**RESOLUTION**
RAS Scientific Council
"Neutrino Physics and Neutrino Astrophysics"
29 June 2012

**The Agenda of the Scientific Council session:**

1. Upgrade of the Baikal deep underwater neutrino telescope (Doctor of Physics and Mathematics **Zhan-Arys Magisovich Dzhilkibaev**) and the development of the Baksan geoneutrino detector (RAS Corresponding member **Vladimir Nikolaevich Gavrin**).
2. Proposals on the projects recommended to be enclosed into the programme "Neutrino Physics and Neutrino Astrophysics" (RAS Corresponding Member **Grigorij Vladimirovich Domogatsky**).

**THE COUNCIL RESOLUTION**

Primarily, the Council considers it necessary to emphasize an exceptional importance of modern research in neutrino physics and elementary particle astrophysics. The key tasks in this area are such studies, for example, as baryonic asymmetry of the world, neutrino properties and the origin of the dark matter – that have a highest scientific significance and fundamental character. They lie in the main route of the development of modern physics of elementary particles and its astrophysical aspects. In the degree of their fundamentality in modern physical science, these studies are in fact among apparent leaders.

It is considered absolutely necessary that adequate financing should be provided for further Russian research in the field of neutrino physics and astrophysics. Losing time in this field will lead to far reaching aftermaths for Russia.

**In general, in paragraph 1 of the agenda,** the Council stresses an exceptional importance for the future of Russia to organize and hold experiments of fundamental significance in the exact territory of Russia that will attract world scientific community to be involved in them, due to their urgent character and promising potential, and facilitate the development of unique national scientific schools.

The Council indicates that the development of the world science logically demands that further development of unique experimental complexes BAIKAL and BAKSAN located in the territory of Russia be not only preserved but by all means be provided. Their international significance has long since stopped requiring any additional justification. The successful work of these complexes is extremely important for establishing a positive image of the country.

**On the issue of upgrading the BAIKAL experiment.**

The Council listened with satisfaction to the report by Doctor of Physics and Mathematics Zh.-A.M.Dzhilkibaev on the R&D status of neutrino experiments in Lake Baikal (INR RAS, JINR, ISU, MSU, NNSTU, SMTU-S. Petersburg, DESY-Zeuthen). The speakers on this issue were the following: Candidate of Physics and Mathematics D.S.Gorbunov, Doctor of Physics and Mathematics M.D.Skorokhvatov, Academician S.S.Gershtein, Academician V.A.Matveev, Doctor of Physics and Mathematics L.B.Bezrukov, Doctor of Physics and Mathematics A.A.Petrukhin, RAS Corresponding Member G.V.Domogatsky, Doctor of Physics and Mathematics Yu.G.Kudenko, RAS Corresponding Member O.G.Ryazhskaya, Candidate of Physics and Mathematics V.M.Ainutdinov and others.

The main topics of applied studies with the deep underwater neutrino telescopes are the search for local neutrino sources and a diffuse neutrino flux of the galactic and metagalactic origin, detection of neutrino from supernova explosions and other transient processes, the search for exotic particles and dark matter particles, as well as a wide range of studies in oceanology, limnology and glaciology.

The Baikal neutrino telescope is the only facility of a kind located in the southern part of Lake Baikal (51°50' Northern Latitude and 104°20' Eastern Longitude). The telescope detectors are about 4 km from the shore, 1100 – 1200 m deep in the lake.

The successful long-term operation of the "pilot" facilities HT200 and HT200+ has proved the efficiency of the method for neutrino and other elementary particles' detection in natural conditions. The detection system of the HT1000-detector of the next generation with the capacity of a cubic kilometer scale has been tested. In 2011 a scientific-technical project was prepared of a deep underwater neutrino telescope in Lake Baikal on the basis of the HT1000-modules. It is planned to launch the first full-scale cluster in the coming couple of years that will consist of 192 large-area photoreceivers (the detection capacity on the level of 0.1 $km^3$), and during subsequent years it planned to develop a full-scale detector BAIKAL-GVD.

This full-scale detector, together with the neutrino telescope ICE-cube (located in the South Pole) will allow observation of the whole celestial sphere. Moreover, situated in the Northern hemisphere the BAIKAL-GVD detector, in contrast to the ICE-cube, will be able to observe the most interesting sector – the centre of our Galaxy.

The importance of these studies has been already acknowledged by the world community – a "Global Neutrino Observatory" is under development that will overlap three projects of the cubic kilometer scale detectors: the ICE-cube, the Mediterranean European project KM3NeT and BAIKAL-GVD. Joint operation of these three detectors will increase the sensitivity to high energy neutrino fluxes from distant sources, establish prerequisites to solve one of the central tasks of astrophysics – the research of sources of powerful energy yield in the Universe, and will make it possible to conduct coherent neutrino monitoring of all the celestial sphere.

It should be mentioned that the Baikal detector has become a most powerful tool for ecological monitoring of South Baikal which is most subject to anthropogenic impact.

Thus, the deep underwater laboratory BAIKAL and its neutrino detectors complex can successfully solve a wide range of fundamental tasks of modern physics and astrophysics. It is a unique construction which has already become an important part of world science.

Taking into account that absolutely new unique data appear in the given research area from the ICE-cube detector, the Council **stresses** the utmost importance and considerably greater necessity to upgrade in no time the Baikal deep submergence neutrino telescope – to develop the facility BAIKAL-GVD with the capacity up to 2 cubic km.

The Council **resolves** that the implementation of the discussed plan of upgrading the neutrino telescope in Lake Baikal be one of the top and most urgent tasks in the activities under discussion.

**On the issue of development of the Baksan detector of geoneutrino,** the Council listened to the presentation by RAS Corresponding Member V.N.Gavrin. **The following persons took part in the discussion:** RAS Corresponding Member O.G.Ryazhskaya, Doctor of Physics and Mathematics Yu.G.Kudenko, Doctor of Physics and Mathematics A.V.Derbin, Doctor of Physics and Mathematics L.B.Bezrukov, Academician S.S.Gershtein, Doctor of Physics and Mathematics M.G.Skorokhvatov, Academician V.A.Matveev and others.

The Council marks that the Baksan neutrino observatory (BNO) of INR RAS is the only underground low-background laboratory in Russia for multi-purpose precision research in the field of neutrino physics and astrophysics. There are several laboratories of that kind in the world; among them BNO occupies the leading position in the depth of the underground location (up to 5000 m of water equivalent). The suppression of the space-radiation induced background processes is of crucial importance for the conditions of underground laboratories.

The Council lays emphasis upon the fact that urgent and radical upgrading of the BNO complex should be done to put unique opportunities of BNO into practice on the full-scale level and develop here a wide programme of fundamental and interdisciplinary research.

In this connection, the Council considers the new ambitious project of the development of a multi-purpose neutrino mega-detector the key element in the process of the BNO experimental base refurbishment. The Council regards the studies of the neutrino flux from the Earth's interior (geoneutrino) an urgent task for this detector. The distant location of BNO from Nuclear Power Stations (NPS, whose antineutrino fluxes are considered the sources of fatal background, is an attractive factor in this context.

The development of a high sensitive multi-purpose neutrino spectrometer will allow our country to occupy leading positions in the solution of key tasks of modern physics – search for proton decay and other rare processes, studies of fundamental properties of neutrino, neutrino oscillations in experiments with big transmission base, search for the double beta decay and violation of lepton number conservation law, search for neutrino radiation outbursts from star gravitation collapses, Solar activity monitoring, etc.

The Institute for Nuclear Research of the Russian Academy of Sciences (INR RAS) and the Scientific Research Centre the Kurchatov Institute (SRC KI) have started to develop such an experimental complex whose core will be a large-scale detector on the basis of a liquid scintillator (up to 50 kt). It is also planned to develop facilities for deep purification of liquids and gases, an electron measuring complex and other auxiliary detectors and services. The unique experience of accomplishment of the BOREXINO project can be used in designing and construction of the complex.

The implementation of the project presupposes the development of the BNO infrastructure that opens big prospects for the development of international cooperation, as the number of adequate physics laboratories in the world is quite limited while the huge number of proposals to conduct underground low-background experiments is constantly growing.

The Council **decides** that the proposed programme of the BNO complex upgrade and the establishment of a multi-purpose neutrino mega-detector at BNO deserve absolute support. The implementation of the programme is a first-priority task for the development of the Russian programme of research dynamics in neutrino physics and neutrino astrophysics.

The Council **stresses** the necessity to start without delay the work-out of pre-drafting proposals. At the same time the Council expects RAS and the RF ministry of education and science to find possibilities for financial support of the necessary research and design activities for the coming two-three years. The establishment of the all-Russian status for the project (and later, the international status) could also facilitate the successful accomplishment of the project, as leading scientific centres of Russia (SRC KI, JINR, MSU and others) would be constructively involved in it.

**Concerning paragraph 2 of the agenda,** the Council listened to the presentation of RAS Corresponding Member G.V.Domogatsky. **The following persons took the floor in the discussion of the topic**: RAS Corresponding Member V.N.Gavrin, Candidate of Physics and

Mathematics D.S.Gorbunov, Academician V.A.Rubakov, Doctor of Physics and Mathematics A.V.Derbin, Academician V.A.Matveev, Doctor of Physics and Mathematics L.B.Bezrukov, Doctor of Physics and Mathematics M.G.Skorokhvatov, Academician S.S.Gershtein, Doctor of Physics and Mathematics A.I.Studenikin, Doctor of Physics and Mathematics A.G.Olshevsky and others.

Primarily, the Council **remarks** that the main task of the meeting was the discussion of the strategy of further development of neutrino physics and astrophysics of elementary particles in Russia (shaping the strategic programme of research). In view of this, most fundamental, or in other words, core "system-forming" Russian projects were thoroughly discussed, as well as key international experiments where the involvement of Russian scientists is especially important and has big prospects.

The Council did not set the task to consider all proposals of Russian scientists in this sphere at this meeting. Nevertheless, the Council notes with satisfaction the successful involvement of Russian scientists in such international projects as LVD, OPERA, ANTARES, TWIST, EXO and others.

The Council states that it is, undoubtedly, necessary to discuss new proposals, when they reach the adequate level of study, at subsequent special meetings of the Council. They should be regarded from the point of view of their readiness and provision of participation of Russian scientists in most fundamental projects (Russian and main international projects), including the frames of the given programme.

**Development of a new neutrino laboratory at the Kalininskaya NPS.**

The Council stresses that beside two mega-projects under discussion – BAIKAL and BAKSAN – (that have the status of Russian neutrino laboratories) special attention should be paid to the unique opportunity to accomplish a new modern neutrino interdisciplinary project in Russia at the Kalininskaya Nuclear Power Station (KNPS).

Russia has great experience in construction of neutrino laboratories in the vicinity of atomic reactors and research at reactor antineutrino. In the 1980s the Kurchatov Institute built such laboratories on the Rovenskaya NPS and in Krasnoyarsk. Staff members of this Institute take an essential part in experiments at the industrial nuclear reactor in Chooz, France (The Double Chooz experiment). The main peculiarity of the experiments is in intense fluxes of antineutrino ($10^{13}/cm^2$ in the detector location point). Laboratories of such type at industrial nuclear reactors are in the USA, Japan, China, France, and South Korea.

The Council confirms that it is possible to conduct fundamental research of world level at the Kalininskaya NPS. In particular, the experiment GEMMA has obtained the best in the world restrictions for the magnetic moment of electron antineutrino. The antineutrino fluxes in blocks 3 and 4 of KNPS are record indeed – they are an order higher than in neutrino laboratories of the countries mentioned above. That is why the Council considers it expedient to develop a modern neutrino laboratory at KNPS.

Among the fundamental tasks under one title "Studies of Neutrino Characteristics in Experiments at Reactors" it is possible to choose the search for neutrino magnetic moment (electromagnetic neutrino interaction), precision studies of neutrino scattering processes (including the coherent scattering), studies of neutrino oscillations, search for sterile neutrino and processes with the lepton charge violation, etc. To solve these tasks it is necessary to work out new methods of neutrino registration and develop new neutrino detectors on their basis. Unique prospects for

applied research are obvious – these are studies of in-reactor processes with antineutrino for nuclear energy industry (continuous measurement of the reactor power and degree of fuel burn, real-time fuel burn tomography, etc.). They also include the design and development of compact antineutrino detectors for remote control of plutonium production and its unsanctioned siphoning during the reactor operation in real time to prevent nuclear-weapons proliferation (IAEA missions).

The Council acknowledges that in the frames of the agreement on cooperation among JINR, ITEP and KNPS fundamental research is conducted at KNPS at present in the experiments GEMMA and DANSS. However, in future it is necessary to have a higher status of the agreement among SC Rosatom, the Academy of Sciences and the ministry of education and science, to which, correspondingly, relate KNPS and research institutes (INR, JINR, ITEP, KI and others). So, the first priority task, connected to the development of a specialized neutrino laboratory at KNPS, is to conclude an interdepartmental agreement that will provide these studies. The KNPS administration expressed its interest in such cooperation.

The Council is of the view that the modern neutrino laboratory at KNPS is a unique opportunity that will really allow Russia to be the world leader, both in fundamental research at reactor antineutrino and in applied research for nuclear energy industry and safety of nuclear reactors.

This opportunity will undoubtedly be very attractive for the world community. The development of a neutrino laboratory at KNPS will provide the necessary infrastructure for studies by interested institutes of Russia and international collaborations.

The Council pays special attention to the promising outlook and diversity of opportunities for the Russian science in the given field, due to organization of a special laboratory at the Kaliniskaya nuclear power station, and **suggests** that the concerned participants prepare an agreement to develop such a laboratory.

**On neutrino studies at research reactors.**

The Council **marks** that the precision measurement of energy spectra of reactor antineutrino is the key factor for the control of nuclear reactors and physics research. In this connection, the Council considers the work aimed at the "dynamic" high precision description of the energy spectra of reactor antineutrino most important, with an account for the fuel burn and plutonium accumulation, accumulation and decay of the fission products, retarded neutrons' emission, neutron capture with nuclei, etc.

The Council approves new measurements of beta-particles' spectra from irradiated targets of the main fissionable isotopes at research reactors RR-8 of the Kurchatov Institute and PIK at PINP SRC KI, as well as specification of the electron spectra conversion into antineutrino spectra. These measurements are also important for the solution of the "reactor antineutrino anomaly" problem.

The Council notes that in Russia there is a unique opportunity to hold new experiments in search for antineutrino oscillations in sterile conditions at research reactors that have intense fluxes of reactor antineutrino. These are the reactor SM-3 in the State Scientific Center Research Institute of Atomic Reactors (Dimitrovgrad) and (in the nearest future) the research reactor PIK at PINP SRC KI, where the minimal distance to the antineutrino source for possible measurements does not exceed 5-6 m. The small (almost dot-like) dimension of the active zone of these reactors is of special importance, that is significant exactly for the search of oscillations into the new sterile condition of neutrino that differs from three known mass states in the value $\delta m^2 \sim 1$ eV$^2$ and the

effective mixing angle $Sin^2(2\theta) \sim 0.1$. Such experiments have been proposed and worked out at SRC KI with the application of liquid-scintillation position-sensitive detectors for the search of reactor antineutrino in the short basis (5-15 meters). The sensitivity of the experiments to the parameters of neutrino oscillations is expected to be in the region of $\delta m^2 = (0.1 - 6)$ eV$^2$ and $Sin^2(2\theta) > 0.01$.

The Council marks that the organization of experiments at research reactors is also important for the development of new neutrino sources on the basis of isotope-enriched materials that, in its turn, is necessary for new experiments in neutrino flux of the known spectral contents.

The Council agrees with the fact that it is expedient to conduct research experiments at Russian experimental reactors of the BBP-M type (PINP), PIK (PINP) and others, that are aimed at the studies beyond the Standard Model, such as the search for the electric dipole moment of neutron and electron, search for CP-violation and T-invariance, effects with the lepton charge violation, etc.

**On the production of isotope-enriched materials.**

The Council notes that SRC "Kurchatov Institute" has been still occupying one of the leading positions in the world in the level of physics and technology development in isotope production the demand for which is constantly growing. The centrifugal methods of isotope enrichment have been developed here and large quantities of germanium, chrome, xenon isotopes have been obtained. The method of $^{150}$Nd neodymium samples' enrichment with the laser method has been recently developed at the Institute. At present, the work in this field is reaching the phase of development of a semi-industrial facility.

The Council underlines that the preservation and development of the national experimental base for isotope production will undoubtedly play the decisive role in the accomplishment of experiments for the search of dark matter, search and study of double beta-decay, and in the development of intensive neutrino sources as well, for example, for the search of sterile neutrino, etc. This work has a special attractiveness internationally, as at present the world observes a sharp decay in research with isotope-enriched materials, while scientific programmes in neutrino physics that plan application of large amount of monoisotope materials rank among scientific priority programmes in Europe, the USA and Japan.

As an example of a new promising proposal, the Council **stresses** an interesting opportunity to hold an experiment for the search of sterile neutrino SAGE-3 (INR RAS) based on the use of an artificial neutrino source $^{51}$Cr of high activity 3 MCi. The expected sensitivity of the experiment to the oscillations active-sterile neutrino is $\Delta m^2 \sim 1$ eV$^2$ in the length 0.5 m. Taking into account the significance of the problem and its urgency, the Council expects that SRC KI render support in the solution of the task of the source production on a tight schedule.

**On involvement of Russian Institutes in key international experiments.**

The Coucnil regards it utterly necessary to continue and strengthen such involvement, especially in those key international neutrino projects where the contribution of Russia is already significant, or where non-participation deprives Russia of the access to scientific-technical information of first-priority importance.

It is well-known that neutrino oscillations (predicted in Dubna in 1957 by B.M.Pontecorvo and further developed in the studies by S.P.Mikheev and A.Yu.Smirnov) are sensitive only to the neutrino mass square discrepancy. Experiments on direct neutrino mass measurement are necessary for the definition of absolute values of neutrino masses. Scientists from the Kurchatov

Institute and INR RAS (P.E.Spivak and V.M.Lobashev) have basically contributed to the development of the method and equipment to measure the mass of electron (anti) neutrino (in tritium beta decay). The best restriction for the electron (anti)neutrino mass was obtained from the experiment in Troitsk; the methodology of this experiment is scaled out in the international experiment KATRIN, where INR and other Russian Institute are involved. The Council states that the participation in the KATRIN experiment is undoubtedly worthwhile and necessary as it justifies the Russian priority in this vital measurement.

The Council notes that the international experiment BOREXINO that is held with participation of Russian Institutes, after a rather long and labourious preparatory phase, has obtained a number of very good results. In particular, first precision measurements of solar neutrino fluxes from key thermonuclear reactions are of special importance, as well as the discovery of geoneutrino. The experimental complex BOREXINO in the international underground laboratory LNGS (Italy) has unique background characteristics that are related to the achievements of the collaboration in the purification of materials from radioactive impurities. The tasks of the new phase of the multi-purpose experiment BOREXINO include new measurements with a calibration source for the search of possible oscillations into sterile neutrino, measurement of the geoneutrino fluxes, monitoring of solar neutrino, search for dark matter (DARK SIDE project) and others.

The Council considers the involvement of Russian Institutes necessary that should be obviously continued, due to the unique character of the mastered methods and the significance of the tasks included into the BOREXINO programme.

The Council makes note that as a result of successful work in the experiments T2K, MINOS and Double Chooz and Daya Bay (where Russian Institutes took part) in 2011, the value of the mixing angle $\theta_{13}$ of the Pontecorvo-Maki-Nakagava-Sakata matrix was determined and turned out to be quite big, on the level of 0.15 rad. This fact allows one to expect forward-looking continuation of reactor and accelerator experiments in the studies of the neutrino mass hierarchy and CP-violation effects in the lepton sector.

As it is well-known, the idea of the experiment in Daya Bay was suggested by Russian physicist L.A.Mikaelyan and his colleagues for the Krasnoyarsk reactor. Besides, JINR physicists made a considerable contribution into the development of the Daya Bay experiment and continue successfully to take part in it in the phase of data acquisition and analysis. The development of one more detector in the several-decade distances from the reactor is a natural extension of this experiment. It will allow division of the direct and reverse neutrino mass hierarchy with the help of experimental data.

Thus, the Council states that the involvement of Russian physicists in the projects Daya Bay and Double Chooz is well grounded and fully justified, both from the point of view of the importance of the experiment itself and the existing methods and trained personnel.

The Council indicates that a relatively big value of the $\theta_{13}$ angle makes it possible to plan accelerator «off-axis» experiments in super big distances where it is expected that it will be possible to measure CP-violation effects by comparison of the results of muon neutrino and antineutrino oscillations. Most probably, the world milestone project will be the European projects LAGUNA where the neutrino beam formed at CERN will be forwarded into the detector in Finland for the distance above 2000 km. Until this experiment is launched, as it is tentatively scheduled for 2020, similar measurements, though with lower sensitivity, will be done in the experiments T2K and NOVA**.**

The Council expresses its opinion that Russian Institutes should remain in the highway of the development of this trend. So, the participation in the experiments T2K, NOVA should be continued; later on an opportunity to take part in the European project LAGUNA should be regarded.

The Council underlines the utmost importance of the issue about the origin of the neutrino mass. The only process for today where the Majorana origin of neutrino can be proved experimentally is the neutrinoless nuclear double beta decay.

The Council stresses the fact that the contribution of Russian Institutes into the experiments on double beat decay can hardly be overestimated. First, these experiments use special isotopes whose production is obviously connected with unique Russian scales and new technology developed by KI and the Russian atomic industry. Second, Russian Institutes have been taking an active part in these experiments for many years, and the experience they have accumulated will be of great importance in future. It relates to the semiconductor detectors' methods as well, where Ge76 itself is a sample under study and a detector at the same time, together with the methods of application of big external universal spectrometers with various isotopes as samples under research. The international projects that will apply these two methods in the nearest future are GERDA/Majorana and Super NEMO. It should be stressed that the contribution of Russian scientists (both intellectual and material) into these projects is decisive.

These are the reasons why the Council regards the participation of Russian Institutes in the experiments on the search of neutrinoless double beta decay, such as GERDA/ Majorana and Super NEMO, worth continuing and extending.

The Council notes that beside neutrino physics, experiments on direct detection of dark matter particles are most important in this field (observation of rare acts of scattering of such particles on nuclei). Astrophysical data present irrefutable evidence of the presence of non-baryon dark matter in the Universe. Understanding of its origin, detection and study of the properties of the particles it consists of is a fundamental task for modern cosmology and elementary particle physics.

To conduct the research in this field, Russian scientists should take part in international projects DARK SIDE and EDELWEISS which are implemented in the underground laboratories of Gran Sasso (Italy) and Modane (France).

The project DARK SIDE is constructed on the basis of the BOREXINO project and all scientific groups from Russian Institutes SRC KI, PINP, JINR and SRCNP MSU take part in the preparation of the first phase of this experiment. It is expected that the sensitivity of the experiment in search for dark matter will be 2 orders higher than in other experiments. The two-phase emission detector on liquid argon will be used in the project. The detectors of this type were first proposed in MEPI (where first methodical studies at reactors were also conducted); at present these methods is developed in Russia on the basis of the RED cooperation of Russian Institutes (Russian Emission Detector). The detector on liquid xenon RED-3000 is regarded now as one of the variants of the final phase of the DARK SIDE detector in addition to the argon detector.

The experiment EDELWEISS (Great Britain, Germany, Russia, France) is aimed at direct detection of dark matter particles in the laboratory for observation of rare acts of scattering of such particles on germanium nuclei. Russian Institutes make a considerable contribution into this experiment and are key participants for its accomplishment. It is with the involvement of Russia that the application of detectors made of enriched Ge-73 is expected, together with the technology developed by EDELWEISS to suppress all background components. It is planned to apply the

technology of JINR in low-threshold detectors development. The natural continuation of the EDELWEISS experiment is the participation in the all-European project EURECA.

Therefore, the Council states that the activities in the frames of the RED project and involvement of Russian Institute in the projects DARK SIDE and EDELWEISS are important and expedient.

**In conclusion**

The Council marks that the given programme is open to new proposals (for example, experiments at PIK and/or the IHEP accelerator) which will be included into the list when they are ready and considered at subsequent meetings of the Council.

The Council is of the opinion that additional measures in training qualified staff at leading higher institutions of the country should be undertaken to accomplish successfully the given programme.

The Council stresses that Russia has always played a significant role in neutrino research. Russian scientists are the authors of many basic concepts, fundamental results and unique techniques in this field. Scientific communities, established in many years, have high qualification and are still able to continue the research. The scientific and industrial potential of Russia also allows the application of this experience. But the time when delays in adequate financing of these studies is very near; otherwise “he who hesitates is lost”.

Chairman of the Scientific Council
RAS Corresponding Member G.V.Domogatsky

Scientific Secretary
Doctor of Physics and Mathematics V.A.Bednyakov