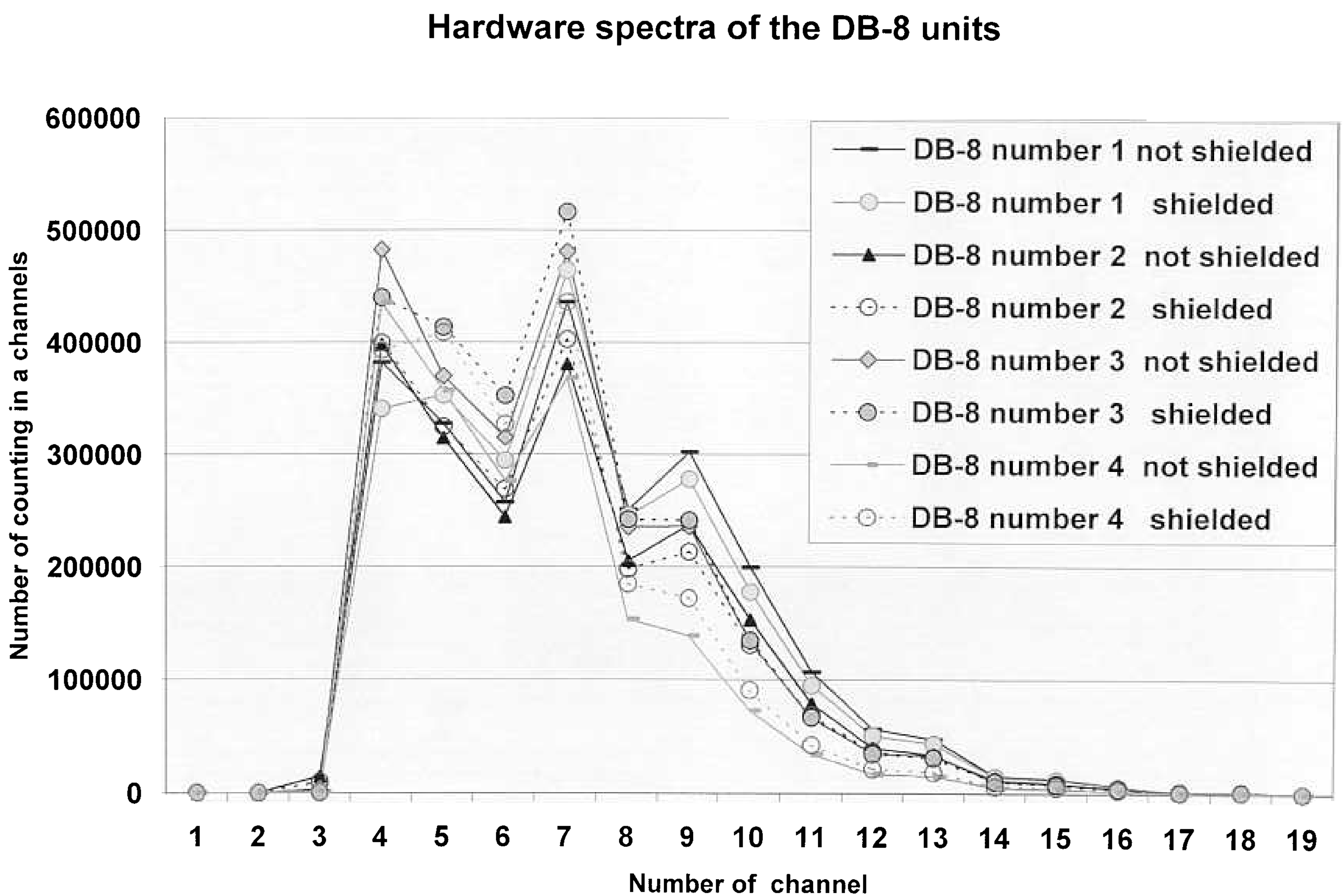

Number of particles registered by the DB-8 units since August 1, 2001
Number of particles
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
01.08.01
03.08.01
05.08.01
07.08.01
09.08.01
11.08.01
13.08.01
15.08.01
17.08.01
19.08.01
21.08.01
Date

Fig. 4.



Hardware spectra of the DB-8 units
DB-8 number 1 not shielded
DB-8 number 1 shielded
Number of counting in a channels
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Number of channel

Fig. 5.



Hardware spectra of the DB-8 units
600000
500000
400000
300000
200000
100000
0
Number of counting in a channels
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Number of channel
DB-8 number 1 not shielded
DB-8 number 1 shielded
DB-8 number 2 not shielded
DB-8 number 2 shielded
DB-8 number 3 not shielded
DB-8 number 3 shielded
DB-8 number 4 not shielded
DB-8 number 4 shielded

Fig. 6.

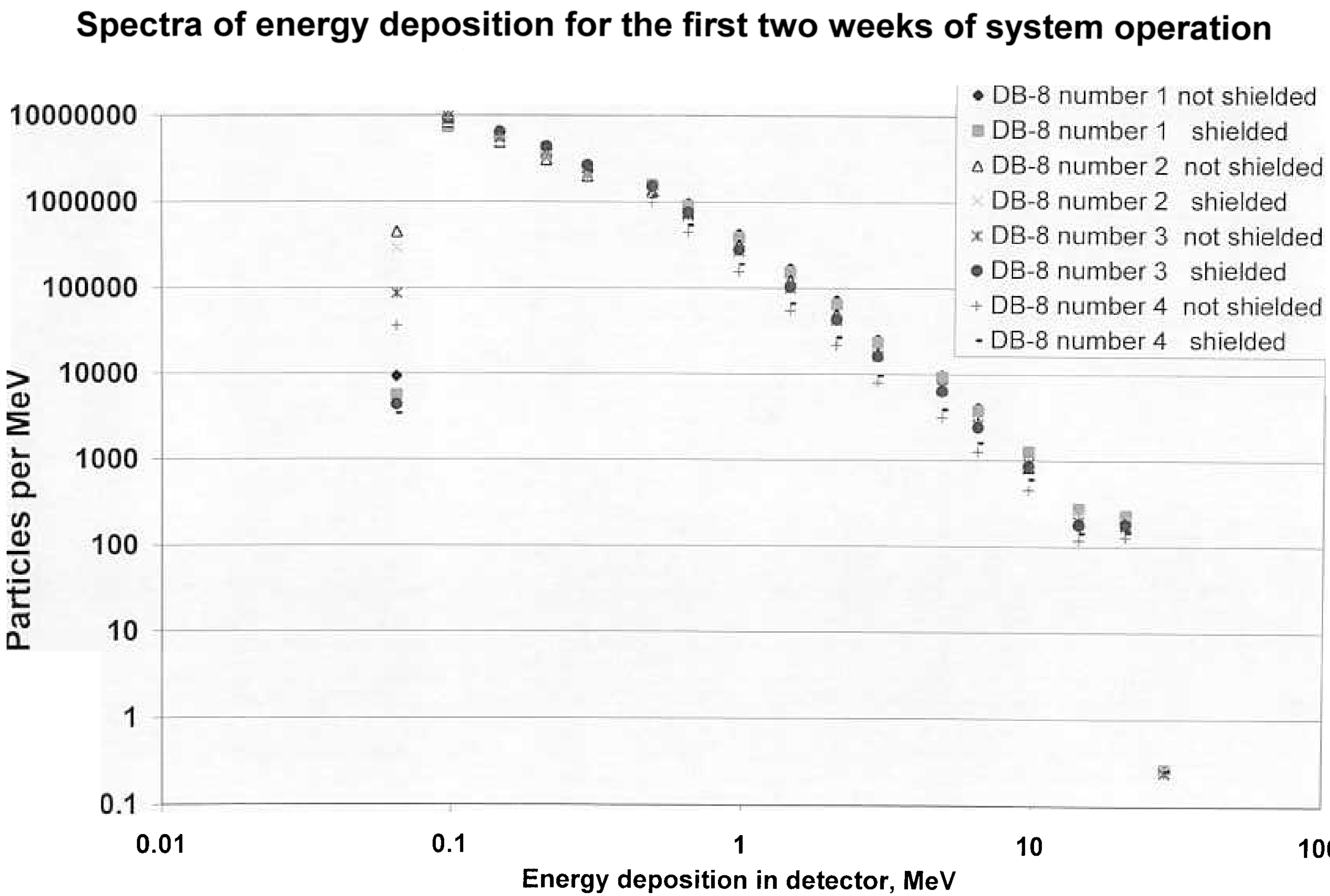

Spectra of energy deposition for the first two weeks of system operation
DB-8 number 1 not shielded
DB-8 number 1 shielded
DB-8 number 2 not shielded
DB-8 number 2 shielded
DB-8 number 3 not shielded
DB-8 number 3 shielded
DB-8 number 4 not shielded
DB-8 number 4 shielded
10000000
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.1
1
10
100
Particles per MeV
Energy deposition in detector, MeV

Fig. 7.

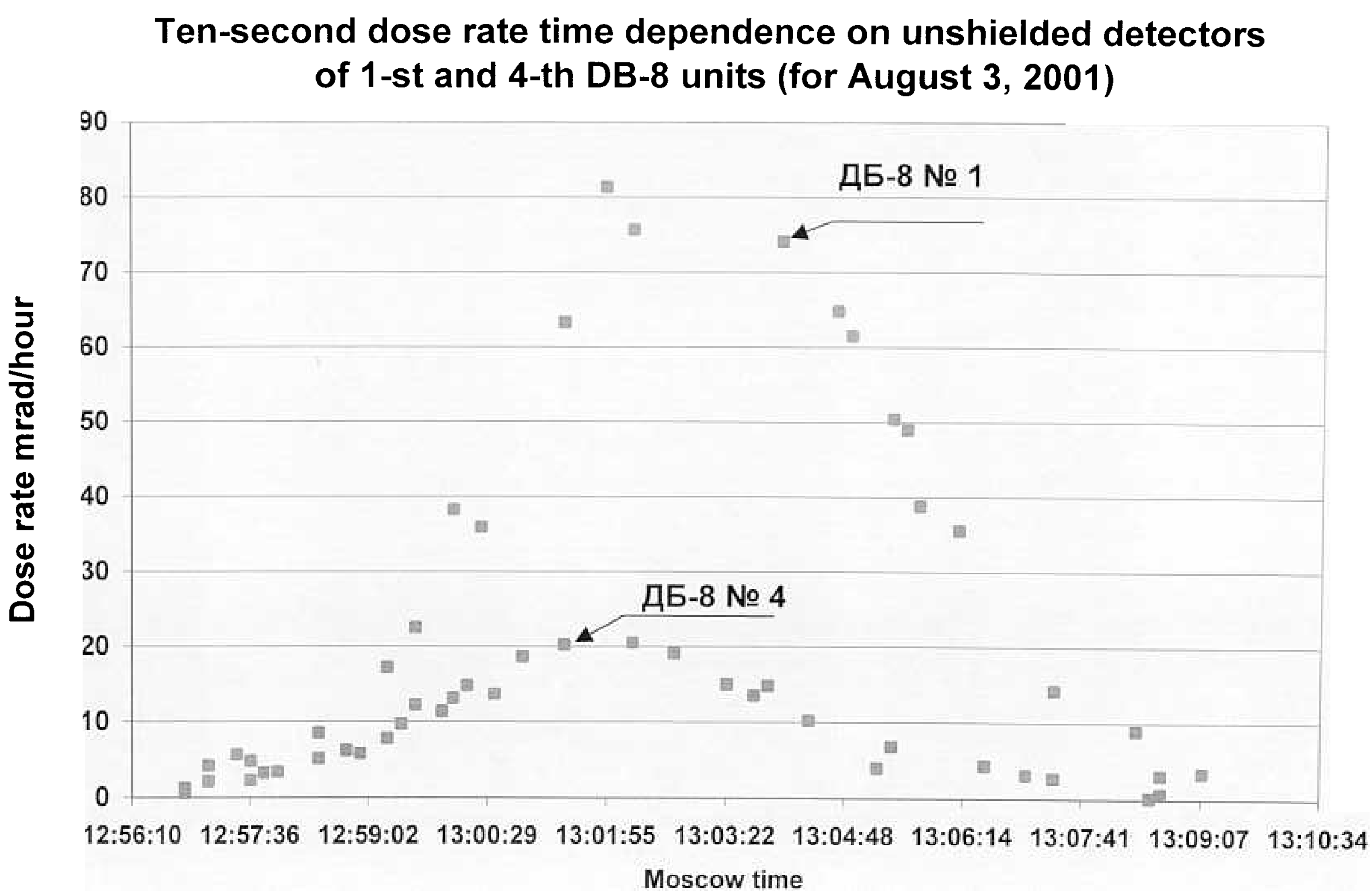

Ten-second dose rate time dependence on unshielded detectors
of 1-st and 4-th DB-8 units (for August 3, 2001)
ДБ-8 № 1
ДБ-8 № 4
Dose rate mrad/hour
90
80
70
60
50
40
30
20
10
0
12:56:10
12:57:36
12:59:02
13:00:29
13:01:55
13:03:22
13:04:48
13:06:14
13:07:41
13:09:07
13:10:34
Moscow time

Fig. 8.

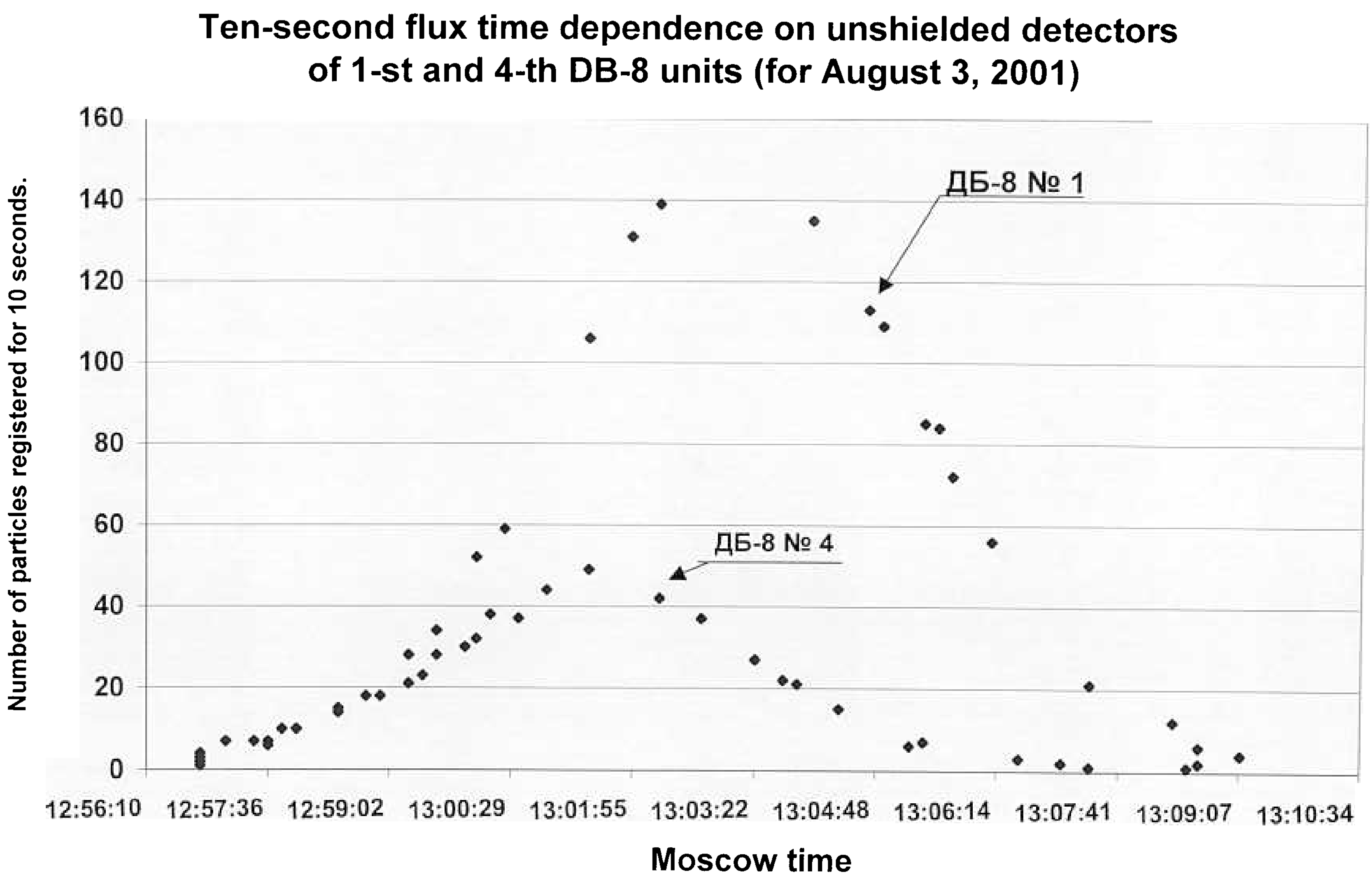

Ten-second flux time dependence on unshielded detectors
of 1-st and 4-th DB-8 units (for August 3, 2001)
Number of particles registered for 10 seconds.
160
140
120
100
80
60
40
20
0
ДБ-8 № 1
ДБ-8 № 4
12:56:10
12:57:36
12:59:02
13:00:29
13:01:55
13:03:22
13:04:48
13:06:14
13:07:41
13:09:07
13:10:34
Moscow time

Fig. 9.

radiation exposures during radiation alerts, it is necessary to know the method to estimate the dynamics of the dose distribution in different compartments of the space station during solar particle events. The idea of this method based on the RMS data was proposed in /10/. We are going to verify this method using the Liulin and Pille instruments as well as other experimental equipment planned for the delivery on board the ISS. In case of success, the utilization of this method, together with the Liulin and Pille instruments, allows to estimate radiation environment for all the habitable compartments of the Russian Segment of the ISS (RS ISS).

Conclusion

The RMS equipment specified for the 1st stage of deployment was designed, manufactured, tested, delivered to the ISS, installed and put into operation.

The results obtained show that it is possible to expand and improve the radiation monitoring on the ISS using data from the RMS.

The development of the RMS in the second phase with usage of the mobile dosimeters "Liulin" and "Pille" will allow the radiation monitoring in all crew compartments of the RS ISS.

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