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NUCLEON Satellite Mission. Present status.

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This paper presents the current status of the NUCLEON experiment aimed to the direct measurements of the elemental energy spectra of high-energy (10^{12}-10^{15} eV) cosmic rays (CR) during 5 years (2008-2012) abroad the Russian regular satellite. The main goal is to clarify the long-standing problems of CR origin sites and mechanism of acceleration, peculiarities of diffusion in the Galaxy in the energy region near the knee by the measuring of secondary to primary ratio, differences in slopes of different nuclear components. Advantages and peculiarities of the project are discussed.

1. Introduction

One of the most crucial problems in cosmic ray physics is the origin of the knee in Galactic cosmic ray spectrum. The astrophysical reason of it remains still unknown, mostly due to the absence of reliable data about different nuclei components composing the all particle spectrum in the knee region, because it has been measured by a large number of ground-based extensive air shower (EAS) experiments, where the procedure of the primary particle charge estimation is model and energy dependent. To improve situation the data of the individual elemental energy spectra from protons to nickel before the knee at 10 TeV – 1 PeV must be substantially improved. These elemental spectra comprise the signatures of the cosmic ray sources, acceleration mechanism and the parameters of CR diffusion in the Galaxy, such as the energy dependence of the diffusion coefficient (DE). This dependence can be obtained from the secondary to primary nuclei ratio, and only if this dependence is known we can transform the observed near the Earth secondary spectra to the primary spectra near the acceleration sites in the Galaxy. But this is a complicated task, because this ratio gradually decreases with energy as E-0.6-1.0 and can reach very small value. It seems that balloon and satellite experiments can help to do this work, but it could be done only with large aperture apparatus with long time exposure due to small intensity of nuclear species of CRs at high energy, especially as concerned the flux of secondary nuclei. But among the huge arsenal of modern experimental methods for energy measurement in energy region >1 TeV only the ionization calorimeter (IC) method may be applied over a wide energy range for all CR nuclei ($Z = 1 - 30$) simultaneously. But even thin calorimeters (like CREAM or ATIC balloon installation) have very large weight ~ about 2-3 ton, and as a result these investigations become very expensive. So in [1, 2] the new method (Kinematic Lightweight Energy Meter) was proposed as a new approach to CR spectral measurements. KLEM method is based on event for event measuring the spatial density of the flux of secondary charged and neutral particles produced in the vertex point of nuclear interaction in the carbon target and passing through a thin tungsten gamma-converter. The KLEM concept is now realizing in the NUCLEON project.

2. Device concept, space vehicle

A main idea of this project – to develop the method and to design a scientific instrument being able to measure elemental spectra of cosmic rays in a wide energy range 10^{11}-10^{15} eV with the high charge resolution. At the same time the principal condition is that this instrument should be a relatively light (weight <200 кг) and small (size <1.0 $м^3$) to be of use on regular serial Russian satellites as an additional load. That makes possible long duration (5 years) regular flights and provides the rather low price of the project. During last tree years (2001-2003) R&D stage has been finished and at the beginning of the 2004 the Russian Federal Space Agency turned the project NUCLEON to the construction stage. In these years acceleration beam tests of various prototype NUCLEON systems and many sets of Monte-Carlo simulations were performed. As a result the design of the device was optimized, basing on the latest investigations and on new parameters of the satellite. The design of the device is presented in the next chapter, the results of the test beams and Monte Carlo simulations are presented in [6].

During R&D stage we have considered a possibility to arrange the instrument on different satellites. As the most optimal for the NUCLEON project the new regular Russian KOSMOS type satellite (Figure 1) developed by “DB Arsenal” (St. Petersburg) was approved. In 2004 the optimization of the device was performed taking into account the facility of the Spacecraft, integration with the satellite support and scientific purposes. The NUCLEON scientific facility consists of: NUCLEON scientific device; special mechanical/electronic system for NUCLEON device installation; additional separate remote telemetry system; separate antenna-feeder system; cooling system. Power supply and NUCLEON complex control will be realized by the base satellite.

The NUCLEON instrument is planned to be launched in 2008 with exposure time in orbit not less than 5 years. Main technical limitations: a total weight should be not more than 265 kg (for scientific device should be not more than 165 kg), a total complex power consumption must not exceed 150 W (for scientific device must not exceed 120 W), and the nominal telemetry rates are expected to be 270 MB per day.

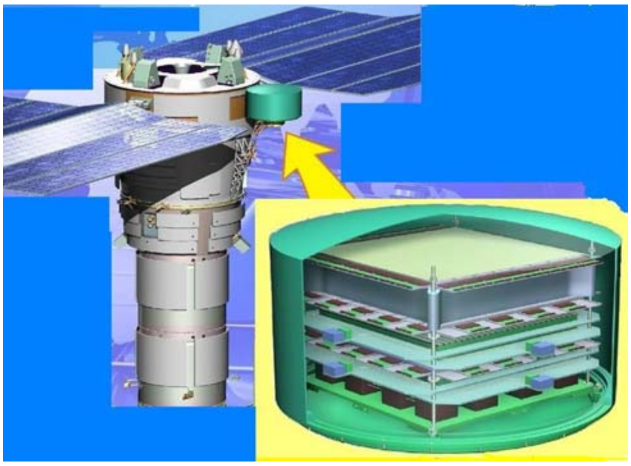

Figure 1. KOSMOS type satellite with NUCLEON system.

3. The structure of the NUCLEON device

The schematic view of the NUCLEON device is shown in Figure 2. It includes charge measuring system, tracker and energy measuring system, the trigger system, control electronics. All systems are mounted inside a pressurized container. The thickness of the container wall is equal to 2.5 mm of aluminum (~ 0.7 g/cm^2), that is much less that the residual atmosphere in balloon experiments.

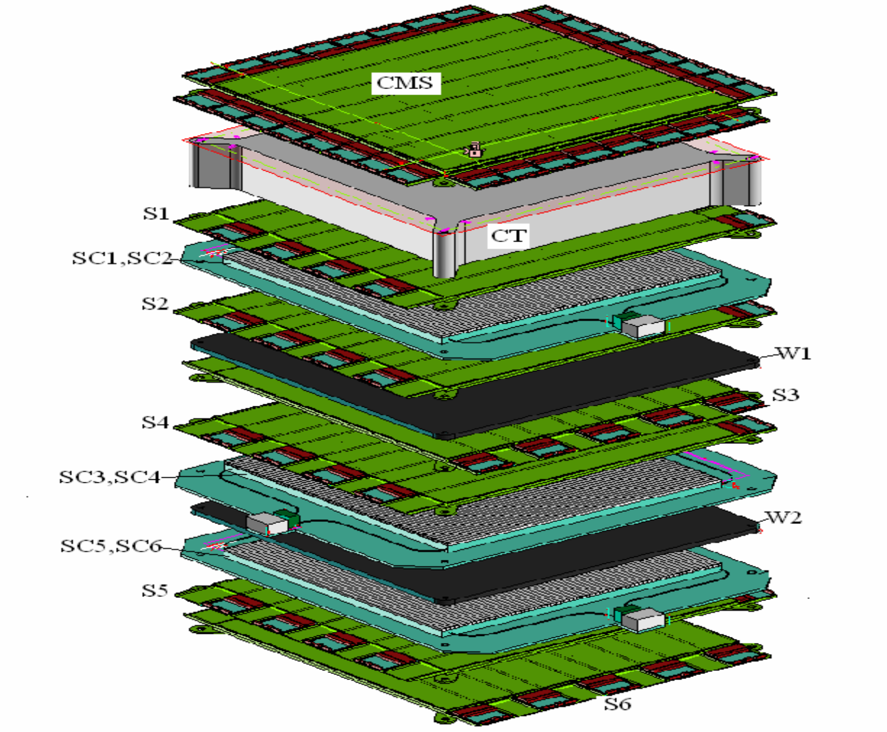

Figure 2. Schematic view of NUCLEON instrument

The charge measuring system (CMS) consists of 4 silicon detectors layers in the volume of 53×53×2.5 см^3. Every silicon detector layer contains 64 subdetectors 6.2×6.2×0.3 см^3, every of which is divided by 16 pads with the size ~ 2.4 см^2 These layers are used for precise charge measurements. A fine segmented structure of the charge detector allows to decrease influence of back scattered particles and 4 layers allow to minimize the ionization fluctuations. Results of detailed simulations and the test experiment [3] have shown that the accuracy of charge measurement turned out to be about 0.3 unit of charge that is enough to measure nuclei charges at high energy in the Z = 1 – 30 domain.

The tracker and energy measuring system consists of 8 elements: 6 identical layers of micro-strip silicon detectors (**S1-S6**), the carbon block (**CT**) with the size 50×50×9 см^2 served as a target, 2 identical tungsten layers (**W1,W2**) with the size 50×50×0.7 см^3 served as a gamma-converter. Every layer of silicon micro-strip detectors occupies a volume 53×53×1.0 см$^{3.}$ Every silicon micro-strip layer contains 72 detectors with the size 6.2×6.2×0.3 см^3, arranged in 9 ladders with 8 detectors linked in series. A micro-strip pitch optimization has been done, and pitch size was reduced to 0.46 мм, to reduce a power consumption of the device. Our calculation shows this reduce without essential degradation of energy resolution [6]. The spatial density of secondary particles is measured by the two lowest micro-strip silicon layers. The energy of incident particle is estimated based on the S parameter of KLEM method [2]. Two prototype NUCLEON beam test experiments and full Monte-Carlo simulations [6] show that the accuracy of energy determination is about ~ 70-80% in an individual event. The accuracy of track trajectory reconstruction at the level of charge detector comprises several mm depending on the arrival angle of the particle. A probability of wrong localization of the nuclear interaction vertex point in a target is less than <8%.

The trigger system (SC1-SC6) consists of three double layer 16-strip scintillator detectors (size ~ $500\times30\times0.5$ mm^3) with a few 1 mm multicladding WLS KURARAY Y-11 fibers. Light signals are detected from an opposite side of each strip by 1 and 16-channel PMTs . Signals at the level of ~10 photoelectrons are obtained from MIP particles. System of 1-channel PMTs is used to get the total amplitude signal from every scintillator plane in production of the 1-st level trigger signal during 50 ns. A few planes of scintillator strips were produced and tested with β-source^{90}**Sr**, cosmic muons and accelerator beams. Their mechanical stability were checked against of vibrations, strokes etc. expected at the launch.

Control electronics are placed at the bottom of the device in the box $50\times50\times16$ см^3 .

4. Scientific Objectives.

The effective exposure factor of NUCLEON instrument calculated for 5 year exposition is GT_{eff} = 170 m^{2}sr days for protons and 460 m^2 sr days for iron nuclei. It allows to collect statistics, being enough (together with high charge resolution) to realize scientific objectives listed below, that provides the basis for understanding the origin of cosmic rays:

1. Measurement of the composition and spectra for individual elements in the largely unexplored high-energy region 10^{12}-10^{15} eV,
2. Measurement of secondary to primary ratios to determine the energy dependence of particle propagation in the galaxy,
3. Performance of 5 year monitoring of different CR nuclei arrival intensity in space.

5. Acknowledgements

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