Program of scientific researches at the BNO INR RAS – 50 years into operation

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Abstract Brief historical information about different episodes of the Baksan Neutrino Observatory of the INR RAS creation is presented. Ground-based and underground facilities are described. A list of the main tasks solving with these facilities and some main results are given. Perspective plans of the investigations are viewed.

Keywords: Cosmic Rays, Solar Neutrino, Low Background Researches, Ground Level and Underground Installation Complex

1. Introduction

In the late 1950s, the ideas were proposed to build an underground complex of scientific facilities to carry out fundamental researches in cosmic ray physics and neutrino astrophysics. 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. The suggested technique was based on registration of muons generated in the interactions of neutrino with nucleons of matter of the Earth's interior. Theoretical calculations were performed and first evaluation of intensity of high energy neutrino flux from possible galactic sources was obtained.

Another field of research that needs underground laboratories is studying 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.

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" with Professor G. T. Zatsepin as its Head and Professor A. E. Chudakov as his Assistant was organized. The scientific bases and a Neutrino station project were finished to the 1967 year. On June 29, 1967 Council of Ministers of the USSR enacted an order about a creation of the Station (Observatory) and building works ware started at the same year. Professor A. A. Pomansky assigned as a first director of the Station. The mentioned personalities are shown on the photos ***Fig1*** and ***Fig2***.

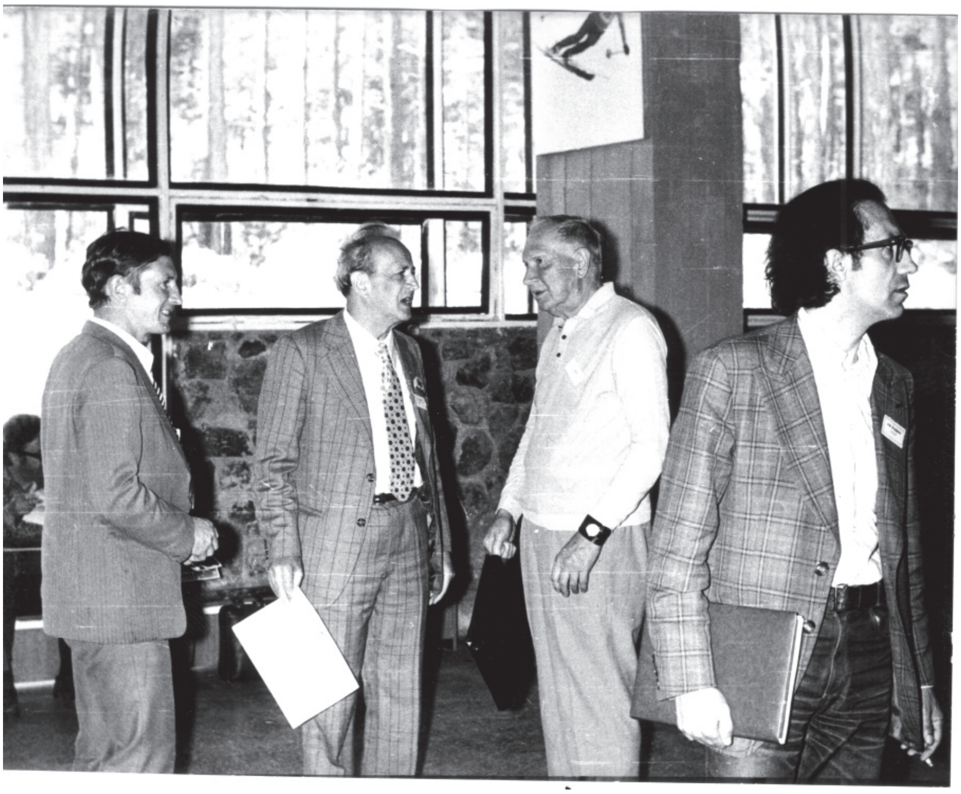

Fig1. *In the lobby of the NEUTRINO'77 conference. (from left to right): 1. Vise director of the BNO INR AS of the USSR E. N. Alexeev; 2) Academician G. T. Zatsepin; 3) Academician M. A. Markov; 4) Corresponding Member V. A. Kuzmin.*

Fig2. *Photo (1972 y.) of people involved in the Baksan Neutrino Observatory creation, (from left to right) the first Director of BNO A. A .Pomansky, the building manager, the researchers V. V. Alekseenko and V. A. Kuznetsov, the official people, Academician G. T. Zatsepin, President of the AS of the USSR Academician M. V. Keldysh, vice Director of BNO E. N. Alexeev, Director of the INR AS USSR Academician A. N. Tavhelidze, Corresponding Member of the AS of the USSR A. E. Chudakov.*

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 (3937 m) to accommodate future underground laboratories. Cosmic ray flux at the end of the main 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 chlorine-argon neutrino telescope. Further scientific development lead to construction of many other scientific laboratories related to cosmic ray studies and other researches that require underground shielding conditions. Necessary engineer and utility structures, 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 a 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], [2]. In 1998 a group of scientists, namely 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 awarded with State Prize. Later V. N. Gavrin and G. T. Zatsepin were awarded with B. M. Pontekorvo Prize and with D. V. Skobeltzin Gold Medal for the creation of Gallium-Germanium Neutrino Telescope and a valuable contribution into the study of solar neutrino.

2. The ground-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”[3]. Each detector is a rectangular aluminum tank (70 cm·70cm·30cm) filled with 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). 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”[3]. Each detector is a rectangular aluminum tank (70 cm·70cm·30cm) filled with 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. This ground-based facility of 200 m^2 shown in ***Fig3*** is an exact replica of the one of the eight layers of the Baksan Underground Scintillation Telescope that came into operation later.

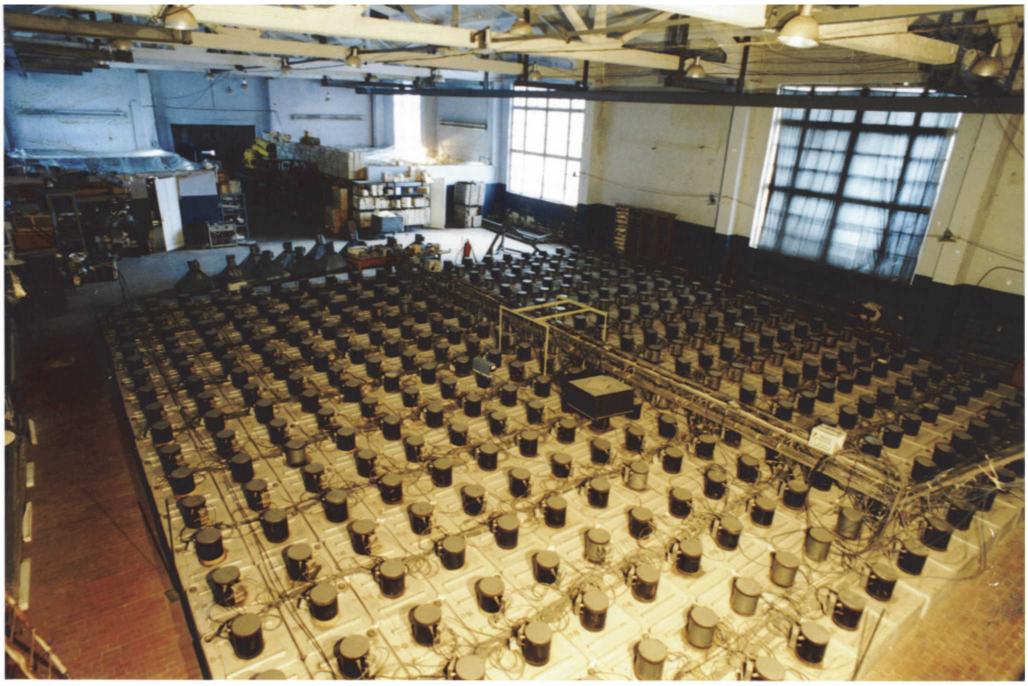

Fig3. *The overview of the "Carpet" facility.*

The "Carpet" facility was targeted to study primary cosmic rays of $5.7 \cdot 10^9 \div 10^{16}$ 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.

2.1.1. Main directions of researches

1. **EAS's core.** Analysis of the obtained data allowed one 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. This experimental result was the first one to confirm quantum chromodynamics predictions [4].
2. **Cosmic rays variations.** Large counting rate of single muons from cosmic rays ($\sim 4.3\ 10^4\ s^{-1}$) allows high statistical accuracy even for small time intervals (0.003% for 4 min), 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. 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 [5]. The gigantic increase of cosmic ray intensity during 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 an event, and it was the "Carpet" facility that provided the most evident and accurate data at that time [6].
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. C.r. anisotropy for 10^{13} eV was calculated to be (0.057 ± 0.005)% [7].

4. **Ultra-high energy gamma-astronomy.** Air showers of $E \geq 10^{14}$ eV are continuously registered and the data are analyzed along several lines: search for point sources of gamma-quanta of the same energy; search for signals from extended gamma-ray sources (mainly in the galactic plane); search for c.r. anisotropy at these energies; search for x-ray and gamma-ray bursts for known sources. 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 "Carpet" that first published the result [8]. Later it was confirmed by teams of Kolar Gold Mine (India) and EAS Top (LNGS) facilities.
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 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.

2.2. "Carpet-2(3)"

"Carpet" performance was significantly improved after coming into operation in 1998 of one section (the middle one) of the three-sectioned large underground Muon Detector facility (MD). The middle section is at ~ 40 m from the "Carpet"'s center. MD is under 2 m layer of the ground (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 plastic scintillator of 5 cm thickness). The continuous registering area of the facility is 175 m^2 (5 m x 35 m). The new complex installation was named "Carpet-2". The "Carpet-2" facility allows studying EAS muon component. The dependence of the mean number of muons of ≥ 1GeV (N_μ) registered by MD on the total number of EAS particles (N_e) has been found as $N_\mu \sim N_e^\alpha$, 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 ultrahigh energy gamma-quanta, to start studying 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 [9].

The creation of "Carpet-3", the advanced version of "Carpet-2", is now in progress. Occupation of the two residual underground hall sections with the detectors is finishing. The sensitive area will increase up to 615 m^2. It is supposed to be a multipurpose 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 1GeV); 3) hadron.

2.3. "Andyrchy"-array

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 (1 m^2 each, plastic scintillator of 5 cm thickness) evenly spread over the area of 45.000 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 [10]. The central detector of "Andyrchy" is located over BUST, and a vertical thickness of mountain rock separating them is 350 m.

The following researches are carried out at “Andyrchy”: ultrahigh energy gamma-astronomy [11]; anisotropy of cosmic rays with $E_0 \geq 10^{14}$ eV [12]; search for gamma-ray bursts with hard energy spectrum [13].

3. The underground complex of the BNO facilities

Schematic view of a longitudinal section of the BNO adit and Andyrchy slope is shown in ***Fig4*** 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.

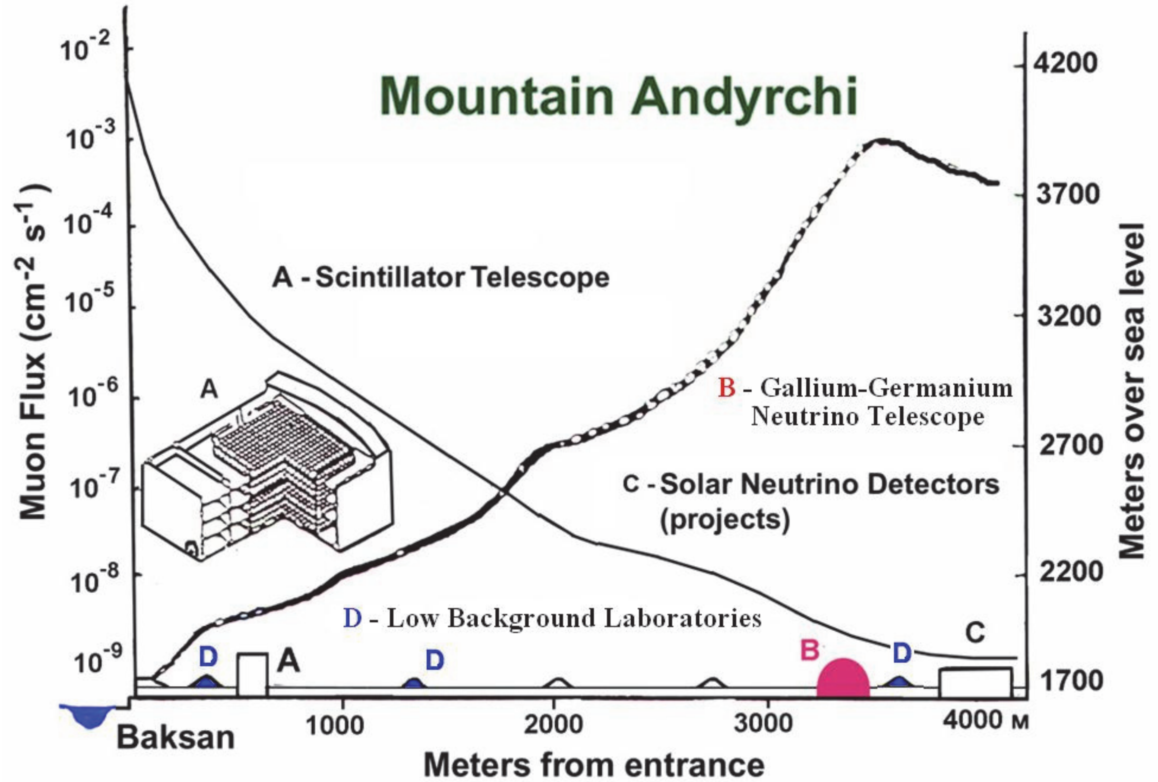

Fig4. *Schematic view of a section of the Andyrchy slope along the adit (right scale) and dependence of underground muon flux on the laboratory location depth (left scale).*

3.1. 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 [14]. BUST is situated in the underground hall of ~ 12.000 m^3 at a distance of 550 m from the entrance to the underground horizontal tunnel.

A view of the BUST hall at the one of the building moment is shown in ***Fig5***.

The telescope is a rectangular building of 11.1 m height and 280 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). The total mass of the telescope is 2500 t, that one of the scintillator is 330 t. A view of one of the horizontal planes is shown in ***Fig6***.

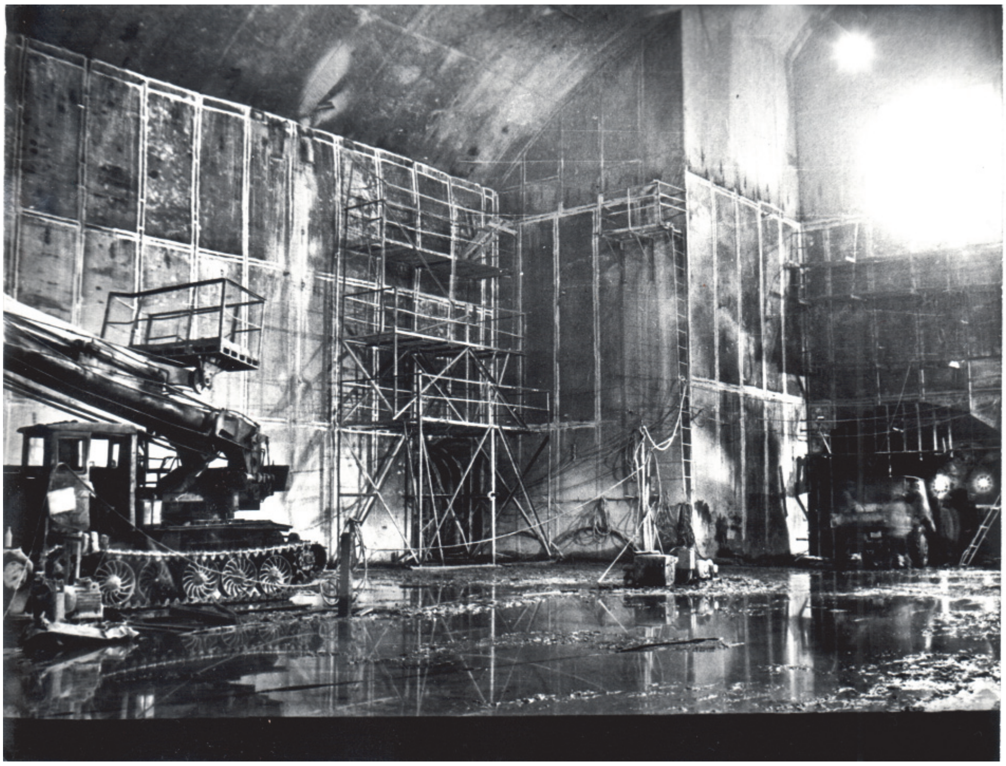

Fig5. *Photo of the BUST hall at the one of the building* moment

Fig6. *View of the BUST top horizontal plane.*

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 $E > 0.2$ TeV is 12 s^{-1}). The reduced c.r. background allows scientists to study problems related to rare processes registration, such as measurement of the muon flux generated by high-energy neutrino; 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 one to carry out a research into a wide range of tasks of cosmic ray physics: anisotropy of c.r. of > 10^{12} eV, chemical composition of primary c.r. of $10^{12} \div 10^{16}$ eV, interaction of muons of > 1TeV with matter, and others.

3.1.1. Main results of the BUST experiments

Series of the important results was obtained at the BUST. Some of them are:

1. Muon flux generated by atmospheric neutrino of cosmic rays in the rock under BUST has been measured to be [$I_\mu^\nu = (2.60 \pm 0.15)\ 10^{-13}$ cm^{-2}s^{-1}sr^{-1}] [15].
2. One of the first limits obtained for the oscillation parameters of atmospheric neutrinos of $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_e$ types [16].
3. A limit on high-energy neutrino flux from local sources in the galactic plane was obtained.
4. The best limit, for a time, on the slow and heavy magnetic monopoles was determined [17].
5. The amplitude [$(12.3 \pm 2)\ 10^{-4}$] and phase [1.6 ± 0.8] (in sidereal time) of the first harmonic of c.r. anisotropy have been measured [11].
6. Data accumulated during 34 years (live time 29.8 years) of monitoring the Galaxy in studying neutrino bursts from gravitational stellar collapses gave a limit on the frequency of bursts f to be f<0.077 yr^{-1}(90% C.L.) [18].
7. Neutrino flux from SN 1987 A that collapsed in the Large Magellan Cloud was registered simultaneously with USA, Italy and Japan facilities [19].

3.2. 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 one 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 ultrapure shielding materials absorbing radiation, and by making sure that the facility is made of ultrapure material. The researches carried out in the LBL are search for various modes of double beta-decay of a number of isotopes; search for candidate-particles for dark matter of the Universe; test of 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) low-background chamber at a depth of 660 m w.e, 385 m from the entrance to the tunnel;
2) chamber for precise measurements at 1000 m w.e. depth, 620 m distance from the entrance;
3) deep underground low-background laboratory (DULB-4900) at 4900 m w.e. depth, 3670 m from the entrance [20]. A view of DULB-4900 is shown in ***Fig7***.

Cosmic ray flux in these three chambers is reduced by $2{\cdot}10^3$, $8{\cdot}10^3$, and 10^7, respectively.

Fig7. *A view of DULB-4900.*

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:

1) Study of cosmogenic radioactive isotope distribution in the samples of moon rock brought by Automatic Interplanetary Stations Luna-16, Luna-20 and Luna-24;
2) 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 [21];
3) Experiments searching for two-neutrino and neutrinoless double beta-decay of isotopes of ^{100}Mo, ^{150}Nd. The ($2\beta2\nu$)-process was obtained for the ^{150}Nd for the first time in the world [22];
4) A series of experiments to search for 2β-decay of the ^{136}Xe [23];
5) A series of experiments to search for 2K-capture in ^{78}Kr [24] and ^{124}Xe isotopes and $2\beta^{+}$- and $e\beta^{+}$-decays of ^{78}Kr;
6) Joint (Spain-Russia-USA) experiment IGEX to search for 2β-decay of the ^{76}Ge [25];
7) Search for hypothetic solar axions [26], and many others.

3.3. Gallium-Germanium Neutrino Telescope

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) [27].

The experiment is based on the reaction ($^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$) 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 energy up to 0.423 MeV and constituting the main portion of solar neutrino flux, can be registered through this reaction. Radioactive isotope, ^{71}Ge produced in this reaction undergoes decay by electron capture, with $T_{1/2}$=11.4 days half-life. Registering ^{71}Ge decays allows one 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. A view of the GGNT hall is shown in ***Fig8***.

Fig8. *A view of the GGNT hall.*

About 50 t of metallic gallium in a melted state is placed into seven chemical reactors as a target. A unique and effective technique has been developed to extract ^{71}Ge atoms from the melted metallic gallium target containing $5\cdot10^{29}$ 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. The whole cycle of operations called a run includes ^{71}Ga-target exposition, extraction of ^{71}Ge, and measurement of ^{71}Ge decays.

3.3.1. The results of calibration and solar neutrino experiments

1. The analysis of data obtained in the period of January 1990 - December 2016, including 259 complete runs, yielded $64.76^{+3.5}_{-3.7}$ SNU [28] (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 Modal (SSM) BPS08. The SSM value does not take neutrino oscillation into account. This result of SAGE experiment together with the results of other underground experiments registering solar neutrino (Homestake, USA; GALLEX/GNO, LNGS; Kamiokande/SuperK, Japan; SNO, Canada) allows to calculate estimations of : 1) pp-neutrino flux that reaches the Earth in the form of electron neutrino (electron flavor), [(3.4 ± 0.47) 10^{10} $cm^{-2}s^{-1}$]; 2) total neutrino flux produced in pp-reactions inside the Sun and reaching the Earth in various flavors (electron-, muon- and tau-neutrino) due to oscillation of original electron neutrino, [(6.0 ± 0.8) 10^{10} $cm^{-2}s^{-1}$]. The experimental value of the total neutrino flux is in good agreement with the one predicted by SSM, $(5.95 \pm 0.06)\cdot 10^{10}$ $cm^{-2}s^{-1}$.

2. To test and calibrate the techniques used in the SAGE experiment a ^{51}Cr source of $1.91\cdot 10^{16}$ 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 [29].

Another calibration experiment was made with artificial neutrino ^{37}Ar source emitting 811 keV neutrinos of $15.1\cdot 10^{15}$ s^{-1} intensity. The same ratio of the ^{71}Ge production rates has been found to be $0.79^{+0.09}_{-0.10}$ [30].

3.3.2. The experiment BEST

The experiment BEST (Baksan Experiment on Sterile Transitions) with the two concentric zones Ga-target and 3MCi artificial ^{51}Cr neutrino source is preparing at the BNO now [31]. The goals of this experiment are to search for the short-baseline neutrino oscillation and to test of sterile neutrino hypothesis. The detector preparation is finished. A method of the measurements has tested. An intensive work on the power neutrino source preparations is doing.

3.4. 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. Acoustic vibrations of solid-state detector (manufactured in the form of cylindrical aluminum bar with a central axial tunnel) induced by gravity wave are registered by optical resonator Fabri-Perro, whose mirrors are mounted on the far ends of the detector. Low noise of such an optical read-out system allows sensitivity of 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 Institute for Nuclear Research of RAS, Institute of Laser Physics of SB RAS and Moscow State University (Sternberg Astronomical Institute- SAI MSU).

The detector would come into operation in 2018.

3.5. 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 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) 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 [32];
2) the geophysical laboratory No1, at ~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 ~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.

Data obtained in geophysical experiments allow scientists to monitor 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.

3.6. Project of the Baksan Underground Large Volume Scintillation Detector

It is proposed to create in the BNO a multipurpose large volume liquid scintillator neutrino detector with a mass of 10 kt intended for the investigations of the neutrino and antineutrino fluxes from the Sun, Earth and other astrophysical sources. It is planning that the detector will placed at the 5000 m w.e. depth. The geographic features of the Observatory location allows one to suppress a background connected with the antineutrino fluxes from nuclear power plants that gives a possibility to register antineutrino flux from the Earth, which gives an information about a constitution and composition of the region earth crust [33].

4. Conclusion

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, Kabardino-Balkarian State University, Federal South University, Moscow State University, National Research Nuclear University MEPHI, Schmidt Institute of Physics of the Earth RAS, Pushkov Institute of Earth magnetism, ionosphere and radiowaves propagation RAS (IZMIRAN), Polar Geophysical Institute RAS, Geophysical Survey RAS, Institute of Astronomy RAS, JINR, Kharkov National University (Ukraine), Institute of Nuclear Problems (Cosmic Ray Laboratory, Lodz, Poland), international collaborations AMoRE, GERDA, LEGEND 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.

References

[1] A. A. Pomansky, “Baksan Neutrino Observatory of INR AS of USSR”, Atomnaya energiya, v.44, (1978), 376-383. (in Russian)

[2] V. V. Kuzminov “The Baksan Neutrino Observatory”. Eur. Phys. J. Plus (2012) 127: 113

[3] E. N. Alekseev, V. V. Alekseenko, A. V. Voevodsky et al. “Scintillation detector of 200 m^2 area for the cosmic rays registration”, Izvestiya Akademii Nauk SSSR. Seriya Fizicheskaya, v.38, (1974), 1097-1100. (in Russian)

[4] A. E. Chudakov, D. D. Dzhappuev, A. S. Lidvansky, V. A. Tizengauzen, V. P. Sulakov, G. Navarra. “Investigation of EAS with multicore structure”. Proc. of the 16th ICRC, Kyoto, v.8, (1979), 222-226.

[5] V. V. Alexeenko, N. S. Khaerdinov, A. S. Lidvansky, V. B. Petkov, "Transient variations of secondary cosmic rays due to atmospheric electric field and evidence for pre-lightning particle acceleration". Physics Letters A 301 (2002) 299-306.

[6] V. V. Alexeenko, A. B. Chernyaev, A. E .Chudakov, N. S. Khaerdinov, A. M. Semenov, A. V. Voevodsky. “29 September 1989 GLE at Baksan Air shower Array (BASA)”. Proc. of the 23th ICRC, Calgary, v.3, (1993), 163-166.

[7] Alexeyenko V. V., Chudakov A. E., Gulieva E. N., Sborshikov V.G. “Anisotropy of small EAS (~10^{13} eV)”. Proc. of 17th ICRC, Paris, v.2, (1981), 146-149.

[8] V. V. Alexeenko, Yu. M. Andreyev, A. E. Chudakov, A. S. Lidvasky, S. S. Ozrokov, V. V. Sklyarov, V. A. Tizengauzen, S. L. Osborn. “Burst like event observed by Baksan EAS Array from the Crab Nebule 23 Feb.1989”. Proc. of the 22th ICRC, Dublin, v.1, (1991), 293-295.

[9] D. D. Dzhappuev, A. U. Kudzhaev, V. V. Alexeenko, N. F. Klimenko, A. S. Lidvansky, O. I. Mikhailova, V. B. Petkov, Yu. V. Stenkin, A. L Tsybuk and A. B. Chernyaev. “Studying the Muon and Hadron Components of Extensive Air Showers with the Carpet-2 Array”. Bull. of the Russian Academy of Sciences, Physics, vol. 73, № 5, (2009), 642-644.

[10] E. N. Alekseev et al., "Air shower array 'Andyrchy' above the Baksan Underground Scintillation telescope", Bull. Russ.Acad.Sci. Phys 57, (1993), 668.

[11] V. A. Kozyarivsky, A. S. Lidvansky, V. B. Petkov, and T. I. Tulupova, “Mean Diurnal Variations of Cosmic Ray Intensity as Measured by Andyrchi Air Shower Array (E≥ 100 TeV) and Baksan Underground Scintillation Telescope (E≥ 2.5 TeV)”. arXiv:astro-ph/0406059v1, 2004.

[12] V. B. Petkov, A. S. Pozanenko, V. M. Loznikov, A. N. Gaponenko, M. V. Andreev, and A. V. Sergeev, "Search for high energy gamma-ray bursts". Astrophys. Space Sci. Trans, 7, (2011), 97-100.

[13] V. B. Petkov, E. V. Bugaev, P. A. Klimai, M. V. Andreev, V. I. Volchenko, G. V. Volchenko, A. N. Gaponenko, Zh. Sh. Guliev, I. M. Dzaparova, D. V. Smirnov, A. V. Sergeev, A. B. Chernyaev, A. F. Yanin, "Searching for Very-High-Energy Gamma-Ray Bursts from Evaporating Primordial Black Holes", Astronomy Letters, v. 34, No. 8, (2008), 509–514. (arXiv:0808.3093v1 [astro-ph], 2008)

[14] E. N. Alexeyev, V. V. Alexeyenko, Yu. M. Andreyev, V. N. Bakatanov, A. V. Butkevich, A. E. Chudakov, M. D. Galperin, A. A. Gitelson, V. I. Gurentsov, A. E. Danshin, V. A. Dogujaev, V. L. Dadikin, Ya. S. Elensky, V. A. Kozyarivsky, I. M. Kogai, N. F. Klimenko, A. A. Kiryushin, Yu. N. Konovalov, B. A. Makoev, V. Ya. Markov, Yu. Ya. Markov, Yu. V. Malovichko, N. A. Metlinsky, A. R. Mishelev, S. P. Miksheyev, Yu. F. Novoselsev, V. G. Sborshikov,

V. V. Sklyarov, V. I. Stepanov, Yu. V. Stenkin, Yu. R. Sulla-Petrovsky, T. I. Tulupova, A. V. Voevodsky, V. I. Volchenko, V. N. Zakideshev. “Baksan underground scintillation telescope”. Proc. of 16th ICRC, Kyoto, v.10, (1979), 276-281.

[15] M. M. Boliev, A. V. Butkevich, A. E. Chudakov, B. A. Makoev, S. P. Mikheyev, V. N. Zakideshev. “ν-flax as measured by Baksan underground telescope”. Proc. of 17th ICRC, Paris, v.7, (1981), 106-109.

[16] М. М. Болиев, А. В. Буткевич, В. Н. Закидышев, Б. А. Макоев, С. П. Михеев, А. Е. Чудаков, «Ограничения на параметры осцилляций нейтрино по данным Баксанского подземного телескопа». Ядерная физика, т.34, вып.5, стр. 1418-1421, 1981.

[17] Yu. F. Novoseltsev, M. M. Boliev, A. V. Butkevich, S. P. Mikheev and V. B. Petkov, "A search for massive magnetic monopoles at the Baksan Underground Scintillation Telescope (BUST)", Nuclear Physics B (Proc. Suppl.), v.151, N1, (2006), 337-340.

[18] Novoseltsev Yu. F., Boliev M. M., Dzaparova I. M., Kochkarov M. M., Novoseltseva R. V., Petkov V. B., Volchenko V. I., Volchenko G. V., Yanin A. F. “A search for neutrino bursts signal from supernovae at the Baksan Underground Scintillation Telescope”. Proc. of International Workshop on Quark Phase Transition in Compact Objects and Multimessenger Astronomy: Neutrino Signals, Supernovae and Gamma-Ray Bursts, (Nizhnij Arkhyz – Terskol, October 7014, 2015), Pjatigorsk, Izdatelstvo "SNEG", 2016, pp. 76-84

[19] E. N. Alexeyev, L. N. Alexeyeva, I. V. Krivosheina, V. I. Volchenko. “Detection of Neutrino Sygnal from SN1987A, using the INR Baksan underground scintillation telescope”. Proc. of the 2nd Int. Sym. UP-87, M., (1988), 85-93.

[20] Ju. M. Gavriljuk, A. M. Gangapshev, A. M. Gezhaev, V. V. Kazalov, V. V. Kuzminov, S. I. Panasenko, S. S. Ratkevich, S. P. Yakimenko. “Working characteristics of the New Low-Background Laboratory (DULB-4900, Baksan Neutrino Observatory)”arXiv: 1204.6424 [physics.ins-det] 01 May 2012 Nuclear Instruments and Methods in Physics Research A 729 (2013) 576–580.

[21] V. V. Kuzminov, A. A. Pomansky. "^{81}Kr production rate in the atmosphere". Proc. of the 18th Int. Cosmic Ray Conf., India, Bangalore, v.2, (1983), 357-360.

[22] A. A. Klimenko, S. B. Osetrov, A. A. Pomansky, A. A. Smolnikov, S. I. Vasilyev. “Search for a two-neutrino mode of double beta decay of the isotope ^{150}Nd”. Pis'ma Zh.Eksp. Teor.Fiz., 58, No.3, (1993), 177-179. (in Russian)

[23] Ju. M. Gavriljuk, A. M. Gangapshev, V. V. Kazalov, V. V. Kuzminov, S. I. Panasenko, S. S. Ratkevich, D. A. Zhantudueva, S. P. Yakimenko. “Results of a search for 2β-decay of ^{136}Xe with high pressure copper proportional counters in Baksan Neutrino Observatory INR RAS”. arXiv:1112.0859v2 [nucl-ex] 20 Dec 2011

[24] Yu. M. Gavrilyuk, A. M. Gangapshev, V. V. Kazalov, V. V. Kuzminov, S. I. Panasenko and S. S. Ratkevich. “Indications of 2ν2K capture in ^{78}Kr” Phys. Rev. C 87, 035501 (2013)

[25] C. E. Aalseth, F. T. Avignone, R. L. Brodzinski, J. I. Collar, E. Garcia, D. Gonzales, F. Hasenbalg, W. K. Hensley, I. V. Kirpichnikov, A. A. Klimenko, H. S. Miley, A. Morales, J. Morales, A. Ortis de Solorzano, S. B. Osetrov, V. S. Pogosov, J. Puimedon, J. H. Reeves, C. Saenz, A. Salinas, M. L. Sarsa, A. A. Smolnikov, A. S. Starostin, A. G. Tamanyan, A. A. Vasenko, S. I. Vasiliev, A. Villar. “Recent Results from the IGEX Double-beta Decay Experiment”. Nucl. Phys. B (Proc.Suppl.), 48, (1996), 223-225.

[26] Yu. M. Gavrilyuk, A. N. Gangapshev, A. V. Derbin, I. S. Drachnev, V. V. Kazalov, V. V. Kobychev, V. V. Kuz’minov, V. N. Muratova, S. I. Panasenko, S. S. Ratkevich, D. A. Semenov, D. A.

Tekueva, E. V. Unzhakov, S. P. Yakimenko. “New experiment on search for the resonance absorption of solar axion emitted in the M 1 transition of 83 Kr nuclei”. JETP Letters, May 2015, Volume 101, Issue 10, pp 664-669

[27] J. N. Abdurashitov, V. N. Gavrin, S. V. Girin, V. V. Gorbachev, P. P. Gurkina, T. V. Ibragimova, A. V. Kalikhov, N. G. Khairnasov, T. V. Knodel, I. N. Mirmov, A. A. Shikhin, E. P. Veretenkin, V. M. Vermul, V. E. Yants, G. T. Zatsepin et al. (SAGE Collaboration), “Measurement of the solar neutrino capture rate with gallium metal”. Phys. Rev. *C* **60** 055801 (1999); astro-ph/9907113

[28] V. N. Gavrin “Contribution of Gallium experiments to the understanding of solar physics and neutrino physics”. Physics of Atomic Nuclei, v.76, N10. (2013), 1238-1243.

[29] J. N. Abdurashitov, V. N. Gavrin, S. V. Girin, V. V. Gorbachev, P. P. Gurkina, T. V. Ibragimova, A. V. Kalikhov, N. G. Khairnasov, T. V. Knodel, I. N. Mirmov, A. A. Shikhin, E. P. Veretenkin, V. M. Vermul, V. E. Yants, G. T. Zatsepin et al. (SAGE Collaboration), et al. (SAGE Collaboration). “Measurement of the response of a gallium metal solar neutrino experiment to neutrinos from a ^{51}Cr source”. Phys. Rev. *C* 59 2246 (1999)

[30] J. N. Abdurashitov, V. N. Gavrin, S. V. Girin, V. V. Gorbachev, P. P. Gurkina, T. V. Ibragimova, A. V. Kalikhov, N. G. Khairnasov, T. V. Knodel, I. N. Mirmov, A. A. Shikhin, E. P. Veretenkin, V. M. Vermul, V. E. Yants, G. T. Zatsepin et al. (SAGE Collaboration), et al. (SAGE Collaboration). “Measurement of the response of a Ga solar neutrino experiment to neutrinos from a ^{37}Ar source”. Phys. Rev. *C* 73 045805 (2006).

[31] V. Gavrin, B. Cleveland, S. Danshin, S. Elliott, V. Gorbachev, T. Ibragimova, A. Kalikhov, T. Knodel, Yu. Kozlova, Yu. Malyshkin, V. Matveev, I. Mirmov, J. Nico, R. G. H. Robertson, A. Shikhin, D. Sinclair, E. Veretenkin, J. Wilkerson. “Current status of new SAGE project with 51Cr neutrino source”. Phys. Part. Nucl. 46 (2015) 131-137

[32] V. K. Milyukov, V. N. Rudenko, B. S. Klyachko, A. M. Kart, A. V. Myasnikov. “Wide-Band Laser Interferometer for Monitoring the Earth Strains”. In: Solid State Laser (Laser Optics’98). Proceedings of the International Society for Optical Engineering (SPIE). v.368, (1998), 116-121.

[33] I. R. Barabanov, L. B. Bezrukov, A. V. Veresnikova, Yu. M. Gavrilyuk, A. M. Gangapshev, V. Yu. Grishina, V. I. Gurentsov, V. P. Zavarzina, V. V. Kazalov, S. D. Krokhaleva, V. V. Kuz’minov, A. S. Kurlovich, B. K. Lubsandorzhiev, S. B. Lubsandorzhiev, A. K. Mezhokh, V. P. Morgalyuk, P. Yu. Naumov, G. Ya. Novikova, V. B. Petkov, A. M. Pshukov, A. Yu. Sidorenkov, V. V. Sinev, Sh. I. Umerov, E. A. Yanovich, T. Enquist, P. Kuusiniemi, J. Joutsenvaara, A. Virkajarvi. “Large-volume detector at the Baksan Neutrino Observatory for studies of natural neutrino fluxes for purposes of geo- and astrophysics”. Physics of Atomic Nuclei, Volume 80, Issue 3, May 2017, pp 446–454