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The Baksan Neutrino Observatory*

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Abstract. An overall view of the history of the Baksan Neutrino Observatory INR RAS creation is presented. Ground-based and underground facilities used to study cosmic rays, rare nuclear reactions and decays, register solar neutrinos, observe various geophysical phenomena are described. Some main results obtained with these facilities are given.

1 History

In the late 1950s, the ideas to build an underground complex of scientific facilities to carry out fundamental researches in cosmic-ray physics and neutrino astrophysics were proposed. In the 1960s academician M.A. Markov, the leading figure in this field at that time, suggested to study the weak interaction in underground experiments using neutrino from cosmic rays. (A photo of M.A. Markov is shown in fig. 1.) The suggested technique was based on the registration of muons generated in the interactions of neutrinos with nucleons of the matter of the Earth's interior. Theoretical calculations were performed and a first evaluation of the intensity of the high-energy neutrino flux from possible galactic sources was obtained.

Another field of research that needs underground laboratories is the study of the neutrino flux coming from the Sun. The background of ground-based detectors is significantly larger than that of the underground environment, due to cosmic-ray muons, and therefore completely masks the sought-for effect. As there was no deep underground mine in the USSR at that time that would fit the required conditions, it was proposed to build one for a complex of underground laboratories situated on the horizontal plane under some high mountain. On June 19, 1963 the resolution of the Academy of Sciences of the USSR approved the construction of an underground complex of laboratories, and a new section in the P.N. Lebedev Physical Institute of the AS of the USSR called "Neutrino" was organized with Professor G.T. Zatsepin as its Head and Professor A.E. Chudakov as his assistant.

By 1967 the necessary scientific justification for the neutrino complex project had been promoted and the building of the future Baksan Neutrino Observatory, as a department of the Institute for Nuclear Research of the AS of the USSR, had been started. The first Director of the Neutrino station was Professor A.A. Pomansky.

(The leaders of this program are shown in the photo in fig. 2.)

The proper place for the future observatory was found in the vicinity of Mount Elbrus, in the Baksan valley of Kabardino-Balkaria (Russia). According to the building project, two parallel horizontal mines were to be excavated under the mount Andyrchy (3922 m) to accommodate future underground laboratories. The cosmic-ray flux at the end of the mine tunnel (~ 4000 m from the entrance) is at least 7 orders of magnitude lower than that on the surface.

The original project was to create only two underground laboratories: for the scintillation telescope and the chlorine-argon neutrino telescope. Further scientific development led to the construction of many other scientific laboratories related to cosmic-ray studies and other research that require underground shielding conditions. Necessary engineer and utility structures, as apartment houses for the staff were built and finally the original project of two facilities gave rise to the Baksan Neutrino Observatory of the Institute of Nuclear Research of RAS, and the newly born village was called Neutrino. That was the first specialized scientific underground complex built to carry out investigation into a wide spectrum of studies in cosmic-ray physics, elementary particles physics, and neutrino astrophysics [1]. In 1998 a group of scientists, *viz.* E.N. Alexeyev, A.V. Voevodsky, V.N. Gavrin, G.T. Zatsepin, A.A. Pomansky, A.N. Tavhelidze and A.E. Chudakov, who had made a major contribution into the creation of the Baksan Neutrino Observatory, was

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Fig. 1. Photo of M.A. Markov.

Fig. 2. Photo (1972) of people involved in the Baksan Neutrino Observatory creation. From left to right: the first Director of the BNO, A.A. Pomansky; the building manager; the researchers V.V. Alekseenko and V.A. Kuznetsov; the official people, the Academician G.T. Zatsepin, the President of the AS of the USSR Academician M.V. Keldysh; the vice-Director of BNO E.N. Alexeev; the Director of the INR AS USSR Academician A.N. Tavhelidze; the Corresponding Member of the AS of the USSR A.E. Chudakov.

Fig. 3. The overview of the BNO INR RAS and Neutrino village: 1) Elling building with Carpet detection facility; 2) shallow underground hall with Carpet-2 detection facility; 3) laboratory's buildings; 4) schematic view of Andyrchy-array at the mountain slope; 5) entrances to the Main and Auxiliary adits.

awarded with a State Prize. Later, V.N. Gavrin and G.T. Zatsepin were awarded with the B.M. Pontecorvo Prize and with the D.V. Skobeltzin Gold Medal for the creation of the Gallium-Germanium Neutrino Telescope and a valuable contribution into the study of solar neutrino.

The overview of the BNO INR RAS and Neutrino village is shown in fig. 3.

2 The surface based complex of BNO

2.1 Carpet

In 1973 the first facility of the Observatory came into operation. It was the ground-based detection facility Carpet composed of 400 standard scintillation detectors situated in the experimental hall called Elling [2,3]. Each detector is a rectangular aluminum tank (70 cm × 70 cm × 30 cm) filled with a liquid scintillator on the base of white spirit (a high-purity kerosene fraction of petroleum). Each tank is viewed by PMT (15 cm in diameter) through a viewing port mounted on the central round hole of the larger face of the tank. Each PMT is covered with an opaque screening cylindrical casing with a unit of primary electronics attached to its top. Data are taken from 5th and 12th diode of PMT. A charged relativistic particle (r.p.) passing through the scintillator gives an energy release of about 50 MeV inducing a signal on the anode of PMT of 70 mV amplitude for the load of 75 Ω. Anode signals of standard scintillation detectors are summed into groups composed of 20, 100 and 400 detectors. Pulses from the dynodes go to the amplitude-to-time (A-T) converter and integral discriminator which are on the casing of PMT. Analysis of the amplitude distribution of signals and of their delay in arrival to the registering device allows one to reconstruct the spatial distribution and

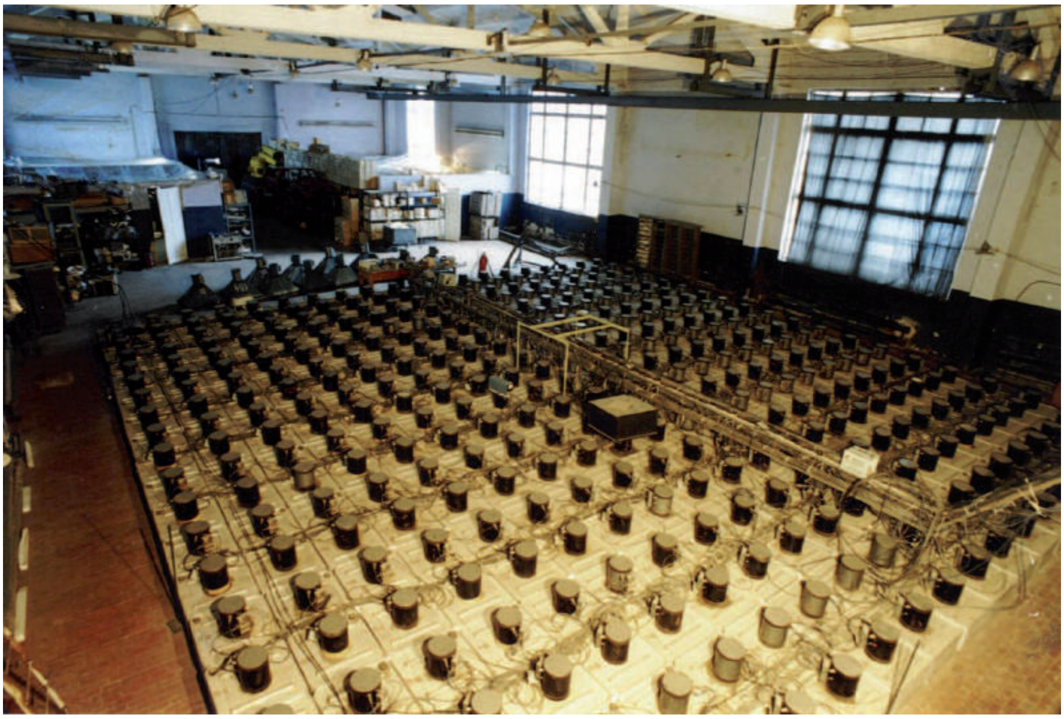

Fig. 4. The overview of the Carpet facility.

direction of particles of an extensive air shower. This ground-based facility of 200 m^2, shown in fig. 4, is an exact replica of the one of the eight layers of the Baksan Underground Scintillation Telescope that came into operation later.

The Carpet facility was targeted to study primary cosmic rays of $5.7 \cdot 10^9$–10^{16} eV, mechanisms and characteristics of their interaction with particles of the atmosphere by registering a single secondary component together with EAS generated in such interactions. Six outdoor points, each containing nine scintillation detectors, have been added to the central multiple-unit detector. Four of these points are distributed symmetrically on a circle of 30 m radius, and two points are on a circle of 40 m radius with regard to the Carpet's center. A neutron monitor in a separate compartment of the basic hall is targeted to register neutrons generated by cosmic rays.

The Carpet (now Carpet-2 [4]) performance was significantly improved once one section (the middle one) of the three-sectioned large underground Muon Detector (3MD) facility has come into operation in 1998. The middle section is at about 40 m from the Carpet's center [5]. MD is under a 2 m ground layer (5 m.w.e.), which absorbs the soft c.r. component, and is composed of 175 scintillator detectors (1 m^2 each and made of a plastic scintillator of 5 cm thickness). The continuous registering area of the facility is 175 m^2 (5 m $\times$ 35 m). The threshold energy for muons is 1 GeV. The sensitivity of the facility is 0.006 particles/m^2.

The creation of Carpet-3, the advanced version of Carpet-2, is now in progress. It is supposed to be a multi-purpose facility registering cosmic rays. Its main purpose would be to study the knee of the c.r. spectrum. Carpet-3 would register the following components of EASs: 1) electron and photon; 2) muon (with threshold of 1 GeV); 3) hadron [6,7].

2.2 Carpet, main researches

2.2.1 EAS's core

Analysis of the obtained data allowed to interpret the presence of multi-jets showers as a result of a generation of streams of particles with large transverse momentum, and to evaluate the cross-section of this process in hadron-hadron interactions for the range of energies up to 500 GeV [8,9]. This experimental result was the first one to confirm quantum chromodynamics predictions and was published before the SPS-collider in CERN had measured this value.

2.2.2 Cosmic-rays flux variations

Large counting rate of single muons from cosmic rays ($\sim 4.3 \cdot 10^4\,\mathrm{s}^{-1}$) allows high statistical accuracy even for small time intervals (0.03% for $4'$), and as a consequence makes it possible to observe short-time variations (micro-variations). None of these have been found with the Carpet array at a confidence level of 0.001%. During this research work a new type of sporadic temporary variations characterized by small time was discovered and attributed to the meteorological effects [10–12]. Their strong correlation with the electric field of the atmosphere (such variations occur only during thunderstorms) allowed one to explain this phenomenon and quantitatively describe it. The gigantic increase of cosmic-ray intensity during the powerful solar burst on September 29, 1989 is one of the most interesting examples of temporary variations in the muon counting rate.

Particles of solar origin with energies up to 10^{10} eV were observed for the first time in such event, and it was the Carpet facility that provided the most evident and accurate data at that time [13].

2.2.3 Cosmic-ray anisotropy

Studying showers of low energy corresponding to primary cosmic rays (c.r.) of 10^{13} eV revealed anisotropy of the latter. First and second harmonics have been found in the count rate of these showers for sidereal time. Cosmic-ray anisotropy for 10^{13} eV was calculated to be $0.05 \pm 0.005\%$ [14].

2.2.4 Ultra-high-energy gamma astronomy

Air showers of $\geq 10^{14}$ eV are continuously registered and the data are analyzed along several lines: search for point sources of gamma-quanta of the same energy [15]; search for signals from extended gamma-ray sources (mainly in the galactic plane) [16]; search for c.r. anisotropy at these energies [17]; search for X-ray and gamma-ray bursts for known sources [18]. One of the interesting results is the registration of the burst in Crab Nebula, on February 23, 1989. It was the team of scientists of the Carpet that first published the result [19]. Later it was confirmed by teams of Kolar Gold Mine (India) and EAS Top (LNGS) facilities.

2.2.5 Neutron flux variations in the atmosphere

Studying air neutron flux variation involves continuous recording of neutron monitor count rate; the data obtained are sent across the Internet to `www.nmdb.eu-nest-seach.php`. Analysis of the parameters of variations presents information used in further studies of characteristics of solar bursts and their effect on the interplanetary magnetic field.

2.3 Carpet-2

The Carpet-2 facility allows studying EAS muon component. The dependence of the mean number of muons of energy not smaller than 1 GeV (N_μ) registered by MD on the total number of EAS particles (N_e) has been found to be $N_\mu \sim N_e^\alpha$, where $\alpha = 0.8$. Analysis of the data obtained with MD and Carpet allowed scientists to significantly increase the sensitivity of the experiment searching for local sources of ultra-high-energy gamma-quanta, to start studying the chemical composition of primary cosmic rays of $E \geq 10^{14}$ eV, and to carry out investigation of variations of muons with energies above 1 GeV [20].

2.4 Andyrchy

In 1996 the Andyrchy array targeted to register EASs with $E_0 \geq 10^{14}$ eV came into operation. It consists of 37 standard detectors of the same type as those of Carpet-2 ($1\,\mathrm{m}^2$ each, plastic scintillator) evenly spread over the area of $45000\,\mathrm{m}^2$ on the slope of the Andyrchy mountain with a maximum gradient of altitude of 150 m and at a distance of 40 m from each other [21,22]. One of the detectors is shown in fig. 5.

The central detector of Andyrchy is located over BUST, and a vertical thickness of mountain rock separating them is 350 m. It is important to secure the performance of a facility located on the mountain slope during periods of thunderstorm activities. This task has been successfully solved by registering pulses of electromagnetic oscillations generated in lighting discharges. As the increase in amplitude of the pulses with thunderstorm approaching reaches a specified threshold, the electrical network (at the point where the data are collected) automatically disconnects to form short segments, which are switched off from the detector and are reloaded to the dischargers. The network configuration resumes its functioning after the thunderstorm is over [23].

The following researches are carried out at Andyrchy: anisotropy of cosmic rays with $E_0 \geq 10^{14}$ [24]; search for gamma-ray bursts with hard energy spectrum [25,26] and search for of evaporating primordial black holes [27,28].

The Andyrchy array and BUST is a complex of two facilities, situated one upon the other. It is used to study the primary cosmic-ray spectrum and its composition in the energy region of the knee, a change in the spectral index at about $3 \cdot 10^{15}$ eV [29–32].

Fig. 5. One of the detectors of the Andyrchy array.

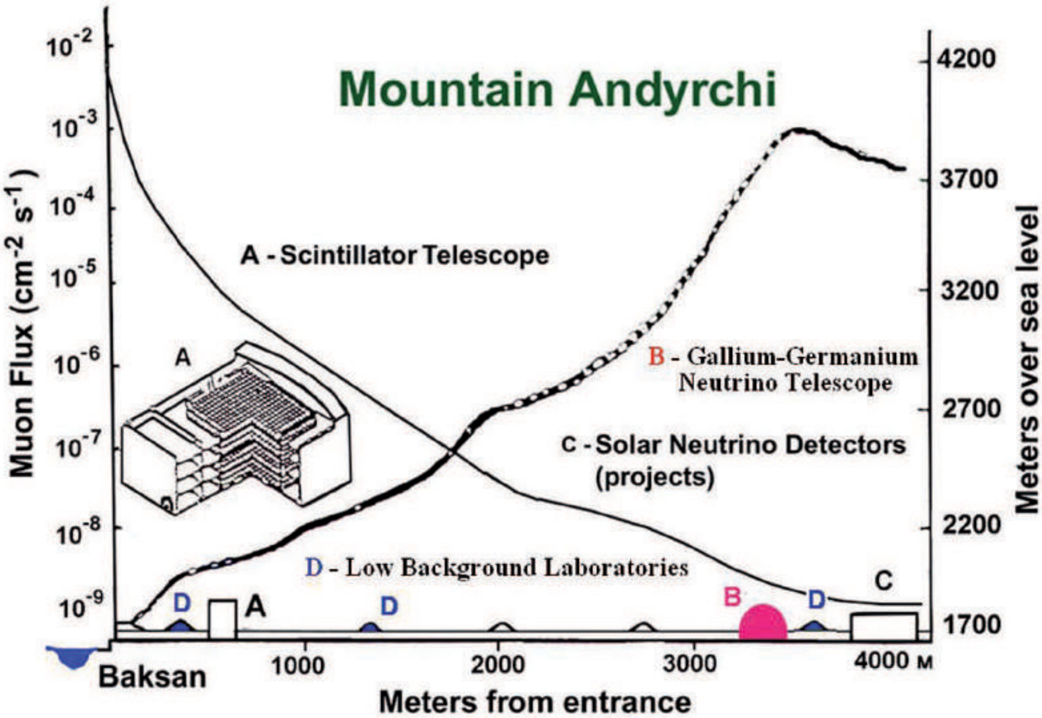

Fig. 6. Schematic view of a section of the Andyrchy slope along the adit (right scale) and dependence of underground muon flux on the laboratory location depth (left scale).

3 The underground complex of BNO

Schematic view of a longitudinal section of the BNO adit and Andyrchy slope is shown in fig. 6 presenting the locations of different underground laboratories and the dependence of underground muon flux on the distance from the entrance. Descriptions of the laboratories are adduced below.

4 The Baksan Underground Scintillation Telescope

The Baksan Underground Scintillation Telescope (BUST) has come into operation in 1978. It was targeted to solve various tasks in astrophysics, cosmic-rays physics and elementary particle physics [33]. BUST is situated in the underground

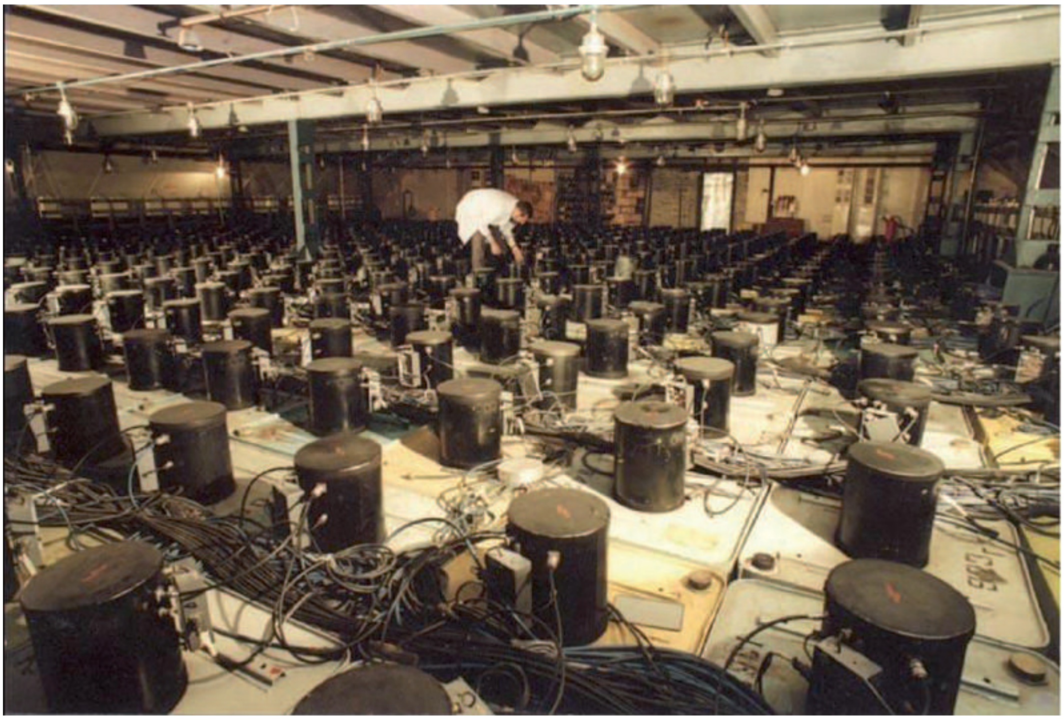

Fig. 7. A view of the BUST top horizontal plane.

hall of $\sim 12000\,\mathrm{m}^3$ at a distance of 550 m from the entrance to the underground horizontal tunnel. The effective thickness of the ground above BUST is $850\,\mathrm{g/cm}^2$. The telescope is a rectangular building of 11.1 m height and $280\,\mathrm{m}^2$ base. The blocks of the building are made of low-radioactive concrete. Its four horizontal and four vertical planes are covered with standard scintillation detectors (3180 in total). A view of one of the horizontal planes is shown in fig. 7.

The total mass of the telescope is 2500 t, that of the scintillator is 330 t. Signals are taken from each of 3180 standard scintillation detectors and processed in the same way as those of the Carpet array. The threshold of the A-T converter corresponds to 10 r.p. passing through the detector. The threshold of integral discriminator corresponds to energy release of 10 MeV in the detector. Signals from individual A-T converters, from integral discriminators, and anode signals from a group of detectors from each of 8 layers of the telescope go to the registering devices in the apparatus hall. Analysis of the signals allows one to determine the coordinates of the detectors through which particles have passed and their arrival directions. The information from registering devices together with that of absolute- and relative-time systems goes via a direct channel to DAS (data accumulation system). Every 15 minutes the collected information that has been preliminary processed goes through the optical fiber to the BUST server. About ten diagnostic programs are running simultaneously providing information on the performance of all the systems of the telescope.

Though relatively small, the thickness of the mountain rock above the telescope reduces the background caused by c.r. by 3600 times in comparison with that on the surface (the count rate of single muons with $E > 0.2\,\mathrm{TeV}$ is $12\,\mathrm{s}^{-1}$). The reduced c.r. background allows scientists to study problems related to rare processes registration, such as the measurement of the muon flux generated by high-energy neutrinos, the search for neutrino bursts accompanying a star collapse in the Galaxy and others. At the same time, the residual c.r. intensity in the underground environment allows to carry out a research into a wide range of tasks of cosmic-ray physics: anisotropy of c.r. of energy higher than $10^{12}\,\mathrm{eV}$, chemical composition of primary c.r. of 10^{12}–$10^{16}\,\mathrm{eV}$, interaction of muons of energy larger than 1 TeV with matter, and others.

4.1 BUST: Experiments and results

The most important results obtained over the years of research are the following:

- the muon flux generated by atmospheric neutrino of cosmic rays in the rock under BUST has been measured to be $[I_\mu^\nu = (2.60 \pm 0.15) \cdot 10^{-13}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}]$ [34];
- one of the first limits obtained for the oscillation parameters of atmospheric neutrinos of $v_\mu \to v_\tau$ and $v_\mu \to v_e$ types [35];
- a limit on high-energy neutrino flux from local sources in the galactic plane;
- the best limit, for the time, on the slow and heavy magnetic monopoles $[P \leq 5.5 \cdot 10^{-16}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}]$ [36];

- the amplitude $[(12.3 \pm 2) \cdot 10^{-4}]$ and phase $[1.6 \pm 0.8]$ (in sidereal time) of the first harmonic of c.r. anisotropy have been measured [24];
- data accumulated during 30 years (life-time 26.2 y) of monitoring the Galaxy in the study of neutrino bursts from gravitational stellar collapses gave a limit on the frequency of bursts f to be $f < 0.088$ y (90% CL) [37];
- the neutrino flux from SN 1987 A that collapsed in the Large Magellan Cloud was registered simultaneously with USA, Italy and Japan facilities [38];
- the proton stability had been tested in 1981–1983 years and the limit for the half-life of proton was achieved: $T_{1/2} > 0.9 \cdot 10^{31}$ y [39,40];
- the data obtained in studying of chemical composition of primary c.r. of 10^{13}–10^{15} eV are in good agreement with the results of direct measurements for lower energies (10^{12} eV) [41];
- the technique to separate hadronic and electromagnetic cascades, based on the registration of π- μ- e-decays accompanying the cascade, has been developed and realized in an experiment [42];
- the total cross-section of hadronic photo absorption has been measured for photons with energies up to 10 TeV [43];
- the experimental data on cross-section of γ-N interaction for the range of energies of 40–130 GeV have been obtained using the measured value of the nuclear cascades fraction. These data together with those obtained at DESY's HERA collider, confirm the effect of more rapid growth of cross-section of photon-hadron interaction than that of hadron-hadron interactions [44,45].

5 Low-Background Laboratories

Low-Background Laboratories (LBL) carry out research of extremely rare reactions and decays with energy release up to 4 MeV. For these studies one needs to diminish not only the background caused by cosmic rays but also that due to the decay of natural radioactive elements always present in the environment. The latter task has been solved by screening the experimental underground facility with a combination of layers of ultra-pure shielding materials absorbing radiation, and by making sure that the facility is made of ultra-pure material. The researches carried out in the LBL search for various modes of double-beta decay of a number of isotopes, for candidate-particles for the dark matter of the Universe; and test the law of electrical charge conservation and many others.

There are three underground laboratories, situated at a different depth, where LBL researches are carried out: 1) a low-background chamber at a depth of 660 m.w.e, 385 m from the entrance to the tunnel, a useful area of 100 m^2, put into operation in 1974 [46]; 2) a chamber for precise measurements at 1000 m.w.e. of depth, at 620 m of distance from the entrance, a useful area of 20 m^2, put into operation in 1985; 3) a deep underground low-background laboratory (DULB-4900) at 4900 m.w.e. of depth, 3670 m from the entrance, a useful area of 200 m^2, put into operation in 1993, modernized in 2008 [47]. A view of DULB-4900 is shown in fig. 8. The cosmic-ray flux in these three chambers is reduced by $2 \cdot 10^3$, $8 \cdot 10^3$, and 10^7, respectively.

A number of low-background facilities based on semiconductor, gaseous and scintillation detectors have been designed, made and used over the years in various experiments such as: the study of cosmogenic radioactive isotope distribution in the samples of moon rock brought by the Automatic Interplanetary Stations Luna-16, Luna-20 and Luna-24; the test of the hypothesis of cosmic-ray intensity being permanent during the last several hundreds of thousands of years performed by measuring the content of cosmogenic isotope ^{81}Kr in the atmospheric air [48]; the investigation of the radioactive purity of industrial metal and a selection of those to be used in the construction of low-background facilities with the lowest possible natural radioactive contamination [49]; the experiments searching for two-neutrino and neutrinoless double-beta decay of isotopes of ^{76}Ge, ^{100}Mo, ^{150}Nd, ^{136}Xe [50–53]; for 2K-capture in ^{78}Kr and ^{124}Xe isotopes [54,55], as well as other experiments have been carried out.

6 Gallium-Germanium Neutrino Telescope

The Gallium-Germanium Neutrino Telescope (GGNT) is targeted to measure solar neutrino flux, which carries unique information on thermonuclear reactions in the central regions of the Sun, as well as on neutrinos themselves. Since 1986 the experiment has been carried out within the frames of the Soviet American Gallium Experiment (SAGE) [56].

The experiment is based on the reaction ($^{71}\mathrm{Ga} + \nu_e \rightarrow {}^{71}\mathrm{Ge} + e^-$) that was suggested in 1965 by Dr. V.A. Kuzmin. The advantage of this reaction is its low threshold of 0.233 MeV. The pp-neutrinos, having an energy up to 0.423 MeV and constituting the main portion of the solar neutrino flux, can be registered through this reaction. The radioactive isotope, ^{71}Ge, produced in this reaction undergoes decay by electron capture, with $T_{1/2} = 11.4$ d half-life. Registering ^{71}Ge decays allows to determine the number of interacting neutrinos and to calculate the solar neutrino flux.

The underground complex of GGNT laboratories is situated at a distance of 3.5 km from the entrance to the tunnel, at a depth of 4700 m.w.e. where the muon flux is reduced by 10^7 times due to the mountain rock shielding, and is $(3.03 \pm 0.10) \cdot 10^{-9}\,\mathrm{cm^{-2}\,s^{-1}}$. The main hall of this complex is of 60 m × 10 m × 12 m dimensions. A view of the hall is

Fig. 8. A view of DULB-4900.

shown in fig. 9. To reduce the background caused by neutrons and gamma-rays coming from the surrounding natural rocks the hall is encased in low-radioactivity concrete and steel sheets of 600 mm and 6 mm thickness, respectively. The flux of neutrons with energies of 1.0–11 MeV in the laboratory is $\leq 2.3 \cdot 10^{-7}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The underground complex of the GGNT laboratories includes rooms for: analytical chemistry, ^{71}Ge decay registration system, low-background semiconductor Ge detector and a number of other auxiliary subdivisions. About 50 t of metallic gallium in a melted state is placed into seven chemical reactors. Natural abundance of ^{71}Ga isotope in gallium is 39.6%. Given the expected solar neutrino flux of $6 \cdot 10^{10}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, there should be produced 25 atoms of ^{71}Ge during one month of 50 t metallic gallium exposition in the underground conditions. A unique and effective technique (90% extraction efficiency achieved and kept over the years) has been developed to extract ^{71}Ge atoms from the 50 t melted metallic gallium target, containing $5 \cdot 10^{29}$ of ^{71}Ga atoms. The periodicity of this extraction procedure, which is the basic technological process of the telescope, is 30 days.

The gas GeH_4 is synthesized on the base of the extracted stable Ge-carrier atoms added to the target to extract the generated ^{71}Ge atoms. It constitutes the main component of the gas mixture filled the proportional counter to register ^{71}Ge decays in the underground registration system of GGNT during 4 months, thereby covering ≥ 10 half-life periods of ^{71}Ge. Then, within the period of two months, the background is measured. Data from the proportional counter are transmitted in the on-line mode, via fiber-optic channel, to the local server of the GGNT ground-based laboratory. The whole cycle of operations called a run includes ^{71}Ga-target exposition, extraction of ^{71}Ge, and measurement of ^{71}Ge decays.

To test and calibrate the techniques used in the SAGE experiment a ^{51}Cr source of $1.91 \cdot 10^{16}\,\mathrm{s}^{-1}$ intensity, emitting neutrinos of 747 keV (90%) and 430 keV (10%) was used. In this calibration experiment the ratio of the measured rate of ^{71}Ge production to the expected one caused by a source of given activity has been found to be 0.95 ± 0.12 [57].

Fig. 9. A view of the GGNT hall.

Another calibration experiment was made with artificial neutrino ^{37}Ar source emitting 811 keV neutrinos of $15.1 \cdot 10^{15}\,\mathrm{s}^{-1}$ intensity. The same ratio of the ^{71}Ge production rates has been found to be $0.79^{+0.09}_{-0.10}$ [58].

The analysis of data obtained in the period of January 1990 - December 2010, including 200 complete runs, yielded $64.6^{+3.7}_{-3.9}$ SNU [59,60] (1 SNU = 1 interaction per second in the target containing 10^{36} atoms of an active isotope). The result obtained in the SAGE experiment constitutes 51% from the value of 127.9 ± 8.1 SNU calculated within the frames of the Standard Solar Model (SSM) BPS08. The SSM value does not take neutrino oscillation into account. This result of the SAGE experiment together with the results of other underground experiments registering solar neutrino (Homestake, USA; GALLEX/GNO, LNGS; Kamiokande/SuperK, Japan; SNO, Canada) allow to calculate estimations of:

- pp-neutrino flux that reaches the Earth in the form of electron neutrinos (electron flavor), $[(3.4 \pm 0.47) \cdot 10^{10}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$ [60];
- total neutrino flux produced in pp-reactions inside the Sun and reaching the Earth in various flavors (electron-, muon- and tau-neutrinos) due to the oscillation of the original electron neutrino, $[(6.0 \pm 0.8) \cdot 10^{10}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$ [60].

The experimental value of the total neutrino flux is in good agreement with the one predicted by SSM, $(5.95 \pm 0.06) \cdot 10^{10}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$.

7 The OGRAN facility

At a distance of 1350 m from the entrance to the main tunnel, the new laboratory is created to accommodate the Optoacoustic GRavitational ANtenna (OGRAN). The OGRAN facility has been constructed using principles of solid-state and laser interferometer gravitational antennae. The acoustic vibrations of the solid-state detector (manufactured in the form of cylindrical aluminum bar with a central axial tunnel) induced by gravity wave are registered by the optical resonator Fabry-Pérot, whose mirrors are mounted on the far ends of the detector. The low noise of such an optical read-out system allows the sensitivity of the relative deformation to be of 10^{-18} for the detector of 2.5 t without any cooling procedure. This sensitivity is good enough to detect bursts of gravity wave radiation generated in relativistic cataclysms in the center of our Galaxy (~ 10 kpc) and its close vicinity (up to 100 kpc) according to optimistic scenarios. OGRAN is the cooperative project carried out by the Institute for Nuclear Research of RAS, the Institute of Laser Physics of SB RAS and the Moscow State University (Sternberg Astronomical Institute- SAI MSU).

The construction of the detector was finished in 2011; its installation in the underground laboratory is in process and will be finished this year. The detector should come into operation in 2013. Measurements of gravity gradient background are supposed to be performed as search for neutrino and gravity events' correlation using simultaneous data of OGRAN and the BUST BNO.

Fig. 10. A view of geophysical laboratory No1.

8 Underground complex of geophysical facilities

Environmental parameters of the underground laboratory complex are held within stable limits; vibration and acoustic noises are lowered by many times in comparison with those on the surface. Such underground environment provides the necessary conditions to carry out various geophysical researches securing their high sensitivity.

There are three underground geophysical laboratories situated at a different distance from the tunnel entrance and supplied with different measuring devices and instruments:

1) the laboratory of SAI MSU, at a distance of 530–610 m from the entrance to the tunnel; researches of the Earth strains are carried out with the high-sensitivity wide-band laser interferometer [61].

2) The geophysical laboratory No1, at $\sim$ 1520 m; it is a nearby geophysical complex of the Schmidt Institute of Physics of the Earth RAS having tilt indicators (inclinometers), magnetic variometers, and earthquake detection station at its disposal.

3) The geophysical laboratory No2, at $\sim$ 4000 m; it is a distant geophysical complex IPE RAS having tilt indicators, magnetometers, gravimeters, thermometers as well as earthquake detection stations pertaining to Geophysical Survey RAS.

A view of geophysical laboratory No1 is shown in fig. 10.

Data obtained in geophysical experiments allow scientists to monitor the seismic activity in the earth crust related to the sleeping volcano Elbrus which is at a distance of about 20 km from the underground geophysical complex of facilities [62].

Various researches at the Baksan Neutrino Observatory INR RAS are carried out in collaborations with institutions all over Russia and the world. To name some of them, the Kabardino-Balkarian State University, the Federal South University, the Moscow State University, the National Research Nuclear University MEPHI, the Schmidt Institute of Physics of the Earth RAS, the Pushkov Institute of Earth magnetism, ionosphere and radio waves propagation RAS (IZMIRAN), the Polar Geophysical Institute RAS, the Geophysical Survey RAS, the Institute of Astronomy RAS, JINR, the Kharkov National University (Ukraine), the Institute of Nuclear Problems (Cosmic Ray Laboratory, Lodz, Poland), and the international Collaborations AMORE, GERDA and EMMA. All these collaborations significantly increase the efficiency of the Baksan complex of ground-based and underground facilities in solving a wide range of problems in modern science.

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