Results of Liulin-F particle telescope pre-flight calibrations with protons and heavy ions

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Liulin-F instrument for a new experiment in radiation research has been developed, tested and space flight qualified [1,2] to be flown onboard the Russian Phobos - Soil mission (Phobos-Grunt) to the satellite of Mars – Phobos (http://www.federalspace.ru/science0615.asp). The launch of the spacecraft Phobos-Grunt originally has been scheduled for October 2009, but in September 2009 Roscosmos postponed it for late 2011 (http://www.laspace.ru/rus/phobos_sheme.php). A Memorandum of Understanding on collaboration concerning development, calibration, space flight measurements and data analysis of Liulin-F instrument onboard the Phobos-Soil mission has been signed between STIL-BAS, IBMP-RAS and NIRS, Japan. From 30.01.2009 to 07.02.2009 Liulin –F was calibrated with protons and heavy ions using charged particle accelerators Cyclotron and HIMAC at NIRS. In the paper we present some results of these exposures.

Instruments description

Liulin- F particle telescope [1] consists of two dosimetric telescopes - D1&D2, and D3&D4 arranged at two perpendicular directions. The block-diagram of the instrument is shown in Fig. 1.

Every pair of telescopes consists of two 300 µm thick, 20x10 mm area Si PIN photodiodes, operating in coincidence mode to obtain Linear Energy Transfer (LET). The distance between the parallel detectors of every telescope is 28 mm. The detectors, the charge –sensitive preamplifiers - shaping amplifiers CSA1-CSA4, and the voltage bias circuits are mounted in a separated volume inside the box of the Liulin-F instrument and are connected to printed circuit boards that contain threshold discriminators, pulse height analysis circuits, coincidence circuits, and other circuitry, mounted in another separated volume. That volume also contains a CPU board, including microprocessor, flash memory for data storage, timer, DC-DC converters, and an interface to the board telemetry/command system. The entire package has a mass of 0.5 kg and consumes 1.4 W.

One of the detectors in every telescope measures the energy deposition spectrum in the range 0.1-10 MeV (namely detectors D1 and D4), and the other in the range 0.3 -70 MeV (namely detectors D2 and D3). In that way every dosimetric telescope provides data in the energy deposition range 0.1 - 70 MeV.

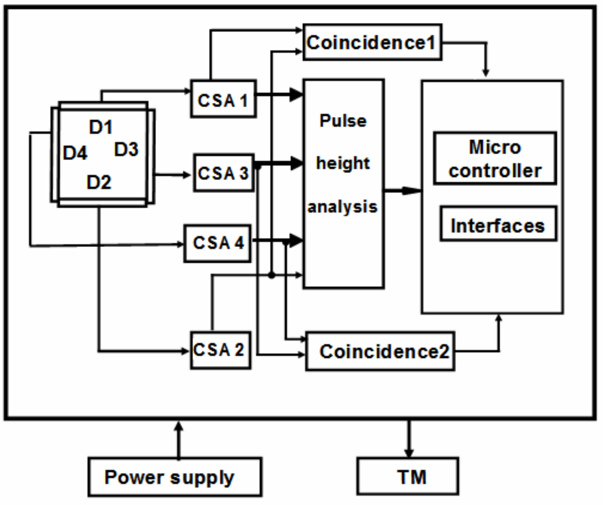

Fig. 1. Block –diagram of Liulin –F charged particle telescope.

The parameters featured by Liulin-F are: Absorbed dose rate in the range 0.04 x 10^{-6} Gy/h - 0.1 Gy/h, measured by every single detector; Particle flux in the range 0 - 10^4 particle/(cm^2.sec), measured by every single detector; Energy deposition spectra in the range 0.1-70 MeV, measured by every dosemetric telescope; LET spectrum (in H_2O) in range 0.5–120 keV/µm, measured by every dosemetric telescope.

Exposures conditions for Liulin-F at particle accelerators

The flight model of Liulin-F was exposed to protons and alpha particles at the Cyclotron Accelerator and to heavy ions at the Heavy Ion Accelerator (HIMAC) in NIRS, Chiba, Japan [4]. The objectives of the exposures were to obtain the response of the instrument to particles of charge and energy similar to that found in the galactic (GCR) and solar (SCR) cosmic radiations, to compare the response and sensitivity of the detectors and dosemetric telescopes of the instrument and to aid in reconciling differences in measurements made by various radiation instruments during space flight.

Liulin-F was positioned on a rotating and moving stage during the exposures. The stage was controlled from the control room and the beam line was represented by a laser beam. The area of the beam was at least 20x20 mm. At first Liulin-F was exposed perpendicular to the beam with beam center at the center of every one of the detectors (0^0 inclinations). After that Liulin-F was inclined at different angles relative to the beam line and rotation was made around the centre of the telescopes. Fig.2 shows the position of Liulin-F on the rotating stage in the experimental room of Cyclotron. There

Fig. 2. Liulin-F experiments at Cyclotron facility.

Table 1
Exposure conditions for Liulin-F

Accelerator	**Particle**	**E[MeV]**	**E/n[MeV]**	**LET (H2O) [keV/µm]**	**DE Si 300 µm [keV]**
Cyclotron	H	30			1020
Cyclotron	H	70			531
Cyclotron	^{4}He	100	25		4753
HIMAC	^{12}C	4800	400	10.9	6194
HIMAC	^{20}Ne	12000	600	25.5	14491

were special windows in the instrument's box covered with 30 µm Al foil and facing the detectors in order to allow penetration of 30 MeV protons and alpha particles to the detectors. The exposure conditions, representing the characteristics of the used particles - their energies, charges, LET(H2O) and deposited energies in an unshielded 300 µm Si detector at normal incidence are presented in Table 1. The expected energy deposition of these particles in the detectors of the telescopes at different shielding and angles between the telescope axis and ion beam were calculated in advance (Table 2). The calculations were used for comparison with the experimental results and assessment of the detectors shielding nonuniformity.

Experimental data and analysis

Before exposures at particle accelerators, Liulin-F was electronically calibrated and the conversion coefficients, transforming the number of the analog to digital converter channel of the instrument (ADC) to deposited energy and to LET were obtained for all detectors in all ranges of measurement. One of the goals of particle exposures was to verify these coefficients in a real measurement situation.

Experiments at Cyclotron

Liulin-F was exposed to 30 MeV and 70 MeV protons and to Helium 100 MeV, 25MeV/n. Fig.3 show the energy deposition distribution in D1 detector of 30 MeV protons obtained at 0^0 inclination of the detectors D1 and D2 axes to the ion beam. It is seen that there are two maxima, corresponding to 2465 keV and 3441 keV. The existence of two maxima is due to nonuniformity of the detector's shielding. The same way the energy

Table 2

Calculated deposited energies DE1 and DE2 in the first and second detectors of the telescopes at different shielding and incident particle angles

Particle	**E [MeV/n]**	**Shield [g/cm^2] Si**	**Angle degree**	**Shield eff [g/cm^2] Si**	**DE1 [MeV]**	**DE2 [MeV]**
H	30	1.04	0	1.04	3.37	4. 8
H	30	1.04	15	1.08	4.97	1.6
H	30	0.6	30	0.69	1.84	2.02
H	30	0.6	45	0.85	2.81	3.5
H	30	0.6	60	1.2	0.000	0.000
H	30	0.6	75	2.32	0.000	0.000
^{4}He	25	0.4	0	0.4	6.52	7.08
^{4}He	25	0.5	0	0.5	7.41	8.33
^{4}He	25	0.6	0	0.6	8.86	10.8
^{4}He	25	0.7	0	0.7	12.2	23.5
^{4}He	25	0.825	0	0.825	8.16	0.000
^{4}He	25	0.9	0	0.9	0.000	0.000
^{12}C	400	0.6	0	0.6	6.41	6.41
^{20}Ne	600	0.6	0	0.6	16.03	16.0

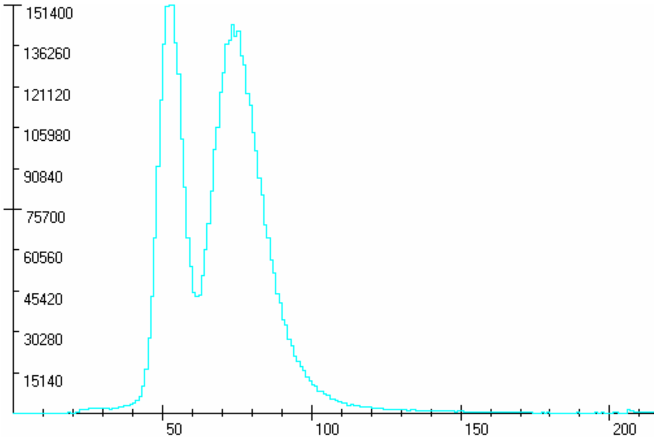

Fig.3. Deposited energy distribution of 30 MeV protons in D1. The instrument was oriented with D1 to the ion beam, the angle between the beam and D1&D2 axes was 0^0. On X is the spectral channel number, on Y –particles number.

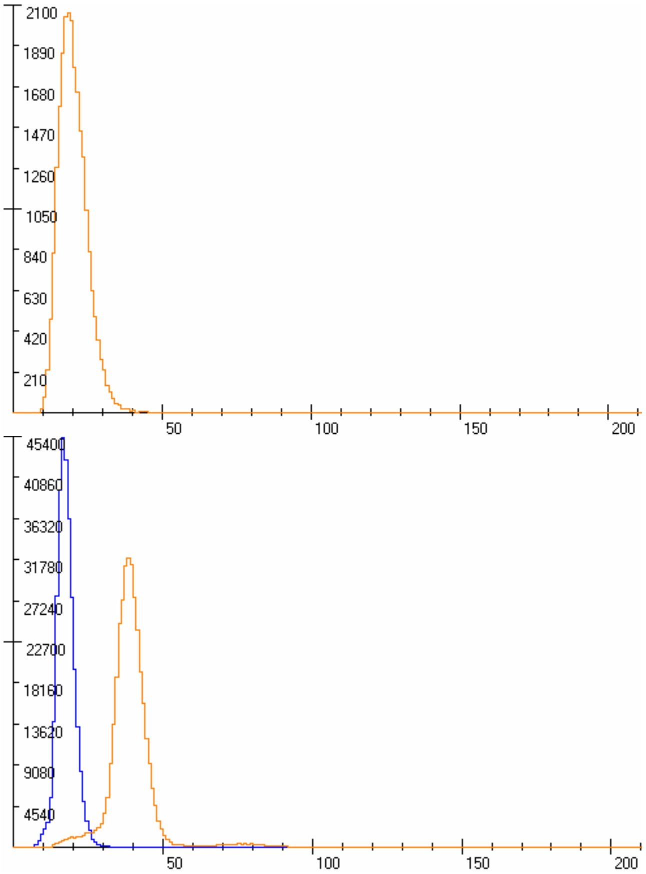

Fig.4. Deposited energy distribution of 70 MeV protons in D2 and D3 at 00^0 inclination of D2 axis to the ion beam (1-st panel) and 30^0 inclination of D3 axis(left curve in the 2-nd panel and 60^0 of D2 axes (right curve in 2-nd panel).

deposition for inclinations of 15^0, 30^0, 45^0, 60^0 и 180^0 were measured. Based on the measurements the shielding thickness of D1 was estimated to vary in the range 0.85-1.04 g/cm2.

Analogical procedure has been used to estimate the shielding of the other detectors of Liulin-F.

The exposures to 70 MeV protons at different directions and rotations allowed the calibration and intercalibration of the two pair telescopes of Liulin-F and obtaining the calibration coefficients for energy deposition and LET distribution in low energy range of measurement of each one Si detector. Fig.4. shows some results of deposited energy distribution measurements in two perpendicular detectors D1 and D3 at different inclinations of the detectors' axes relative to the ion beam. While D2 and D3 are with equal energy deposition ranges, it is seen from the picture that: 1) at 0^0 of D2 and 90^0 inclination of D3 only in D1 were registered particles, because D3 was outside the beam; 2) At 0^0 and 60^0 inclinations the energy deposition maximums in D3 are respectively in 19-th and 39-th channel (twice difference), corresponding to twice larger path length $R=h/\cos\alpha$ in the detector at 60^0 (h-thickness of the detector, α -incident angle). The experiments with 70 MeV protons at different inclinations and positions showed that the conversion coefficients for detectors D2 and D3 are equal. The same concerns D1 and D4. They also show that the conversion coefficients in low energy range of measurement of each one Si detector, obtained during electronic calibrations of Liulin-F, are close to those obtained during exposures with 70 MeV protons.

When the particle flux of 4He, 100 MeV, 25MeV/n was targeted to detectors D1 and D4, the peaks of energy depositions in these detectors were outside the energy deposition range of them and were recorded in the last channels of ADC. In detectors D2 and D3 were registered only few particles. The results of that exposure allowed obtaining of the shielding thickness against D2 and D3. When the alpha particle flux was targeted to detectors D2 and D3, the peaks of energy depositions in these detectors were in the last spectral channels of their low energy ranges and in first channels of the high energy ranges, allowing obtaining the correct limits of the ranges and the conversion coefficients at these limits.

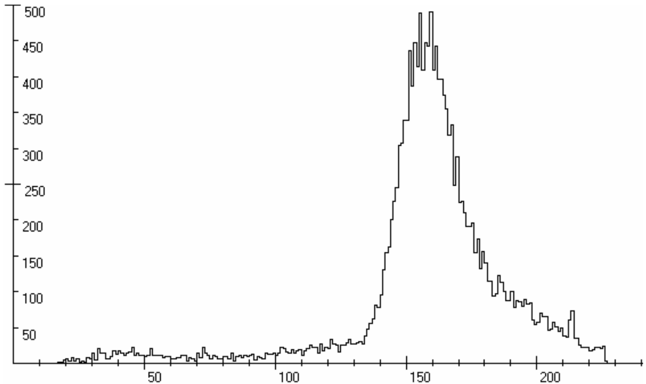

Fig.5. Deposited energy distribution of ^{12}C 400 MeV/n in the high energy deposition range of D4. The peak of the distribution corresponds to 6873 keV.

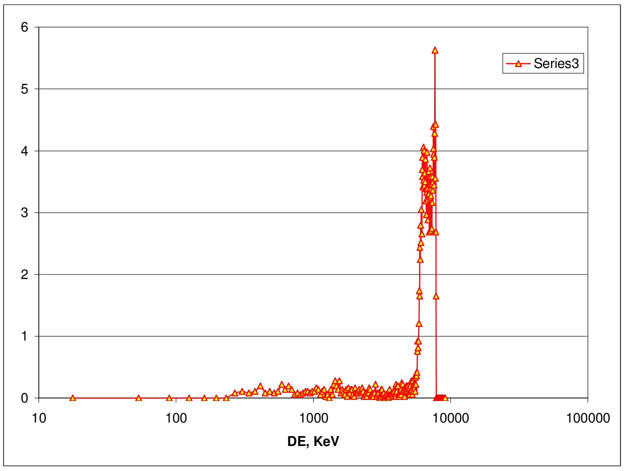

Fig. 6. *LET spectrum of C 400 MeV/u, obtained in D2 detector at 0^0 inclination of D1&D2 telescope axis to the incident beam.*

Experiments at HIMAC

Liulin-F was exposed to Carbon, 400 MeV/n and Neon, 600 MeV/n at HIMAC.

The exposures to Carbon 12C, 400 MeV/n allowed the calibration and intercalibration of the two pair telescopes of Liulin-F and obtaining the calibration coefficients for energy deposition and LET distribution in low energy range of measurement of detectors D2 and D3 and high energy range of D1 and D4. Fig. 5 shows the deposited energy distribution in D4. The peak of the distribution is in 156÷160 channels of ADC, corresponding to 6873 keV, using electronic calibration coefficients. The same way was obtained that the peak of the distribution in D1 corresponds to 6917 keV. It is seen that both distributions are very close, confirming the both coefficients are equal. Simultaneously these maxima differ from the calculated in Table 2 values of 6413 keV for ^{12}C energy deposition in the detectors behind 0.6g/cm^2 shielding by 6-7%. The fact leads to decreasing of the conversion coefficients in high energy ranges of D1 and D4.

Fig.6 shows the energy deposition spectrum in D2 in coincidence mode with D1 (LET spectrum). The distribution was obtained in low energy range of the detector, when the telescope's D1-D2 axis was inclined at 0^0 to the ion beam. The maximum of LET distribution is in 180 ADC channel and corresponds to 6426 keV, practically coinciding with the preliminary calculated value and confirming the correctness of the electronic calibrations.

The same concerns detector D3, showing that the coefficients for D2 and D3 are equal in their low energy ranges and correspond to electronically obtained values. The maximum of LET distribution then is 10.98 keV/μm in water.

The exposures to Neon 600 MeV/n allowed the calibration and intercalibration of the two pair telescopes of Liulin-F and obtaining the calibration coefficients for energy deposition and LET distribution in high energy range of measurement of detectors D2 and D3.The LET range of neon beam was outside the range of D1 and D4 and all measurements in them were registered in their last spectral channels.

Fig.7 shows the LET distributions of Neon 600 MeV/n ions in the high LET ranges of D2 and D3. The maxima of both

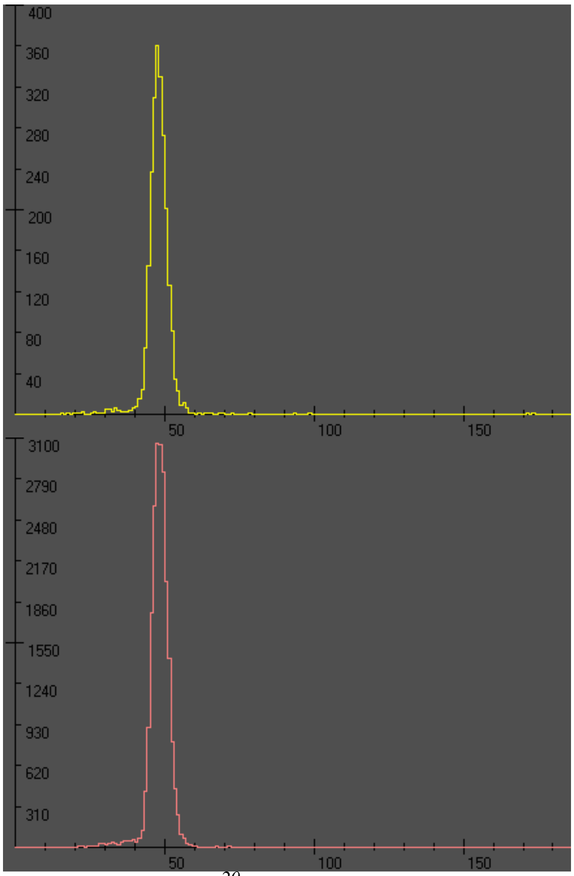

Fig. 7. LET spectra of ^{20}Ne 600 MeV/n ions in high LET range of D2 (upper panel) and D3 (bottom panel).

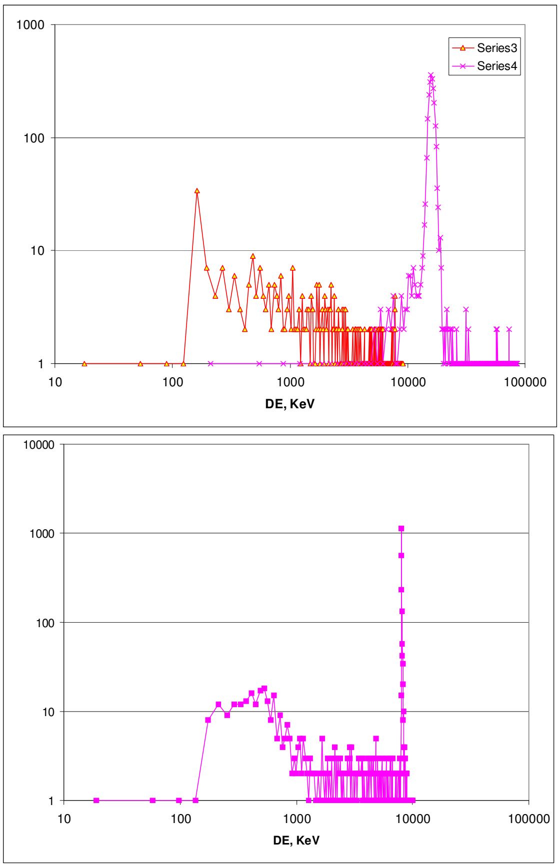

Fig.8. *LET spectrum of Ne 600 MeV/u, obtained in D2 (upper panel) and D1 (bottom panel) detectors at 0^0 inclination of D1&D2 telescope* axis to the incident beam.

distributions are in 49-50 channels of ADC, i.e. the maximum of the deposited energy is 15.63 MeV using electronically obtained coefficients and very close to theoretically calculated value 16.03 MeV. The obtained results confirmed the correctness of electronic calibrations.

The full LET spectra of ^{20}Ne 600 MeV/n ions, measured in D2-D1 telescope are shown in Fig. 8.

The left part of the LET distribution in D2 (upper panel) was measured in low LET range of the detector and is mainly due to secondary radiation, resulting from interactions of primary neon beam with surrounding materials. The main peak represents the LET distribution of the neon ions and was measured in high LET range of this detector. The obtained LET(H2O) of ^{20}Ne 600 MeV/n is 26.7 keV/µm –it is in good agreement with the value of 25.5 keV/µm provided in Table 1, having in mind the shielding of the detectors.

The LET in D1 (bottom panel) was measured in high LET range of the detector- both mean and secondary radiations distributions. It is seen that the main distribution is in the last channel of D1, because the LET range of the detector is lower than the LET of the ion beam.

Conclusions

The main results obtained during exposures of Liulin-F at Cyclotron and HIMAC can be summarized as follow:

The exposures to proton and heavy ion beams allowed estimating the nonuniformity and thickness of detectors shielding, intercalibration of the two pair telescopes of Liulin-F and obtaining the calibration coefficients for energy deposition and LET distribution in both low and high range of measurement of each one Si detector. The results showed the correctness of the electronic calibrations and allowed verification of the obtained coefficients. The obtained results will be used in flight data analysis.

Acknowledgements

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REFERENCES

[1] Semkova J., Maltchev S. , Tomov B. Matviichuk Yu., Dachev Ts. , Koleva R., Benghin V., Chernykh I., Shurshakov V., Petrov V, Charged Particle Telescope Liulin-Phobos for Radiation Environment Study during Upcoming Phobos Sample Return Mission, *Proceedings of Fundamental Space Research Conference,* 351-354, ISSBN 978-954-322-316-9, 2008..

[2] Dachev, Ts.P., J.V. Semkova, S. Maltchev, B. Tomov, Yu. Matviichuk, R. Koleva, V. Benghin, I. Chernykh, V. Shurshakov, V. Petrov, G. De Angelis, Radiation Environment Study During Phobos Sample Return Mission By Charged Particle Telescope Liulin-Phobos, *Proceedings of 40th LPSC*, The Woodlands, Texas, USA, 23-27th March 2009, http://www.lpi.usra.edu/meetings/lpsc2009/pdf/1297.pdf

[3] Uchihory, Y., E.R. Benton. *Results from the first two InterComparison of dosimetric instruments for Cosmic radiation with Heavy Ions Beams at NIRS (ICCHIBAN-1&2) Experiments,* NIRS, JAPAN, 2004.