

# FOREWORD OF ACADEMICIAN ANATOLII ZAGORODNY, PRESIDENT OF THE NAS OF UKRAINE

**D**ear colleagues! The previous year could hardly be mentioned as carefree and full of bright hopes. Like, perhaps, all recent years, it was not an easy one for the Academy as well. Yet, thankfully, it will be remembered not only for its challenges but also for its accomplishments and desirable events.

Academy's scientists continued to work hard and produce significant results of truly high quality. First and foremost, that concerns basic research. Besides, there were numerous developments of practical orientation, which have already been implemented at production enterprises or are to be implemented in the near future.

In line with its long-standing tradition, the Academy did not stay away from current challenges facing Ukraine. To counteract *COVID-19*, its scientists produced forecasts of epidemic spreading, examined new coronavirus mutations, detected outbreaks of new strains, and were developing domestic vaccines.

Our experts proposed steps towards economic transformation of Donetsk and Luhansk oblasts, elaborated the program of the 2023 All-Ukrainian population census. Research projects aimed at enhancing nation's defense potential and security remained a priority.

Academy's collaboration with major industrial enterprises became closer. We deepened our cooperation with "ANTONOV" state enterprise, "Turboatom" joint-stock company, state enterprise "Ivchenko-Progres" machine-building design office, state enterprise 'M.K. Yan-gel "Pivdenne" design office'.

To commercialize R&D projects supported by German colleagues, we continued work on creating "Aca-

dem.City" science park. Experimental research infrastructure was somewhat modernized. The physical launch of nuclear subcritical facility "Neutron Source" was an event of major importance.

Our scientists effectively participated in contests and carried out projects under research programs of EU, NATO, CERN, UNESCO as well as other organizations and foundations. Ukrainian physicists were actively involved in developing and implementing experiments at the Large Hadron Collider, and recently — in the discovery of a new quasiparticle — the odderon, while our biologists were able to join the EU *ORBIT* project.

Very inspiring is the fact that many significant achievements are the results obtained by our young scientists, who win targeted grants for youth research laboratories and groups. In future, we will be even more proactive in encouraging various forms of support for our young scientists.

I cannot help mentioning that last spring the Academy elected worthy new members — 30 academicians and 73 corresponding members, as well as 27 foreign members. All of them are leading experts in their respective fields, represent various regions of Ukraine, work both at the NAS of Ukraine and at other institutions.

We continued to improve Academy's activities, optimize its structure, the principles of its organization and functioning. An updated Academy Charter was approved. The Science and Technology Council of the NAS of Ukraine started its work in 2021. The process of improving the principles of performance-based budget funding distribution among institutions was continued. Competitive approaches to selecting new NAS targeted programs and targeted projects were introduced. Further steps towards optimizing the network of scientific institutions and pilot production facilities were taken.

Realizing new recent challenges, we adopted a new Concept of the NAS development till 2025. Its main aim is to enhance Academy's contribution to priority areas of economic and social development of the state, promote the world-class research, efficiently use budget funding and property, improve the situation with staffing and, undoubtedly, strengthen the ties with the authorities and society. This aim implies specific ways of its achievement, determines steps for its implementation, along with their schedules and expected results.

So, there are very many plans and objectives. And ahead of us is only joint, purposeful and persistent work.

# IMPORTANT EVENTS

**The meeting of the National Council of Ukraine for Science and Technology Development was held on January 12, 2021. Led by Serhiy Shkarlet, head of the Administrative Committee of the National Council,** it discussed numerous issues of strategic importance for Ukraine's scientific, S&T, and innovative activities.

Serhiy Shkarlet, Minister of Education and Science of Ukraine, outlined the current state and development prospects of the scientific and S&T sphere. The results elaborated by working groups of the National Council of Ukraine for Science and Technology Development and the Ministry of Education and Science (MES) of Ukraine were discussed within the second issue of meeting's agenda. It should be noted that in November 2019 the National Council set up eight working groups to draw up proposals for addressing current challenges in the sphere of science and technology. Their leaders presented the results of the work.

In particular, NAS corresponding member Mykola Kyzym, deputy head of the Administrative Committee of the National Council, the first deputy of the minister of education and science, spoke about the situation in updating the system of priority directions in the development of science, technology and innovation.

Following the discussion, it was decided to recommend MES to advance an initiative for the Verkhovna Rada of Ukraine to extend the validity of the current list of priority directions in the development of science and technologies till 31 December 2021. The National Council recommended to the MES of Ukraine, jointly with stakeholders and with the contribution from the National Academy of Sciences of Ukraine and the national sectoral academies of sciences, to submit agreed proposals regarding the new list of priority directions of science and technologies. NAS of Ukraine became actively involved in that work. In March 2021, a joint working group of the NAS of Ukraine and national sectoral academies of sciences was set up, which prepared and forwarded to the MES of Ukraine specific proposals concerning the abovementioned priority directions.

Representatives of the NAS of Ukraine also took an active part in determining priority directions by the working and expert groups set up by the MES of Ukraine. To provide scientific support to forecasting the major trends in the development of Ukrainian science and its interrelations with social, industrial, economic and defense spheres, as well as identify the most relevant directions of science advancement that need priority reinforcement, the NAS of Ukraine organized a comprehensive prognostic and analytical study that engaged many renowned scientists who were recommended by NAS departments, national sectoral academies of sciences and higher education institutions.

Within the second issue of the agenda, the meeting also considered the legislative support to and the ways of reforming the National Academy of Sciences and the national sectoral academies of sciences of Ukraine. The discussion held supported the proposals of the MES of Ukraine and the respective working groups regarding the legislative support to reforming the national academies of pedagogical, agrarian and legal sciences. The MES of Ukraine was recommended to present the respective draft act on approving the planned measures for reforming the national academies of pedagogical, agrarian and legal sciences. Such documents were prepared, and the order of the Cabinet of Ministers of Ukraine of 4 August 2021 #911 approved the planned measures of reforming the National Academy of Agrarian Sciences, the National Academy of Legal Sciences, and the National Academy of Pedagogical Sciences for 2021 and 2022.

At the meeting, the National Academy of Sciences of Ukraine presented its own reformation plan, based on the measures defined by NAS Presidium resolution of 23 November 2020 #171 'On some measures to reform the activities of the National Academy of Sciences of Ukraine'. Of great importance is the fact that the National Council agreed that the NAS of Ukraine is to independently organize and implement measures for improving its structure, as well as administrative and scientific activities.

Taking into account the results of hearing the third issue of the agenda, the meeting approved in general the conclusions and proposals of the Scientific Committee of the National Council regarding the results of hearing the reports of chief budget funds administrators, which was held in summer 2020, and commissioned to analyze the efficiency of the scientific and S&T activities conducted by them.

In the framework of the fourth issue of its agenda, the meeting heard the presentation of Oleksii Kolezhuk, the head of the National Council's Scientific Committee, 'On the first results of the work of the National Research Foundation of Ukraine and the membership of the Scientific Council of the National Research Foun-

dation of Ukraine'. Relying on the results of its consideration, the National Council recommended the MES of Ukraine to initiate forwarding several legislative drafts for improving the National Research Foundation's activities to be considered by the Cabinet of Ministers.

Besides, among the issues on its agenda, the meeting analyzed the proposals of the National Council's working group towards elaborating the draft principles of the system of awarding scientific degrees and academic titles in Ukraine and recommended to the MES of Ukraine to prepare draft amendments to respective legal acts. The ministry also was to consider working group's proposals regarding the system of stimuli for young scientists, which had been approved by the Scientific Committee of the National Council. The meeting of the National Council decided to continue on an ongoing basis the activities of the eight working groups set up by its decision of 5 November 2019.

**On 26 May 2021, the session of the General Meeting of the NAS of Ukraine was held, which elected NAS active members (academicians) and NAS corresponding members.**

The Presidium of the NAS of Ukraine announced 32 vacancies of academicians and 76 vacancies of corresponding members to be elected in 97 specializations.

As NAS President Anatolii Zagorodny stressed, the distribution of vacancies across departments and the choice of specializations were based on the intention to provide priority development of basic science, primarily, in the areas where Ukrainian scientists had world-class results.

The significant interest of the scientific community to the election was shown by the high competition of applicants. 79 contenders for 32 vacancies of academicians were advanced and registered, i.e., two and a half candidates for one position. For 76 vacancies of corresponding members, there were 287 contenders, or nearly four candidates per position.

There were 267 Academy's associates among eligible candidates for the vacancies of NAS active members (academicians) and corresponding members. That amounted to 73% of the total number of contenders. 99 persons (27%) were representatives of higher education institutions, various departmental research institutions, and other organizations. The number of women among those participating in the election was 58, or 15.8%.

Of the 32 candidates for academicians, 26 were employees of the NAS of Ukraine, five were scholars working at higher education institutions, one candidate represented the National Academy of Medical Sciences of Ukraine. Of the 73 contenders for the corresponding member positions, 58 worked at institutions of the National Academy of Sciences of Ukraine, 11 were employees of higher education institutions, four of them



*Session of the General Meeting of the NAS of Ukraine*



*Loading of the container with the first heat-releasing fuel assembly into the biological safety system of nuclear subcritical installation "Neutron source"*

worked at departmental research institutions and other organizations.

The average age of academicians prior to the election was 79.1 years, that of corresponding members was 71.8 years.

The list of the candidates advanced was published in due time, viz., more than a month before the election, in the press and electronic mass media for public discussion. Participating in the discussion were councils of scientific institutions, those of higher education, some leading scientists of both Ukraine and other countries, who sent several thousand reviews of candidates' scientific achievements. Pursuant to the Academy Statute, the whole preparation to the election was held with full openness and freedom of discussing the candidates. At the key stage of the election campaign — the general meetings of the departments — all conditions for free exchange of opinions, criticism, proposals were provided as well, which, undoubtedly, contributed to making the most justified, objective and independent choice. At all departments, expert commissions were working, which recommended priority candidates to be elected.

According to the results of secret ballot, 30 academicians, 73 corresponding members, and 27 foreign



*Building of the nuclear subcritical installation “Neutron source”*

members of the NAS of Ukraine were elected. There were 14 women among the elected candidates. That is much more than had been elected in any other election campaign over the Academy existence. The average age of the elected NAS academicians was 67 years, i.e., 12 years less of that hitherto recorded, while the age of corresponding members was 61 years, which was nearly 11 years less than ever before.

These and other facts prove that in spite of the difficult current situation, the regard of the National Academy of Sciences of Ukraine in the society remains high and shows its importance as the topmost scientific institution of the nation.

**Early in October 2021, the National Science Center “Kharkiv Institute of Science and Technology” of the NAS of Ukraine made the physical launch of the nuclear subcritical installation “Source of neutrons based on a subcritical assembly driven by a linear electron accelerator” (“Neutron source”).**

The installation was built with the involvement of international community — experts from Ukraine, the USA, Great Britain, China, Germany, Switzerland.

The nuclear subcritical installation “Neutron source” is a unique innovative facility whose specifications today have no counterparts in the world. Industrial use of such equipment will make nuclear accident absolutely impossible, enable physicists to burn a wide range of radioactive elements, and make nuclear energy safer and more environment-friendly.

The interest to using subcritical assemblies arose back in mid-1950s. At the time, this idea was generated by the intention to enhance the safety of nuclear facilities since nuclear reactor operates in controlled nuclear-explosion mode.

However, for a long time, the employment of subcritical assemblies was not feasible because powerful accelerators of charged particles were not available. At the current stage of technological progress, there are relevant technologies permitting such accelerators to be built. Subcritical assemblies are operating in some countries, but unlike “Neutron source”, they have zero heat capacity.

After receiving a special permission and taking a number of preparatory measures, the installation was launched. In the framework of implementing the program of its physical launch, which was agreed with the State Nuclear Regulatory Inspectorate of Ukraine, 37 heat-releasing fuel assemblies were loaded to the active zone of the nuclear subcritical installation, and respective measurements of its neutron-physical characteristics were made.

Thus, the operations envisaged by the program of physical launch of the nuclear subcritical installation “Neutron source”, coordinated with the State Nuclear Regulatory Inspectorate, were completed.

Now, the National Science Center “Kharkiv Institute of Physics and Technology” of the NAS of Ukraine is taking steps towards receiving the permission of the State Nuclear Regulatory Inspectorate of Ukraine for the pilot industrial operation of the facility.

Successful commissioning of the nuclear subcritical installation “Neutron source” will guarantee the state-of-the-art experimental infrastructure for scientific support of nuclear energy industry of Ukraine, in particular for extending NPP reactor operation life, as well as neutron-based research in nuclear physics and engineering, radiation medicine, radiation materials science, production of medical isotopes. Besides, the nuclear installation itself will be an object of research as a prototype of novel safe energy sources based on subcritical systems.

# REFORMING NAS ACTIVITIES

In 2021, the National Academy of Sciences of Ukraine made significant efforts and achieved noticeable results in reforming its own activities in accordance with the schedule presented last year in January at the meeting of the National Council of Ukraine for Science and Technologies Development. The plan was compiled with the account of strategically important directions of Academy reforming and respective measures defined by the NAS Presidium resolution of 23 November 2020 # 171 "On some measures for reforming the activities of the National Academy of Sciences of Ukraine", alongside with the targets approved by the decision of the NAS General Meeting of 27 May # 2 "On the report of the NAS activities in 2020 and tasks for the next period". A significant amount of work on preparing and summarizing the proposals for the plan, coordination and control over the measures targeted was done by the Coordination council for reforming the NAS of Ukraine.

An important task in reforming Academy's activities was to take the inventory of its infrastructure and land plots with the purpose of ensuring the efficient use of the property complex of the NAS of Ukraine. A number of steps were taken to regularize its accounting, update the information in the Joint register of state property objects. 200 organizations entered respective data to the digitalized system of managing Academy's real estate. The information was analyzed and proposals were prepared for re-profiling or transferring to other Academy institutions the real estate objects and land plots that were standing idle for long time.

Further optimization of the network of scientific institutions and organizations was carried out. The decisions on liquidation or reorganization through merger of 12 scientific institutions were adopted, and eight NAS organizations were transferred to the jurisdiction of the State Property Fund of Ukraine for prospective privatization. Approved was the list of 44 business entities of the NAS of Ukraine that are to be privatized and respective proposals were forwarded to the Ministry of Economy of Ukraine.

The first cycle of evaluating the performance of Academy's research institutions with reliance on the procedure developed with taking into account the eval-

uation experience in European countries was completed. In total, 160 Academy institutions and 1170 of their subdivisions were evaluated in 2016—2021. The results of this evaluation became the basis for developing measures towards the optimization of research institutions and their internal structure as well as distribution of State Budget funding.

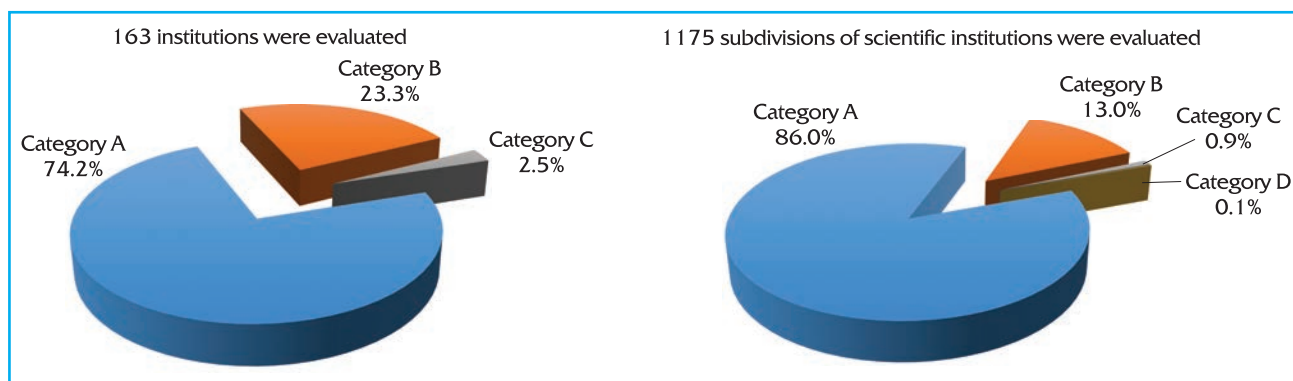
A number of steps were taken to improve the legislative basis of Academy's activities, the system of its administration and organizing its work. The General Meeting of the NAS of Ukraine by its resolution of 27 May 2021 approved a new version of Academy's Statute, which significantly enhanced the democratic principles of NAS life. Besides, some amendments were introduced to the legal documents regulating the activities of the sections, departments and research institutions of the NAS of Ukraine.

In March 2021, the membership of the Scientific and Technological Council was approved, which now includes representatives of the Academy, higher education institutions, executive power bodies, and heads of major high-tech industrial enterprises. The task of this council is to involve the Academy in addressing important S&T challenges of economy branches and social sphere, as well as accelerate the deployment of its institutions' scientific products. The science-coordinating councils set up within NAS sections advanced their work, in particular, that aimed at forming new all-Academy programs, preparing proposals towards improved coordination of basic research and the development of interdisciplinary studies. Supervisory boards were set up within some leading scientific institutions of the Academy.

Further improved was the new model of funding, which abandons the egalitarian distribution of financial and material resources across institutions and takes into account the efficiency of their performance. An important component of this model is the budget-funded program "Support to the development of priority areas of scientific research", which was introduced in 2018 through Academy's initiative. It permitted, in particular, providing considerable addressed support to the best scientific teams. Under this program, in 2021, 400 research subdivisions of the institutions were financed, which won the highest category according to the evaluation results.

Stimulating measures were used with regard to the distribution of State Budget funding: the increased institutional funding in 2021, 2022 was distributed among institutions in accordance with their ratings and taking into account the results of evaluation and of state attestation, the quantity and quality of their staff, the availability of unique scientific equipment, development of institution's research infrastructure etc.

New budget-funded programs — "Providing housing for NAS scientists" and "Creating a modern specialized



Results of evaluating the efficiency of NAS institution performance carried out in 2016-2021 (163 institutions were evaluated) and their subdivisions (1175) by the procedure developed with the account of the experience of evaluating scientific institutions in European countries. Outside experts were widely involved in the evaluation, 12% of them being foreign scientists, and 37% were from non-Academy institutions, as well as from higher education institutions, state authorities, ministries and departments of Ukraine

laboratory for working with infectious materials” — were started.

In 2021, to implement government decisions, the working group involving representatives of the NAS of Ukraine, the Scientific Committee of the National Council of Ukraine for Science and Technology Development, ministries, relevant specialized institutions and higher education institutions, made a review of State Budget expenditures in the sphere of science and S&T activities of NAS research institutions in 2017—2019. According to its results, a number of steps for increasing the efficiency of using budget funds were taken.

Measures were also taken to develop research infrastructure and to improve the material and technical provision of scientific research. As compared to 2020, the finance for procuring state-of-the-art equipment and upgrading the available one was increased by 75%. The NAS budget for 2022 provides for a three-time increase for that purpose. The physical launch of nuclear subcritical installation “Neutron source” was made; it is to be the foundation of innovative experimental base for the scientific support to nuclear energy industry of Ukraine, along with neutron research in nuclear physics and energy engineering, radiation medicine, radiation materials science, and production of medical isotopes.

A significant element of reforming the NAS of Ukraine was the development and implementation of measures in support of young scientists. The funding of research laboratories and groups of young researchers was increased considerably. In 2021, there was a twofold rise in funding for those purposes in comparison with the previous year — up to ₴ 44.5 million, and ₴ 50 million is to be provided in 2022. The implementation of NAS post-doctoral research program was started. The NAS of Ukraine established the Academi-

cian B.E. Paton stipend for young scientists of the Academy — candidates of sciences (PhDs) and doctors of sciences. In 2021, under the new budget-funded program “Providing housing for NAS scientists”, significant finance was allocated for the purchase of housing for young scholars — viz. ₴ 60 million.

Significant effort went into advancing innovative activities, scientific support to solving important nationwide problems. In particular, science park “Academ.City” is being created with the support of the Federal Ministry of Education and Scientific Research of Germany. The Association of Academy Collaboration “Academ.City” was set up in 2021 by twelve NAS institutions and Kyiv Academic University. The activities of the S&T Council of the NAS of Ukraine promoted the effective collaboration with major industrial enterprises. New collaboration agreements were concluded with “ANTONOV” state enterprise, joint-stock company “Turboatom”. The implementation of the NAS targeted S&T program of defense research was continued. The competitive selection of its projects was carried out by the Coordination Council involving representatives of the NAS of Ukraine, Defense Ministry, Ministry of Internal Affairs, State Security Service, National Security and Defense Council of Ukraine and “Ukroboronprom”. An agreement between the Armed Forces of Ukraine and the National Academy of Sciences of Ukraine on scientific and S&T collaboration on the issues of defense potential of the state was concluded. A memorandum of NAS collaboration with the State Security Service of Ukraine was signed. The support to measures for fighting the epidemic caused by SARS-CoV-2 coronavirus was provided. The main directions of these activities and the tasks of NAS scientists in counteracting COVID-19 were discussed on 9 June 2021 by a NAS Presidium meeting, attended by the Minister of Health of Ukraine and the Chief Sta-



*Signing of the Memorandum on the implementation of the “Presidential University” project. Left to Right in the photo: Minister of Education and Science Serhiy Shkarlet; People’s Deputy of Ukraine, head of the education subcommittee of the Verkhovna Rada Committee for Education, Science and Innovation, coordinator of the “Presidential University” project Yulia Hrishina; President of the NAS of Ukraine NAS academician Anatolii Zagorodny and Vice-President of the NAS of Ukraine NAS academician Viacheslav Bogdanov*

te Sanitary Doctor of Ukraine. The work on scientific support to holding the all-Ukrainian population census in 2023 was launched.

The ties of education and science were developed further. Those were promoted, in particular, by the signing in March 2021 of the Collaboration Agreement between the Ministry of Education and Science of Ukraine and the National Academy of Sciences of Ukraine. The Academy, in collaboration with the MES of Ukraine, became actively involved in implementing the ‘Presidential University’ project and prepared a number of proposals regarding its education and training programs and the membership of working groups, whose task was to form new science-based programs for the main directions of preparing specialists by this university. To join the efforts in implementing this project, the NAS of Ukraine and the MES of Ukraine signed a relevant memorandum.

An important aspect of reforming the Academy was the development and broad use of the potential of

international collaboration. NAS scientists actively participated in contests and implemented a number of projects under the scientific programs of the European Union, NATO, UNESCO and other international organizations and foundations, in particular, in experiments at the Large Hadron Collider and in the discovery of a new quasi-particle — odderon, and also joined the EU *ORBIT* project. Financial support to scientific teams that won grants of international foundations, centers, partial funding programs was provided. Besides, funding was provided for scientific programs highly regarded by international experts.

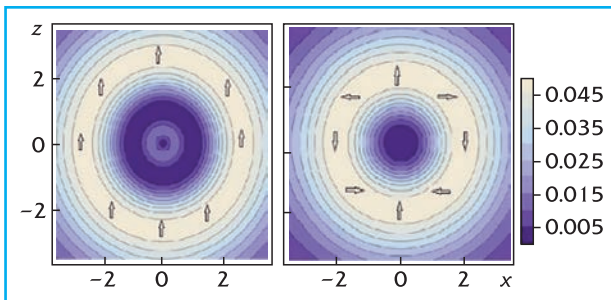
Measures towards improving democratic principles of NAS activities were taken. In 2021, more than 50 institutions of the Academy held elections of their directors according to the new procedure. In nearly half of the institutes, their directors were elected for the first time. The Academy got a new replenishment of its personnel with new members. 30 academicians, 73 corresponding members and 27 foreign members were elected competitively. New Academy members are leading experts in respective science areas, they represent various regions of Ukraine, both Academy and non-academy institutions. The average age of Academy members has decreased drastically. Among those elected to the Academy, there are much more women than ever before in its history.

It should be noted that to further concentrate the efforts and resources in the most important directions of improving Academy functioning, and to implement the decision of the NAS General Meeting of 27 May 2021, the Concept of the development of the National Academy of Sciences of Ukraine in 2021—2025 was elaborated and approved last year in June. To ensure the implementation of this concept, the relevant action plan was adopted (NAS Presidium resolution of 27 October 2021 #330 “On the plan of actions to implement the Concept of NAS development in 2021—2025”). These documents define the tasks for reforming the National Academy of Sciences of Ukraine in the near future, and the Academy will spare no effort for their successful implementation.

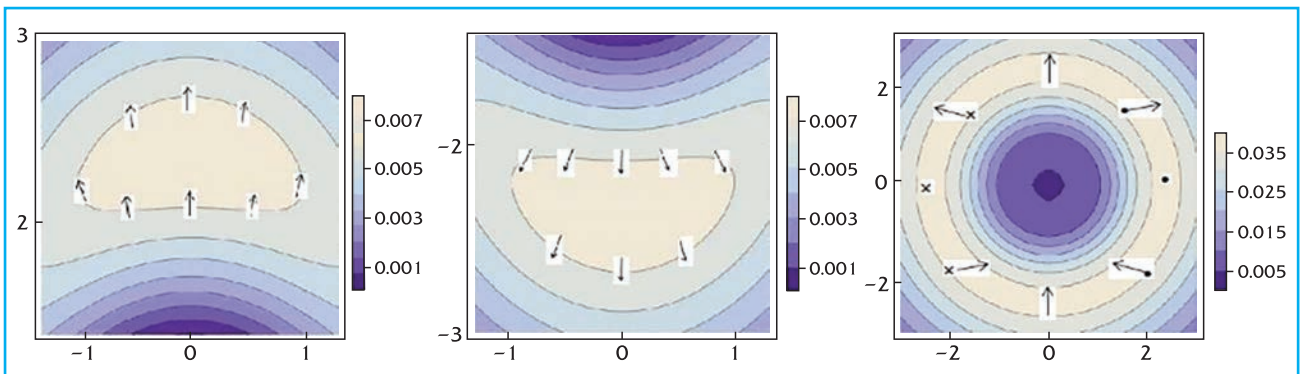
# RESEARCH ACHIEVEMENTS. PHYSICAL, ENGINEERING AND MATHEMATICAL SCIENCES

## Exact solutions of the Dirac equation with a Coulomb potential

For the Dirac equation with a Coulomb potential, scientists of Bogolyubov Institute for Theoretical Physics of the NAS of Ukraine found a new invariant, which complements Dirac and Johnson–Lippman invariants known earlier. It was named Brizhik–Eremko–Loktev invariant. The knowledge of invariants that do not change the original equation is the necessary condition for obtaining its exact solutions. On the basis of these three invariants their generalized analogue was constructed. That permits the complete solution of the Dirac equation in a Coulomb field to be obtained analytically and



Charge density distribution and spin orientation in the region of the highest charge density in the states corresponding to the Dirac invariant, with quantum number  $m = 1/2$ ,  $\sigma +$  (Left) and  $\sigma -$  (Right). In the states  $m = -1/2$ , spin orientations are opposite to the mentioned ones



Charge density distribution and spin orientation in the region of the highest charge density: Left – in the state with quantum numbers  $m = 1/2$ ,  $\sigma +$  (Johnson-Lippman invariant); Center –  $m = -1/2$ ,  $\sigma +$  (Brizhik-Eremko-Loktev invariant). If the additional parameter is changed in the case of Brizhik-Eremko-Loktev invariant, spin may go beyond drawing plane ( $z$ ,  $x$ ) in one direction or the other, which is shown by symbols  $\cdot$  and  $\times$

spin distribution in each quantum state to be determined, which was not known before. This generalized invariant was shown to define the set of quantum numbers characterizing stationary electron hydrogen-like states. Institute's physicists were the first to calculate the distribution of the average value of spin directions in electron bound states, and to show that both charge distribution and spin direction essentially depend on the spin invariant. This was visualized in the presented calculation results for the distribution of charge density and spin orientation in the region of the highest charge density for electron in the states with principal quantum number  $n = 2$ , orbital quantum number  $j = 1/2$ , magnetic quantum number  $m$  and spin quantum number  $\sigma$ .

Such differences in the distribution of spin orientations are important for practical applications in nanotechnologies related to the spin degree of freedom (spintronics etc.) and can be detected experimentally.

*L. Brizhik, O. Eremko, V. Loktev*

## Neutrino research

Back in 2009, scientists of the NAS Institute for Nuclear Research were the first to propose and study lithium molybdate crystals as potential detectors in the search for double beta decay of  $^{100}\text{Mo}$  nuclide. Their choice was good and now these low-temperature scintillators are employed in several experiments: *CUPID-Mo* (Modane Laboratory in France), *CROSS* and *BINGO* (Canfranc Laboratory in Spain), *AMoRE-I* (Yangyang Laboratory in Korea). All these facilities use lithium molybdate crystals produced from molybdenum enriched with  $^{100}\text{Mo}$  isotope. Cooled to super low temperature of several hundredth Kelvin, such detectors allow beta-particle energy to be measured with very high precision, while the location of installations deep underground protects their supersensitive equipment against cosmic rays. Further reduction of radioactive background is achieved



Denis Poda, senior researcher of the NAS Institute for Nuclear Research, installs the equipment at Modane Underground Laboratory. In December 2019, Denis became a research engineer of the Laboratory for the physics of “two infinities” Irène Joliot-Curie at the National Centre for Scientific Research in France

ved through selecting all materials by the level of their radioactive contamination, analyzing data thoroughly to separate the signal of double beta decay from numerous background processes.

Through the initiative and with the active involvement of scientists of the Institute for Nuclear Research, during the preparation of *CUPID-Mo* experiment the two-neutrino mode of  $^{100}\text{Mo}$  nucleus double beta decay was measured with very high precision (at the level of 3%). This is a most prominent result, since it had been believed for a long time that to register this extremely rare process, whose half life is billion times longer than the Universe age, is utterly impossible. But a truly outstanding achievement was a most severe limitation on the Majorana neutrino mass at the level of 0.5 electron volt. This is one of the best results obtained in more than seventy years of double decay research. The limitation will be used in developing new theories, extensions of the Standard Model of elementary particles, which describe massive neutrinos. Besides, the sensitivity achieved points at the feasibility of constructing large-scale next-generation experiments *CUPID* and *AMoRE-I*, where scientists plan to use several hundred kilograms of scintillation lithium molybdate crystals at millikelvin temperatures. These experiments have an ambitious task to achieve unprecedented sensitivity to

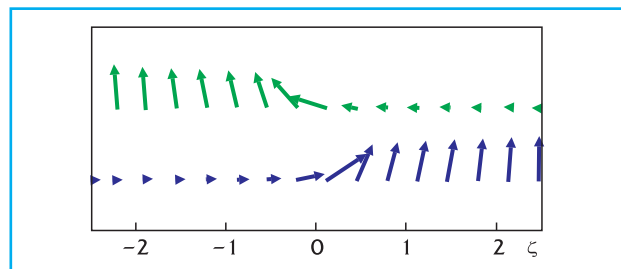
neutrino mass at the level of inverted scheme of neutrino masses, i.e., several hundredth of electron volts. Should the decay be observed, that would be the discovery of a new type of matter, when a fermion particle is identical to its anti-particle (Majorana neutrino). This, in turn, would help explain the fundamental problem of elementary particle physics and cosmology: the baryon asymmetry of the Universe (as a result of which the Universe exists in its present state). Besides, neutrinoless double beta decay would mean that lepton number is not conserved: simply put, electrons are generated in the process. And in spite of significant efforts (e.g., attempts to register proton decay with giant Cherenkov detectors), mankind has not observed that yet.

*F. Danevich, M. Zarytskiy, V. Kobychiev, O. Polischuk, V. Tretyak*

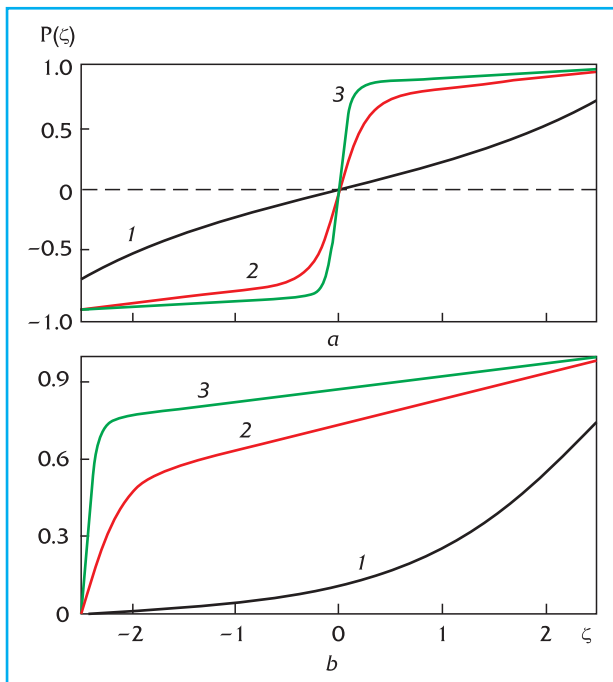
### Control of valley-polarized domains electrically induced in two-dimensional crystals

The development of innovative technologies and achievements in nanophysics have spawned a new direction in nanoelectronics and nanophotonics — *valleytronics*, which uses the so-called valley structure of current carrier spectrum in semiconductor materials as an additional means to control their electrical, optical and magnetic properties.

Scientists of V.E. Lashkaryov Institute of Semiconductor Physics of the NAS of Ukraine analyzed the current carrier kinetics in two-dimensional crystals with two valleys, where carriers are characterized by different anisotropy due to crystal field specifics and Berry curvature. In the external magnetic field, it generates current carrier streams transverse to the field in the opposite directions for different valleys. In the samples of finite thickness these streams cause spatial redistribution of the carriers of both valleys. With the increase of the electric field, the redistribution enhances, and two spatial domains with different valley polarizations are formed. The domains are separated by a thin transition layer of switchable polarization, whose width is inversely proportional to the electric field strength. The



Valley currents depending on the coordinate for valley distribution in two-dimensional crystal that corresponds to symmetric conditions on specimen edges (arrow lengths and directions correspond to the values and directions of current)



Formation of polarization domains in two-dimensional crystals with the increase of external electric field: curves 1, 2, 3 show spatial valley polarization  $\mathbf{P}$  in the fields  $E_1 < E_2 < E_3$ ;  $\zeta$  is dimensionless coordinate, a – for the case of symmetric conditions on specimen edges, b – for the case of essentially asymmetric boundary conditions and significant inter-valley scattering on the left edge of the specimen when one domain is formed

degree of polarization and polarization domain sizes depend on the field and conditions on the edges of two-dimensional crystal. The emergence of valley-polarized domains generates inhomogeneous valley currents.

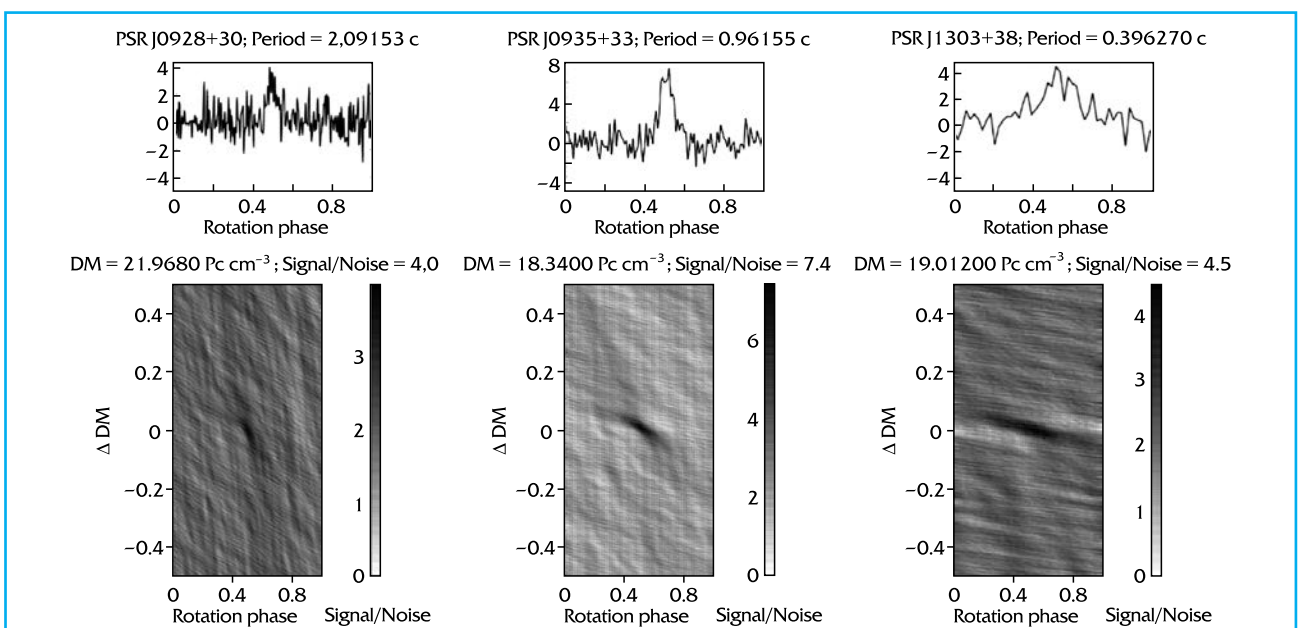
Also studied was the dependence of the phenomenon of valley-polarized domains on carrier transport parameters, inter-valley diffusion both within the sample and on its edges. Experimental research of the phenomenon proposed will permit the determination of materials' basic parameters, which is important for valleytronics, while the phenomenon itself could find application in nanoelectronic and nanophotonic devices.

V. Kochelap, V. Sokolov

### Three pulsars new for decameter wavelengths were detected

**P**ulsar detecting in the decameter wave range is scientifically important since the lowest frequencies provide the highest precision of measuring the dispersion delay parameters and the degree of rotation of linearly polarized pulsar emission. Due to the discovery of pulsar decameter emission, we determine not only emission properties of a particular source but are also able to carry out Galaxy "tomography" in the ever-increasing number of directions.

Despite the fact that Ukrainian radio telescope YTP-2 is the world largest radio telescope in the decameter wave range and provides maximum sensitivity as compared with other instruments, to discover and even detect already known pulsars is extremely difficult because of a very high level of radio interference in the short wave range, a significant rise of cosmic background temperature in the direction to low frequencies and a dramatic rise in the emission sporadicity of the majority of pulsars exactly at the lowest frequencies.



Detecting pulsars PSR J0928+30, PSR J0935+33 and PSR J1303+38 with specification of their rotation periods

Due to the upgrading of telescope equipment and new possibilities of digital procession of observation results, scientists of the Institute of Radio Astronomy of the NAS of Ukraine were able to overcome these problems and significantly increase the number of pulsars detected in the decameter wave range.

The dispersion delay of the arrival of lower-frequency pulse of pulsar radio emission in comparison with higher frequencies, which is caused by interstellar plasma, amounts to tens and hundreds of seconds (or hundreds and thousands of pulsar periods). Therefore, for effective signal accumulation in a broad frequency band, there is a need to “cut” it into the smallest details — frequency channels and time periods, clean it from radio interference and compose in the way that would compensate for huge dispersion delay.

In recent years, the algorithms of search for pulsars were significantly improved, which permitted even very weakly emitting objects to be found. The average profiles of the pulses obtained enable astronomers to specify the period, degree of dispersion, scattering time constant, which is important both for studying pulsar’s external magnetosphere and for diagnostics of magneto-active plasma in the sightline along ever increasing number of directions in the Galaxy.

By using upgraded equipment and improved search algorithms, three pulsars that are new for decameter wavelengths — *PSR J0928+30*, *PSR J0935+33*, and *PSR J1303+38* were detected and their rotation periods were specified. The total number of pulsars detected in the decameter range with YTP-2 is now above 80% of those discovered with all low-frequency radio telescopes in the world.

*I. Kravtsov, V. Zakharenko, O. Ulyanov*

### **Reconstructing the solutions of the Klein–Gordon equation and sphere packing problem**

One of the equations describing wave processes for a number of industrial problems, in particular, those on describing gas condition in a gas storage facility with a small number of pressure-measuring instruments is the Klein — Gordon equation. When the solutions of this equation depend only on time and a single spatial variable, the problem of “reconstructing” these solutions with reliance on discrete data (“measurements”) is to determine where exactly it is necessary to know (“measure”) the solution value, and to construct basic solutions of a special type.

Scientists of the NAS Institute of Mathematics proved that, firstly, even neglecting the traditional assumption that fluctuation has the extreme entropy value, it is

possible to determine the existence of the minimal frequency of “measurements”, when each fluctuation is “reconstructed” by its discrete values in two points lying on equation characteristics. Secondly, they were able to construct the necessary basic solutions of the Klein–Gordon equation. The latter became possible due to discovering a connection between the theory of the Klein — Gordon equation and sphere packing problem.

In 2003, American mathematicians Henry Cohn and Noam Elkies reduced the problem of sphere packing in the spaces of dimensions  $d = 8$  and  $d = 24$  to the existence of functions with specific properties, when this function is non-negative for each value of its positive argument, while its Bessel transform of respective order 3 or 11 is also a non-negative function, but only for all values of its argument greater than unity. In 2016, Swiss scientists M. Viazovska and D. Radchenko (Institute of Mathematics of Lausanne University, Switzerland) used modular form theory for constructing special integrals that represented functions with the same properties. That enabled them to solve the problem of sphere packing in 8- and 24-dimensional spaces as well. In 2020, scientists of the Institute of Mathematics of the NAS of Ukraine noticed that for positive time values the traces on two characteristics of extended fluctuation are interconnected by the Bessel transform of order  $-1$ . They proposed to the above Swiss researchers to check the feasibility of using their method for constructing the function equal to zero for all non-negative integers except one, where it must be equal to 1 and its Bessel transform of order  $-1$  be equal to zero for all natural numbers, including zero. The latter were able to build such functions and thereby explicitly write the above-mentioned basic solutions of the Klein–Gordon equation.

The discovery of a connection between two mathematical problems of absolutely different origins (sphere packing and “reconstructing” the solution of the Klein–Gordon equation) was published in the world’s most prestigious journal *Proceedings of the National Academy of Sciences of the United States of America* (Bakan A., Hedenmalm, H., Montezs-Rodriguez, A., Radchenko, D., Viazovska, V. Fourier uniqueness in even dimensions. PNAS, 118, № 15, e2023227118). This journal is a multidisciplinary and generally recognized forum of knowledge exchange between theoreticians and applied scientists.

The publication of this, without exaggeration, groundbreaking result would be instrumental in using the described mathematical apparatus in physics and engineering.

*A. Bakan*

# RESEARCH ACHIEVEMENTS. CHEMICAL AND BIOLOGICAL SCIENCES

## Catalytic pyrolysis of lignocellulose biomass samples and lignin model compounds

Advanced technologies of catalytic pyrolysis for the conversion of sustainable second-generation non-edible biomass are among the most promising directions of economy decarbonization, since such technologies help produce alternative biofuels and semiproducts for industrial organic synthesis from widely available inexpensive lignocellulose biomass, whose sources could be various waste products (of agricultural, paper, wood-working, food industries etc.). The implementation of such technologies requires fundamental knowledge in the kinetics and mechanisms of thermal conversion of biomass components. To this end, the principal kinetics patterns of direct and catalytic pyrolysis of lignocellulose biomass samples and lignin model compounds (pyrocatechin, guaiacol, ferulic and vanillic acids) were investigated: the structure of surface complexes of lignin model compounds was identified; kinetic parameters ( $T_{max}$ ,  $n$ ,  $E^{\ddagger}$ ,  $\nu_0$  and  $\Delta S^{\ddagger}$ ) were calculated, optimal temperature ranges for the formation of principal pyrolysis products (4-vinylguaiacol, guaiacol, phenol, kresol, naphthalene, methyl-naphthalene, toluol, benzene etc.) were determined, and probable mechanisms of their formation were proposed.

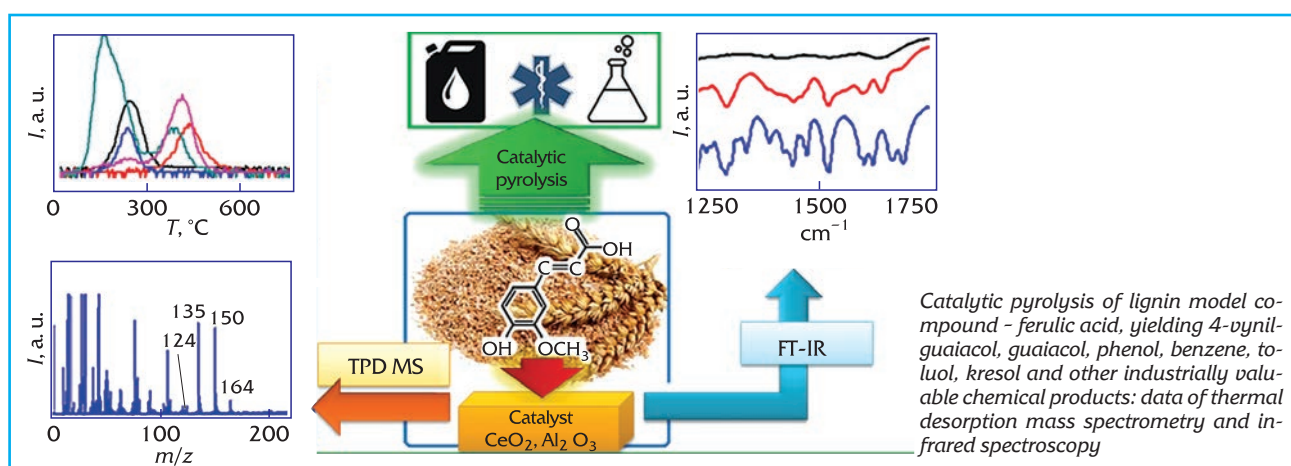
Scientists of Chuyko Institute of Surface Chemistry, National Academy of Sciences of Ukraine, in collaboration with their colleagues from Stockholm University, showed that the use of nanosized catalysts permits the temperature of catalytic pyrolysis process to be reduced drastically, and thus, its energy efficiency to be increased. In particular, catalytic decarboxylation of ferulic acid, yielding 4-vinylguaiacol occurs at considerably lower temperatures  $\Delta T > 200$  °C than in the case of direct pyrolysis of ferulic acid in the absence of the catalyst. Common pathways of pyrolysis of lignin and its model compounds were found, and it was shown that lignin can be a source for obtaining valuable chemical products: 4-vinylguaiacol, vinylpyrocatechin, guaiacol, vinylphenol, pyrocatechin, phenol, benzene, toluol, kresol, and other aromatic compounds.

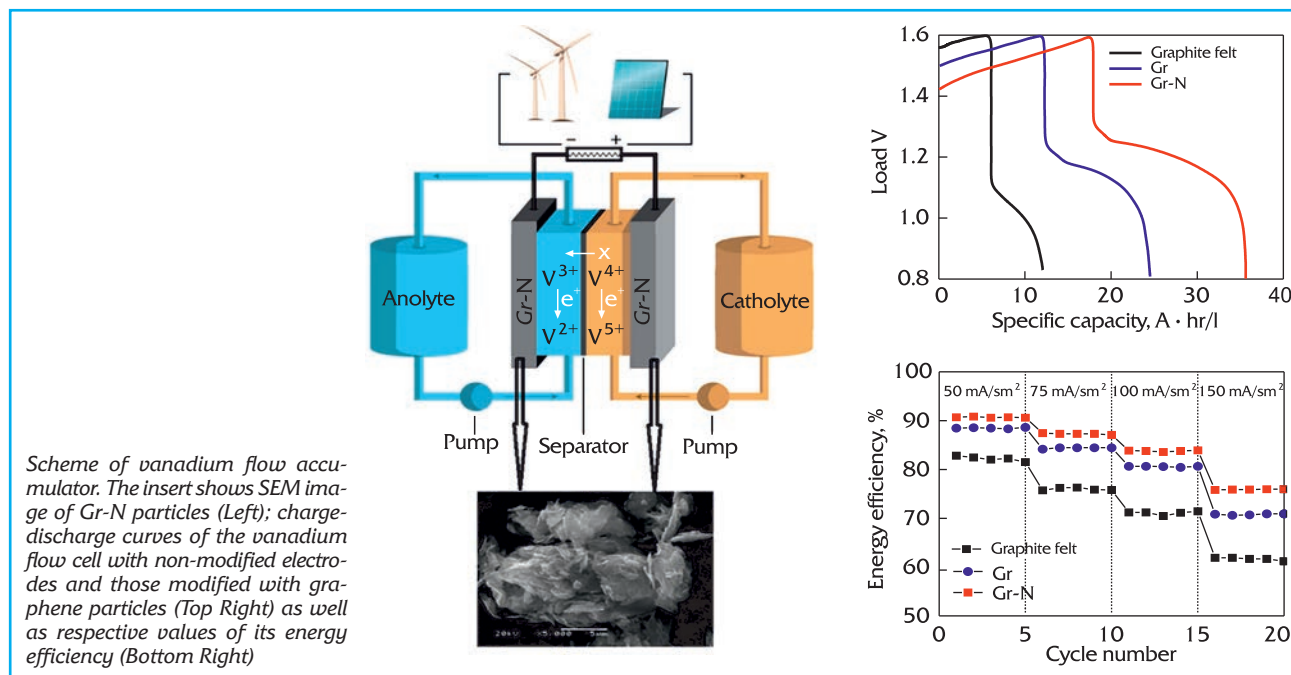
Chuyko Institute of Surface Chemistry, NAS of Ukraine (M. Kartel, T. Kulik, N. Nastasiienko, B. Palianytsia, M. Ilchenko, T. Chernivska)  
Stockholm University (M. Larsson, J. Laskin)

## Effective electrocatalysts of the redox reaction of vanadium ions based on nitrogen-doped graphenes to be used in vanadium accumulators

**L. V. Pisarzhevsky** Institute of Physical Chemistry of the NAS of Ukraine developed a method of mechanochemical graphite delamination in the presence of ammonia, which allows low-temperature doping with nitrogen and obtaining Gr-N graphenes with a large fraction of pyrolytic fragments. It turned out that the graphenes produced exhibit high electrocatalytic properties with respect to oxidation-reduction of vanadium ions of various oxidation degrees:  $V^{2+}/V^{3+}$  and  $VO_2^+/VO^{2+}$ .

Modifying graphite felt, which is used in flow accumulators as an electrode, with particles of nitrogen-doped graphenes leads to a significant rise of electrocatalytic activity in the process of oxidation-reduction of





vanadium ions in both the catholyte and anolyte. The materials produced were tested in a flow accumulator model, and it was shown that the presence of graphene particles in the electrode structure results in an essential increase of the element's performance indicators. The specific discharge capacity of the flow accumulator model under current load 150 mA/cm<sup>2</sup> with the electrodes modified with Gr-N particles can achieve 17.6 A · hr/l, whereas when using the undoped analog (Gr) it is 12 A · hr/l, while for unmodified electrodes it is as low as 5.6 A · hr/l. The energy efficiency of the flow cell in the case of unmodified electrodes is 61.7% at the most, while introducing Gr and Gr-N particles into the electrode structure helps increase this value to 70.8 and 75.9% respectively. Thus, doping graphite felt with Gr-N particles, due to producing catalytic active centers is an effective method to enhance productivity of vanadium flow redox batteries, which opens up prospects for using such systems in accumulating and distributing energy from renewable sources, such as solar and wind energy.

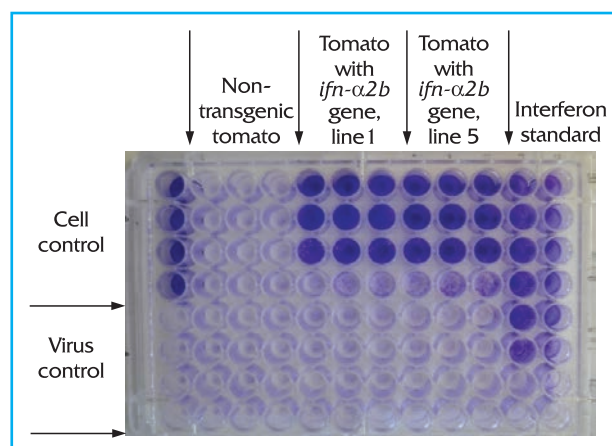
V. Pokhodenko, V. Koshechko, O. Kozarenko

### New approaches to producing antiviral protein – alpha-2b interferon

Alpha-2b interferon plays an important role in regulating cell response to virus infections. It is for this very reason that recombinant alpha 2b interferon produced by bacteria is widely used in medical practice. Researchers of the NAS Institute of Cell Biology and Genetic Engineering created tomato (*Solanum Lycopersicum*) plants of "Shedevr" 1 variety that are able to accumu-

late much larger amounts of this protein than other plant systems. Interferon biological activity in leaf extracts of these plants amounts to 850 IU/g of wet weight, which is more than 10 times higher than the best values known for other biotechnological plants.

Recombinant alpha 2 interferon also accumulates in fruits of the biotechnological tomato plants produced. The results of collaborative research with D.K. Zabolotny Institute of Microbiology and Virology showed that recombinant interferon synthesized in tomato plants displays biological activity not only *in vitro* in monkey cell cultures but also *in vivo* in the case of mice infected with vesicular stomatitis virus, which had been fed with biotechnological tomato fruits. It was de-



Visualization of protective effect of the extracts of tomatoes with ifn-α2b gene against the cytopathic effect of vesicular stomatitis virus: alveola intensively colored in blue contain intact cells; absence of color is the sign of cells ruined by virus

monstrated that the oromucosal delivery of human interferon contained in tomatoes increased the activity of peritoneal macrophages and enhanced the survival of virus-infected mice. Not a single mouse in the group fed with tomatoes containing interferon died, while the lethality in the control group amounted to nearly 20%. It is important that even in the plant material dried by lyophilization the functional activity of recombinant alpha 2b interferon persists. The possibility of preserving interferon biological activity and the presence of its gene in subsequent generations of biotechnological tomatoes was proved.

Institute of Cell Biology and Genetic Engineering (*M. Kuchuk, V. Rudas, O. Ovcharenko, O. Yaroshko*)

D.K. Zabolotny Institute of Microbiology and Virology (*N. Zholobak*)

### Diagnostic assay systems for COVID-19 and prototypes of domestic vaccines

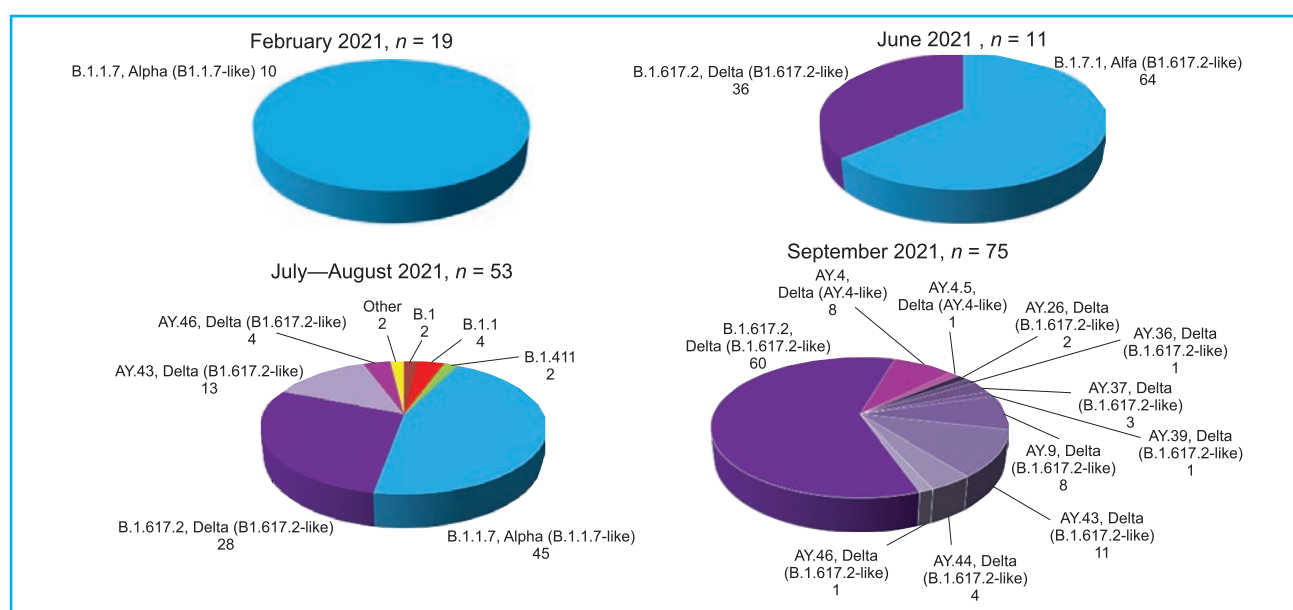
The research of Ukrainian scientists, whose results could be used in counteracting the spread of COVID-19, arouse significant interest in the society. Considerable scientific products in this area were obtained by researchers of the NAS Institute of Molecular Biology and Genetics, who, in particular, developed five different combined assay systems for simultaneous detection of SARS-CoV-2, flu (A and B) viruses and a number of other dangerous respiratory viruses. Among them are parainfluenza viruses 1—3, respiratory syncytial viruses A and B, human *Orthopneumovirus* A2, B1, *Rhynovirus* A (3D) and measles virus (D8, B3).

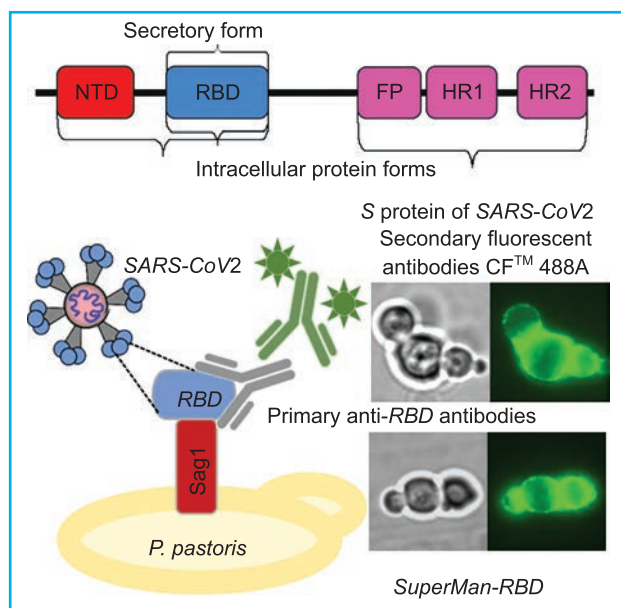
Technologies of developing PCR- and kPCR-based assay systems with different detection types were refined: both fluorescent detection standard for kPCR and chromatographic detection, which is much less expensive and simpler, so it can be used even in district hospitals.

The monitoring of emerging new SARS-CoV-2 strains in various regions of Ukraine was going on, which helped detect two new dangerous variants of SARS-CoV-2 virus: Alfa variant in February 2021 and Delta variant in June 2021. The investigations carried out in November 2021 detected 11 variants of SARS-CoV-2 Delta strain, but in nearly 60% of samples the "parental" variant of Delta (Indian) strain was identified, while in other samples scientists found 10 more variants of Delta of various origins (the USA, Great Britain, Africa etc.).

Researchers of Palladin Institute of Biochemistry, NAS of Ukraine, created producers of SARS-CoV-2 recombinant proteins: nucleocapsid (N) protein, receptor-binding domain (RBD) of spike (S) protein as well as fused RBD conjugates with diphtheria toxoid CRM197 and with green fluorescent protein (eGFP). On the basis of recombinant fused conjugate RBD-CRM197, a prototype vaccine against COVID-19 was developed. Its trials showed sufficient immunogenicity, good local tolerance, and low toxicity of the doses used for immunization. These results could become a starting point for clinical trials and introduction of a domestically produced subunit vaccine against COVID-19 in Ukraine.

To develop protein vaccine prototypes, the NAS Institute of Cell Biology constructed producers of fragments of SARS-CoV-2 virus spike protein on the basis





Constructing the producers of SARS-CoV2 S protein fragments and strains with immobilized RBD of SARS-CoV-2 on cell surface, based on humanized strain of *Pichia pastoris* yeast (Super Man) and using purified protein and cell preparations for investigating their immunogenic properties in mice

of *Pichia pastoris* yeast with the “humanized” type of proteins glycosylation. The proteins were separated and purified by metal affinity chromatography, while laboratory animals were used to evaluate their immunogenic properties. It was determined that the administration of recombinant viral proteins resulted in a significant increase of total IgG titer in mouse serum. The serum also demonstrated a high neutralizing effect on SARS-CoV-2 virus *in vitro*. Using *Pichia pastoris* yeast strain with humanized type of proteins glycosylation, researchers constructed recombinant strains containing on their surface a receptor that binds the RBD domain of SARS-CoV-2 spike protein. It was found that blood serum of mice orally immunized with such cells was characterized by a significant rise in total IgG titer. It also demonstrated a strong neutralizing effect (93%) on SARS-CoV-2 virus *in vitro*. Purified protein preparations and the strains constructed could become prototypes of a prospective vaccine against COVID-19.

Institute of Molecular Biology and Genetics, NAS of Ukraine (M. Tukalo, V. Kashuba, Z. Tkachuk)

Palladin Institute of Biochemistry, NAS of Ukraine (S. Komisarrenko, D. Kolybo, O. Krynina, O. Gorbatiuk, A. Stromolot, M. Guzyk, S. Romaniuk, O. Korchytskyi)

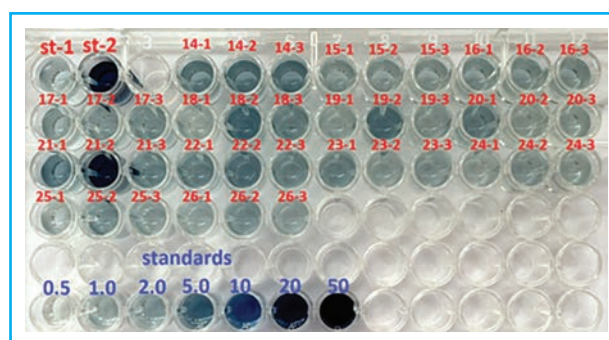
Institute of Cell Biology, NAS of Ukraine (A. Sibirny, K. Dmytruk, D. Fedorovych, L. Fajura, M. Semkiv, R. Vasylyshyn, A. Zazulya)

## Cereals biofortification to increase mineral phosphorus content – reduction of environmental load and enhancement of grain biological value

Leading scientists, geneticists and plant breeders of the NAS of Ukraine have been carrying out research for cereals biofortification by increasing mineral phosphorus content. The solution of this problem, besides a significant positive medical effect, would also improve the environmental situation and, in particular, reduce the so-called algal bloom in rivers and lakes, which results from surface water pollution with organic phosphates contained in waste products of agricultural animals and humans. Usually, barley grain contains an average of 470 mg of phosphorus per 100 g of dry mass, and the content of this mineral in it exceeds that in other cereals: wheat (410 mg), rye (380), oats (340), corn (310), rice (285). However, nearly 65–85% of this phosphorous is bound to phytic acid (phytates) and cannot be digested by humans, animals with unicameral stomach and poultry. The reduction in the amount of phytates can simultaneously solve two important problems, viz., improve the assimilation of mineral phosphorus by the body and prevent environment pollution with it.

Scientists of the NAS Institute of Plant Physiology and Genetics initiated the first Ukrainian breeding program of creating varieties of spring and winter naked *lpa* barley cultivars with mineral phosphorus content higher by 75%, which is intended for food and feed usage. The first promising *lpa* lines of food and feed spring naked barley will be forwarded to the State variety-testing agency. Research for creating high-protein wheat varieties was carried out as well.

V. Morgun, O. Rybalka, B. Morgun



Example of mineral phosphorus content quantitation in individual grains of breeding-population plants

# RESEARCH ACHIEVEMENTS. SOCIAL SCIENCES AND HUMANITIES

The practice of preparing National reports on the issues of utmost importance for the state and society was continued. The previous year's work was summarized in the National Report **"National resilience of Ukraine: the strategy of responding to challenges and forestalling hybrid threats"**, prepared by an expert team of the NAS Section of Social Sciences and Humanities, led by NAS academician Serhii Pyrozhkov.

After the Revolution of Dignity of 2013—2014, Ukraine faced a number of fundamentally new challenges originating from Russia's aggression against Ukraine. They were not limited to territorial losses — annexation of the Autonomous Republic of Crimea and occupation of some territories of Donetsk and Luhansk oblasts — but generated a number of asymmetric hybrid threats. This necessitated a scientific search for new responses to challenges and forestalling hybrid threats in the conditions of an external aggression, in particular, by comprehending the notion of national resilience.

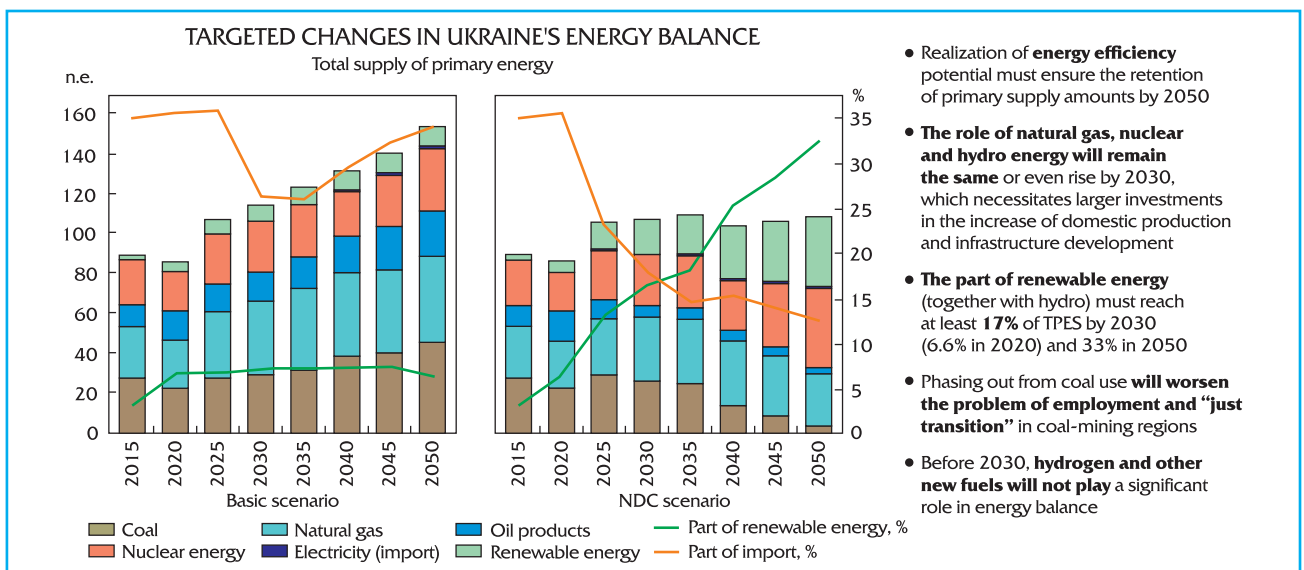
*Resilience* is the term that has recently become firmly established in international policy. From the viewpoint of current international practice, it denotes the ability of a subject of international relations to counter hybrid threats.

One of the main principles of the Strategy of Ukraine's national security, which was approved by a presidential decree in 2020, is the concept of resilience as the ability of the society and the state to quickly adapt to changes in the security environment and to maintain sustainability by minimizing external and internal vulnerabilities.

The report comprehensively examines the resilience of the Ukrainian society, as well as national-state projects, to external challenges and threats in historical retrospective and in the recent period. It analyzes the main types of hybrid threats for Ukraine in conditions of Russian aggression. It also identifies priority directions in implementing the strategy of Ukraine's national resilience, as well as institutional, legal and informational factors of ensuring it in political, economic, social, humanitarian, and military spheres.

Scientists of the State Institution "The Institute for Economics and Forecasting of the NAS of Ukraine" **developed basic provisions of upgrading the current Strategy of Ukraine's low-carbon development till 2050'** in view of the need for extending its sectoral coverage along with organizational and legal mechanisms of its implementation, in particular, with reliance on the principles of technological development, just transformation, green investments, and inclusiveness of socio-economic reforms.

Scenario-based model calculations were performed, which take into account medium-term targets for reducing greenhouse gas emissions in accordance with the updated nationally determined contribution of Ukraine, the declared long-term targets of achieving carbon-neutral economy, as well as the change in foreign trade terms of EU countries. Recommendations were prepared for basic organizational and economic measures towards implementing short- and medium-



term provisions of the Strategy of low-carbon development till 2050, according to the Decree of the President of Ukraine of 23 March 2021 # 111/2021 “On the decision of the National Security and Defense Council of Ukraine dated 23 March 2021 “On challenges and hazards for the national security of Ukraine in the sphere of ecology and priority measures for neutralizing them”.

*V. Heyets, R. Podolets, T. Ostashko, O. Diachuk, B. Serebrennikov, N. Gahovych, U. Pysmenna, R. Yukhimets et al.*

To mark the 30-th anniversary of Ukraine’s Independence, the NAS Institute of the History of Ukraine published the **3-volume edition “Ukraine. Essays in History”**. It presents the history of Ukraine from 1917 till our time in the form of three spatial and chronological segments: the post-empire period (1917—1939), the epoch of world systems confrontation (1939—1990), and the present period, or the epoch of post-totalitarian / post-colonial transit (1991—2019).

The first book **“Ukraine and Ukrainians in the Post-empire Period (1917—1939)”** discloses the phenomenon of Ukrainian revolution, the causes and circumstances of communist-bolshevism, the tragedy of the largest separated nation of Eastern Europe in the epoch of totalitarianism establishing and strengthening, which corresponds with many macro contexts of the Versailles–Washington system of the interwar world order. It is shown that the success of the soviet totalitarian experiment was spawned by both the powerful and merciless repressive machinery and relatively favorable international situation, which the bolshevik regime used to the full. The interwar period is considered altogether as the time of cultivating and critical sharpening of Ukrainian nation’s intrinsic problems under the influence of assimilative and repressive practices of controversial state mechanisms.

The second book **“Ukraine in the Epicenter of World Systems Confrontation (1939—1990)”** describes the essential changes of the united Ukraine that emerged in the framework of the Yalta—Potsdam system. Its fate in the epoch of World War II and the Cold War, consequences of sovietization, unconscious collective traumas, crimes against humanity and their effects on the current society is the subject of examining Ukraine’s historical path in the epoch of world systems confrontation and the collapse of communist-bolshevism, which made possible the sovereignization of Ukraine. The book shows the position of the Ukrainian people in the bipolar coordinate system, the metamorphoses, crisis and collapse of the soviet totalitarian project.



The third book **“Ukraine and the Challenges of Post-totalitarian Transit (1990–2019)”** exhibits the contradictions of Ukrainian state’s post-soviet transit. The post-totalitarian period has its own development logic marked by two Ukrainian revolutions — the Orange Revolution of 2004 and the Revolution of Dignity in 2013—2014. They set the rhythm and a certain cyclic pattern in the fluctuations of the ‘Ukraine’ project, oriented towards withdrawing from coordinates of the post-soviet world. This provides the context for presenting the current Russian aggression against Ukraine, which reflects the prerequisites and realities of the contemporary global world order.

*V. Holovrko, V. Danylenko, H. Yefimenko, V. Krupyna, S. Kulchitskiy, O. Lysenko, R. Pyrih, V. Skalskyi, O. Stiazhkina, L. Yakubova*

In 2021, the scholar team of the NAS Ethnology Institute completed the publication of their collaborative research **“Ecclesiastical Art of Ukraine” in 3 volumes** ((Vol. 1 “Architecture. Monumental Art”, Vol. 2 “Fine art”, Vol. 3 “Decorative art”). The managing editor of the edition is NAS academician Stepan Pavliuk, director of the NAS Ethnology Institute, the project leader and scholarly editor is Lyudmyla Herus, PhD, head of the folk-art department of the NAS Ethnology Institute.

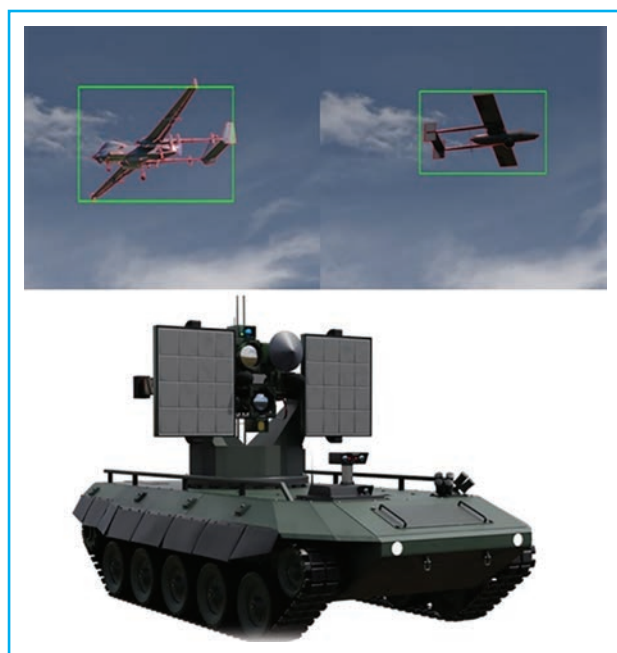
The edition is the first all-inclusive and comprehensive review of ecclesiastical art in a broad variety of its genres and forms over more than millennial development of Christianity on the Ukrainian lands. Due to its authors’ scholarly potential and the level of their research achievements, this fundamental study shows ecclesiastical art to be an inherent component of Ukrainian culture, determines its role in developing world-view ideas, spiritual values, national features and, in general, the mentality of the Ukrainian people.

*L. Herus, Y. Taras, O. Nykorak, A. Klimashevskiy, S. Bonkovska, V. Zhyshkovych et al.*

## Multi-sensor system for detecting and tracking slow-speed and small-size targets on ground-based autonomous robotic platform

Experts of the International Research and Training Center for Information Technologies and Systems, NAS and MES of Ukraine, developed a multi-sensor system based on autonomous robotic platform, which provides high-precision detection and tracking of slow-speed and small-size targets.

To obtain the data necessary for detecting and tracking potentially dangerous objects, a network of sensors operating with reliance on different physical principles and interacting among themselves was built. The characteristic feature of combining sensors is the possibility of diverse highly informative observations within a single facility for monitoring the surrounding space. Using the mutually agreed distributed acoustic and optical tracking of potentially dangerous targets enhances the



Mobile robotic platform for target detection and tracking, based on the multi-sensor system developed by the experts of the International Research and Training Center for Information Technologies and Systems of the NAS and MES of Ukraine

accuracy of their detection, direction finding, identification, and classification, in particular, in conditions of significant interference, poor visibility and difficult terrain.

An important advantage of the facility is that system functions exceptionally in passive mode — in the absence of any active emission that can reveal its location. It is also necessary to emphasize the fast adaptation of the system to narrowing or widening the zone controlled, as well as its relatively low cost even in the case of an extensive sensor network. Besides, the use of multi-spectral and multi-frequency sensors complementary to each other permits generalizing the data on the current environment state.

The implementation of flexible software and algorithmic support and optimal choice of hardware in the prototype produced determined the effectiveness of basing the system on autonomous robotic platforms, which not only allows the multi-sensor system to be used as a part of a stationary ground facility but be the basis of high-precision mobile equipment for target detecting and tracking and enhance its effectiveness and reliability.

The development was presented to the State inter-departmental commission of the General Staff of the Armed Forces of Ukraine. In accordance with the license agreement concluded, the system was deployed at S.P. Korolev "Meridian" JSC of the "Ukroboronprom" State Concern. The work fulfilled was marked with the highest awards of the "Ukroboronprom" SC, the General Staff of the Armed Forces, and the Defense Ministry of Ukraine.

*O. Volkov, G. Gritsenko, M. Komar, Yu. Bogachuk, Yu. Shepetukha*

## Development of decontamination agent for chemical neutralization of poisonous organophosphorus compounds

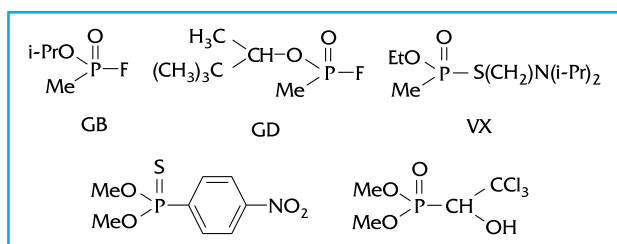
Scientists of L.M. Litvinenko Institute of Physical-Organic & Coal Chemistry, NAS of Ukraine, developed a decontaminating composition for individual neutralization of poisonous organophosphorus compounds.

This product summarized basic research into nucleophile reactivity in the reactions of decomposition of chemical warfare agents and pesticides.

In addition to its high reactivity (see Table) as compared with similar systems (M291, DS2, DF-200), used in

### Comparison of organophosphorus substances deactivation rates

Decontamination system	$\tau_{1/2}$ , sec half life
DS [InPOCC]	30—60
Decon Green [NATO]	450
M291 [NATO]	90
DS2 [NATO]	600
DF-200 [NATO]	600



Specimen of decontamination agent for chemical neutralization of poisonous organophosphorus compounds (a pilot batch)

NATO military units, the composition developed is produced as a solid, which extends its shelf life to two years. It is also environmentally safe and can be used for decontaminating the body surface of humans and animals.

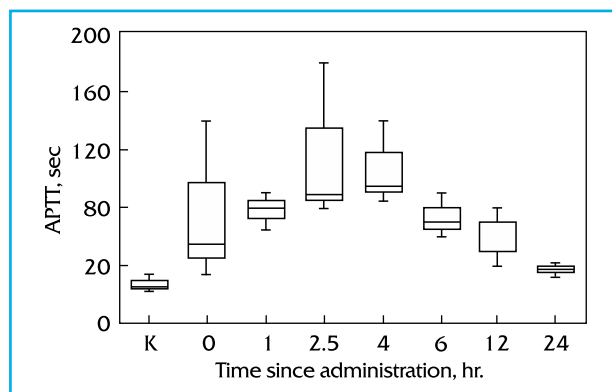
Institute's researchers developed specifications for the production of the abovementioned decontamination agent, which are implemented in pilot batch production.

*L. Vakhitova, V. Bessarabov, N. Taran*

### Development of prototype medical drug "Antithrombotic agent Calix[4]arene C-145" and its preclinical trials

The global COVID-19 pandemic once again drew researchers' attention to the problem of intravascular thrombosis since it is the thrombosis accompanying the disease that not infrequently endangers the lives of coronavirus patients. To prevent intravascular thrombus formation, anticoagulants are commonly used, the most known of which are inhibitors of blood clotting cascade factors — numerous preparations of thrombin and Xa factor inhibitors ("Xarelto", "Pradaxa" etc.) or heparins ("Flenox", "Fraxiparine" etc.).

Scientists of Palladin Institute of Biochemistry, the NAS of Ukraine, and the Institute of Organic Chemistry of the NAS of Ukraine discovered calix[4]arene C-145 compound with a unique antithrombotic action. C-145 is able to selectively and effectively inhibit the polymerization of fibrin — the framework for thrombus — without which the formation of thrombi is *a priori* impossible.



Plasma prothrombin time in experimental rats before and after intravenous administration of calix[4]arene C-145 in the dose of 12 mg/kg of body mass

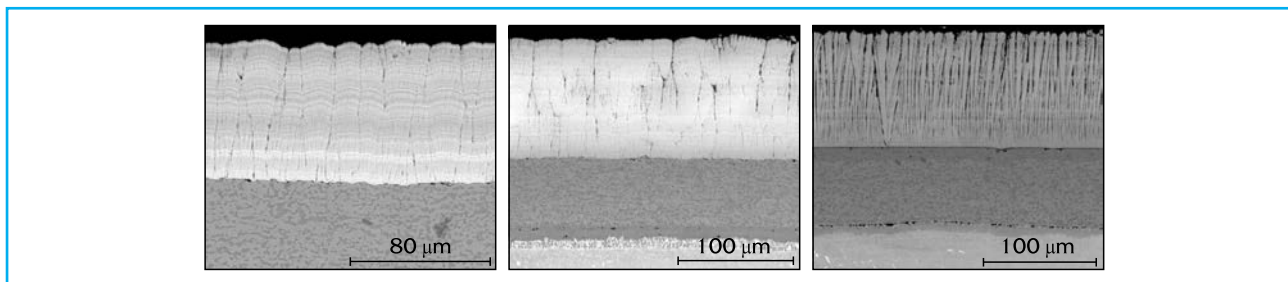
The research for developing the medical preparation "Calix[4]arene C-145" carried out in collaboration with Arterium LTD and preclinical trials complying with GLP standards, conducted at L.I. Medved Research Center of Preventive Toxicology, Food and Chemical Safety, operating under the Health Ministry of Ukraine, officially certified the absence of mutagenic and allergenic effects of the abovementioned preparation, and opened up the possibilities for its further clinical trials and commercialization.

*S. Komisarenko, V. Chernyshenko, V. Didkivskyy*

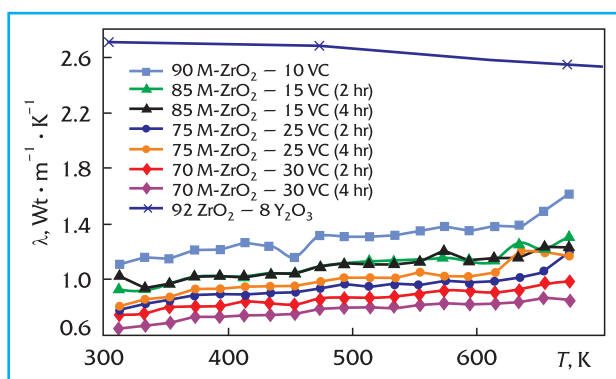
### ZrO<sub>2</sub>-based oxide materials for producing next-generation of heat-shielding coatings for parts of gas turbine engines

Scientists of I.M. Frantsevich Institute for Problems of Materials Science, the NAS of Ukraine, developed the principles of designing the microstructure of thermal barrier coating ceramic layers based on solid solutions of ZrO<sub>2</sub> complex alloyed with rare-earth oxides of cerium (ZrO<sub>2</sub> — LC) and yttrium (ZrO<sub>2</sub> — VC) subgroups. The results relied on the multi-year research into phase equilibria, and phase equilibrium diagrams of refractory systems based on ZrO<sub>2</sub>, HfO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, lanthanoid, yttrium, scandium oxides were built. The substantiated choice of materials composition, knowledge of the principal laws of initial-components phase transformations with an increase in temperature, choice of the optimal sequence of their treatment permitted the targeted formation of defect-rich structure in the process of ZrO<sub>2</sub> complex alloying with natural rare-earth oxide concentrates.

With reliance on the results obtained, specialists of ELTECHMASH research and production enterprise (Vinnytsia) in one technological cycle, using electron-beam atomic/molecular layer vacuum deposition (EB-PVD), applied two-layer thermal-barrier metal/novel ceramic coatings on the blades of first-stage turbines manufactured by Ivchenko-Progres State Enterprise (Zaporizhia).



Microstructures of coatings with ceramic upper layer: a –  $ZrO_2 - LC$ ; b –  $ZrO_2 - VC$ ; c –  $ZrO_2 - Y_2O_3$



Temperature dependence of  $M-ZrO_2 - VC$  specimens as compared with literature data for  $ZrO_2 - 8Y_2O_3$

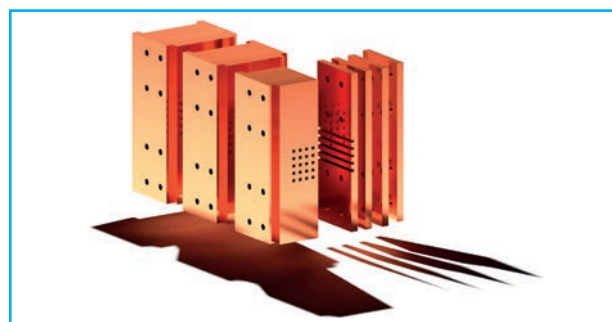
The research and experimental testing of the innovative coating types, carried out at the abovementioned companies proved that the novel ceramic materials are promising for the development of advanced technologies of applying thermal barrier coatings on the blades of the first and second stages of aviation engine turbines. In particular, the peculiarities of forming the laminar (microlayered) microstructure of these novel coatings were determined. It was also shown that their thermocycling durability, which specifies the service time of GTE, is higher by 16% on the average, while their thermal conductivity is lower by 34% as compared with respective parameters of the  $ZrO_2 - Y_2O_3$  serial coating.

O. Dudnik, S. Lakiza, M. Grechaniuk, A. Kopan, V. Redko, O. Ruban

### Enhancing the therapeutic effect in hadron therapy by spatial fractionation of hadron beams

Scientists of the Institute for Nuclear Research of the NAS of Ukraine investigated the feasibility of enhancing the therapeutic effect in hadron therapy by spatial fractionation of hadron beams (the distance between the centers of adjacent beams is about 1 mm and less). This permitted an increase in the tumor irradiation dose with a simultaneous reduction of the dose absorbed by healthy tissue.

The research performed was concerned with developing collimators for beam fractionation along with a



Modular matrix collimator for forming fractionated dose field

detector system for examining fractionation and beam evolution in a body phantom. For the first time, modeled and produced were metal collimators for two-dimensional fractionation that allowed an increase of the local dose in collimator apertures.

Relying on computer modeling, researchers determined optimal collimator materials and geometry. In particular, copper, tantalum, and tungsten proved to be the best collimator materials for protons. If the collimator thickness was twice as large as the distance passed by the beam, the collimator body completely absorbed the secondary radiation produced by the collimator itself, which provided patient protection from additional irradiation.

Dosimetry in mini-beam radiation therapy is a difficult task due to the necessity of high spatial resolution and high doses as well. To investigate fractionated beams, a detector system based on metal microstrip detectors (MMD) was produced. It consisted of nickel strips 1 μm thick and 90 μm wide, with the spacing between strips being 30 μm. Hadron beams are quite aggressive, therefore common detectors degrade and deteriorate over time. MMD do not have this disadvantage, since the only material in contact with the beam is radiation-resistant metal. Another specific feature of super-thin MMD is its practically ideal operation as a measuring device, which relying on the reading system developed provides the measurement of beam profile without distorting it.

Characterization studies of the produced detectors and collimators on medical accelerator at the National Cancer Institute (Kyiv) demonstrated their high efficacy and operation reliability.

V. Pugatch, O. Kovalchuk, D. Ramazanov, I. Anokhin

### Development of hydraulic units for Dniester pumped-storage power plant

Specialists of A. Pidgorny Institute of Mechanical Engineering, the NAS of Ukraine, developed a method for spatial profiling of water wheel blades of radial-axial flow turbines by using circular offsets. In such profiling, design blade cross sections remain unchanged, only their mutual position in a circular direction is changed. With reliance on this method, to expand the range of operation in turbine mode, reduce the level of pulsations in the flow part and to raise the efficiency, two modifications of the Dniester PSPP turbine impeller were developed: PK5217M — with the sleeve cross-section shifted by 35° in the direction of rotor rotation as compared to the initial version, and PK5217M2 — with the sleeve cross-section shifted by 55° in the opposite direction.

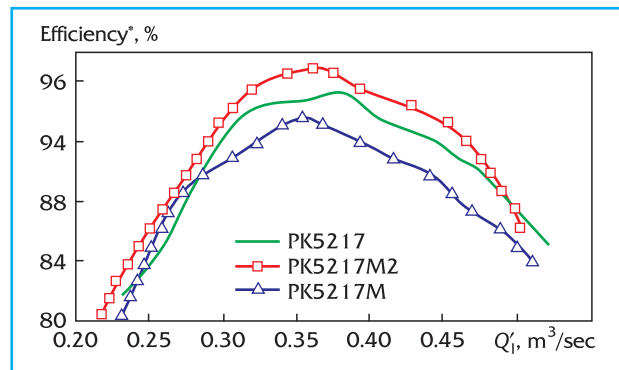
On the basis of software developed at the Institute, numerous studies of the flow of viscous incompressible liquid were carried out, to obtain a preliminary estimation of parameters in the flow parts of turbines with new impellers. Flow modeling was done relying on numerical integration of Reynolds equations with the additional term involving artificial compressibility. As a result of calculations using two-parameter Menter SST turbulence model, the effect of blade spatial geometry on flow structure and energy characteristics was determined.

To verify the calculation results, researchers produced impeller models of 350 mm diameter, which are used at hydraulic units 1—4 of the Dniester PSPP (the initial version) and two modified ones. The blades were produced using 3D printer, which significantly reduced the terms and cost.

Energy tests of the three impeller versions were performed on the Institute's EKC-30 hydrodynamic test bench — the scientific facility that is a National Asset Object. Energy and pulsation characteristics in a wide range of turbine and pump modes were determined. It was confirmed that in the turbine flow part with PK5217M2 impeller, the value of maximum efficiency is by 0.6—0.7% higher than the efficiency of turbines



Model of PK5217M2 upgraded impeller of the Dniester PSPP turbine pump with improved energy and pulsation characteristics



Comparison of relative efficiencies of the Dniester PSPP turbine pumps with the initial and upgraded impellers at rated head in the turbine mode

installed in units 1—4 of the Dniester PSPP. In the generator mode, at the rated head the efficiency of the new flow part in practically entire range of operation proved to be 1.0—1.5% higher as compared to the initial version. Besides, the level of pressure pulsations in the suction pipe was reduced by 20—25%.

The Institute and *Ukrainian Energy Machines* JSC are planning to use this development in designing and manufacturing hydraulic units # 5—7 of the Dniester PSPP. After that, they will be supplied to *Ukrhydroenergo* private joint-stock company.

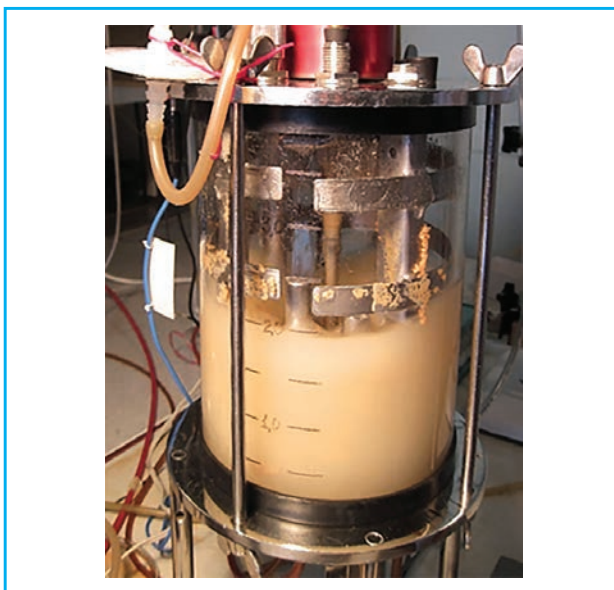
A. Rusanov, O. Khoryev, P. Korotaiev, Ye. Agibalov, V. Dedkov

### Biotechnology of producing polybacterial preparation for eliminating oil contamination of the environment

As of today, oil and oil products are recognized to be among the most common and dangerous pollutants of the environment. Biological methods, relying on microbial destruction of toxic substances, are the most environment-friendly and effective instruments of cleaning oil-contaminated objects.

D.K. Zabolotny Institute of Microbiology and Virology of the NAS of Ukraine developed a next-generation oil-oxidizing preparation "Ekolan-M", which contains active strains of hydrocarbon-oxidizing bacteria, immobilized on an oil-absorbing sorbent of natural origin — charcoal. In conditions of pilot production, scientists improved the technology of obtaining the microbial component of "Ekolan-M" biopreparation and elaborated the laboratory regimen for its production. The most effective compositions of actinobacteria strains that have high destructive activity in respect of hydrocarbons were identified.

The tests of "Ekolan-M" preparation in the process of liquidating the consequences of oil-products spills on the territories of CE *Kyivteploenergo* subdivisions have proved its efficiency. The evidence of this is the fact that the level of residual hydrocarbons in the soil decontaminated with the biopreparation was lower



Accumulation of cellular biomass of actinobacteria comprised in “Ekolan-M” biopreparation during their co-cultivation in Biotec laboratory fermenter

than the maximum allowable concentration of these substances accepted in Ukraine. The decontaminated soil did not exhibit phytotoxic properties, which also proves the recovery of its natural characteristics.

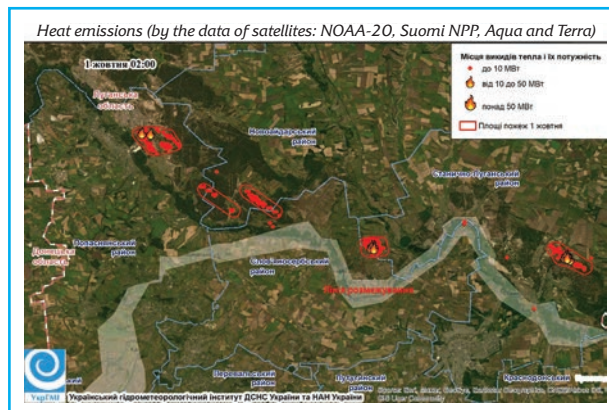
The implementation of this development will be beneficial for the general ecological state of soils on the territory of Ukraine, fast recovery of the natural objects polluted by hydrocarbons, and will minimize the negative impact of oil spills on human health.

V. Podgorskyi, T. Nogina, L. Khomenko, S. Skrotskyi

### System for monitoring heat emissions and identifying potentially dangerous fires, based on satellite data

Scientists of the Ukrainian Hydrometeorological Institute of the State Emergency Service (SES) of Ukraine and the NAS of Ukraine developed a software—hardware complex for obtaining satellite data on thermal anomalies recorded on the Earth surface and detecting potentially dangerous fires on the basis of that information. The sensitivity of the complex is 0.2 MWt, which is sufficient for detecting, e.g., burning grass with the active fire area of 2—3 m<sup>2</sup>. But usually, the fire area is much larger and its average power is 10—30 MWt.

The monitoring system provides information in the form of maps of the entire territory of Ukraine, with denoted heat emissions and detected fire areas. The maps show the time of ignition recording, the burning material and fire power, as well as the names of geographic and industrial objects where groups of heat emissions have been detected. That provides the advantage of this system over its counterparts. Another feature of this complex is its proactive (advance) warning against potentially dangerous fires occurring near



Space photo map with fire sites in Luhansk Oblast

a forested territory or about a possible danger in the locations where fires happened in the past. In this case, the monitoring system visualizes fire areas on several large-scale space photo maps. 4—12 information updates are provided every 24 hours, after 2—4 hours after flight of satellites, viz., approximately after midnight and in the afternoon.

The monitoring system also consists of a geoportal ([geoportal.uhmi.org.ua](http://geoportal.uhmi.org.ua)), which provides access for all stakeholders. An archive of maps and messages is situated on the server of messenger “channel”, the access to it is realized with smartphone and by link ([https://t.me/fires\\_monitoring\\_channel](https://t.me/fires_monitoring_channel)).

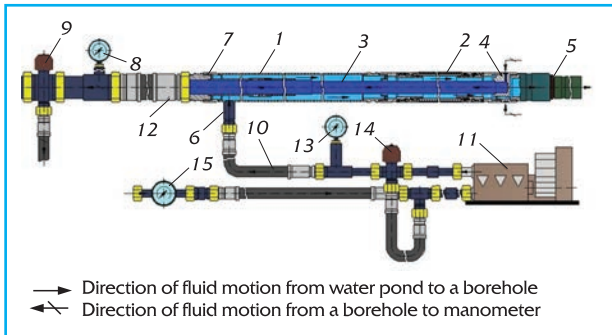
The State Emergency Service has been using this monitoring system for a year and a half. The requirements to safety and security of such complexes are in compliance with Ukraine’s standards.

The development has a potential for use by every citizen of Ukraine, not only by relevant authorities responsible for the state of land and forest resources and nature reserves (*Derzhlisahenstvo, Minahropolityky, and Mindovkillia*). Using the geoportal and telegram channel, any person can assess the actual fire situation online. The system is also useful for assessing the fire situation by oblast and district administrations, as well as territorial communities on the territories under their jurisdiction.

A. Oreshchenko, V. Osadchyi, D. Klebanov, M. Savenets

### Method of hydro-pulse loosening of steep coal seams with outburst hazards

To increase the efficiency of mining steep coal seams with outburst hazards and improve miners’ work safety, experts of M.S. Poliakov Institute of Geotechnical Mechanics of the NAS of Ukraine upgraded and implemented the method of hydro-pulse loosening of such seams. The employment of this method results in releasing the stress-strain state of the coal seam in the development face and prevents the effect of external factors on the reduction in hydro-loosening efficiency.



Mounting scheme of the equipment for hydro-pulse coal seam loosening: 1 – body of the device, 2 – borehole sealing, 3 – drainage channel, 4 – fluid flow distributor, 5 – generator of cavitation self-oscillations, 6 – 15 high pressure sleeves, pump and measuring devices

Equipment upgrading permitted hydro-pulse loosening of outburst-prone coal seams in difficult mining conditions to be implemented through boreholes 2.5—3.5 m long with the sealing depth 1.5 m. That ensured the formation of an effective impact zone that exceeds the working cross-section.

The upgrading of the method and the device consists in 1.5—2-fold decrease of borehole length and sealing depth and the reduction of expenses for boring and sealing as compared to gently sloping seams with outburst hazards, in enhanced hydro-loosening efficiency and reduced outburst hazards in steep coal seams.

The operating principle of hydro-pulse loosening is the supply of highly pressurized water to the cavitation generator. The flow of fluid, passing through generator, becomes a highly pressurized cavitation stream, directed into a coal seam through boreholes.

In the process of hydro-pulse seam loosening, jump-like fluctuations of fluid back pressure occur in the filtering part of a borehole. The process is considered to be effective if maximum back pressure at its active stage is reduced by 30%. The final stage is determined by a sharp drop of pressure and its insignificant fluctuation, which characterizes the end of crack formation in coal.

Technological schemes of using this method have been included in "The set of measures to prevent sudden coal and gas outbursts", intended for developing outburst-prone coal seams in *Tsentralna* mine of *Toretskvuhillia* state enterprise. Besides, the industrial standard COY-П "Method of hydro-pulse loosening of steep outburst-prone coal seams" is being developed, which would improve occupational safety and health, as well as mining safety on hazardous seams that are dangerous due to sudden coal and gas outbursts.

The users of the method for hydro-pulse loosening of steep outburst-prone coal seams are mines of *Toretskvuhillia* state enterprise and mines of other coal-mining basins where steep seams are developed. The deployment of such equipment in two working areas of *Toretskvuhillia* mines is scheduled for the near future.

V. Zberovskiy

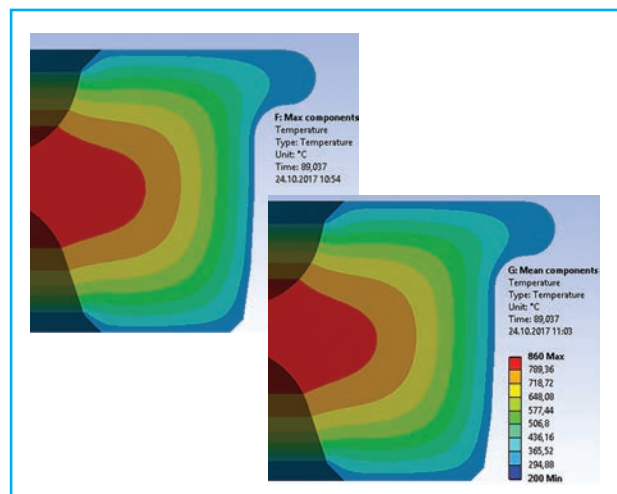
## Optimization of the modes of heat treatment of railway wheels to enhance their reliability and durability

Researchers of Z.I. Nekrasov Iron and Steel Institute of the NAS of Ukraine studied the effect of chemical micro-inhomogeneity in thermally strengthened railway wheel rims of various chemical compositions on the formation of hardened structures induced by accelerated cooling along with their mechanical properties.

The research results showed the relations between the regions enriched with chemical elements and regions with hardened microstructure. They also revealed that their presence produces a negative effect on the fracture toughness of railway wheels. The presence of 10—15.0% of bainite, which is formed due to hardening, leads to a decrease of steel fracture toughness by 40—70%, respectively, while an increase of bainite content in microstructure by 1.0%, on average, reduces fracture toughness by 2.7%.

A procedure was developed for determining the maximum allowable rate of rolling surface cooling, as well as the minimum necessary cooling rate of the central areas of railway wheel rim to achieve high hardness and homogeneous microstructure formation. Relying on these data, for each steel grade of railway wheels, Institute's researchers experimentally determined the interval of cooling rate in heat treatment, which would ensure the compliance with the requirements of normative documentation for railway wheels in terms of microstructure (the absence of needle-like structures of martensite, bainite, widmanstätten), and of hardness level.

Using finite element method, a model of calculating temperature variation over wheel rim cross-section in the process of heat treatment was developed on the basis of experimental determination of cooling rates at



Temperature distribution over railway wheel cross-section in the process of spray cooling depending on the variation of steel chemical composition, %: Left – C – 0.58, Si – 0.38, Mn – 0.70; Right – C – 0.70, Si – 0.50, Mn – 1.0

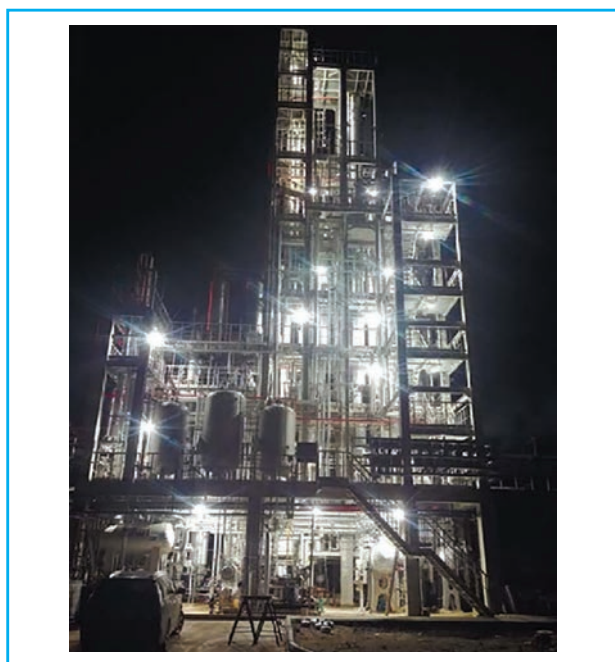
various distances from the wheel rim surface. Using this model, the patterns of chemical inhomogeneities effect, as well as the influence of temperature and time parameters of railway wheels heat treatment on the thermal field variation over wheel rim cross-section, were determined. The liquation of the main chemical elements in railway wheel steels was also taken into account.

With reliance on the results obtained, recommendations for varying modes of heat treatment of wheels produced from steels with different chemical compositions were developed with a view to enhancing their reliability and durability. On the basis of these recommendations, scientifically grounded modes of accelerated cooling in the process of railway wheels heat treatment were implemented in mass production on upgraded equipment at the private joint-stock company *INTERPIPE NPRP*. That increased the efficiency of railway wheel manufacturing by reducing costs for repeated heat treatment and for machining tolerances, along enhanced with products' reliability and durability.

*O. Babachenko, G. Kononenko*

### Implementation of a new technology for propylene oxide production

Specialists of the Institute for Sorption and Problems of Endoecology, the NAS of Ukraine, in collaboration with *Techinservice* Production Group Ltd and *Karpatnaftokhim* Ltd., developed a new HPPO technology of producing propylene oxide from propylene and hydrogen peroxide. The essence of the new technology consists in replacing toxic methanol, which is the solvent



24 HPPO installation for propylene oxide production at "Karpatnaftokhim" Ltd.

in propylene epoxidation reaction, with widely available acetonitrile, employing a new *TIS-1* catalyst, a three-reactor unit with separate supply of hydrogen peroxide, an absorber for saturating azeotropic acetonitrile with propylene, and in using monoethanolamine instead of toxic hydrazine hydrate for deep purification of marketable propylene oxide.

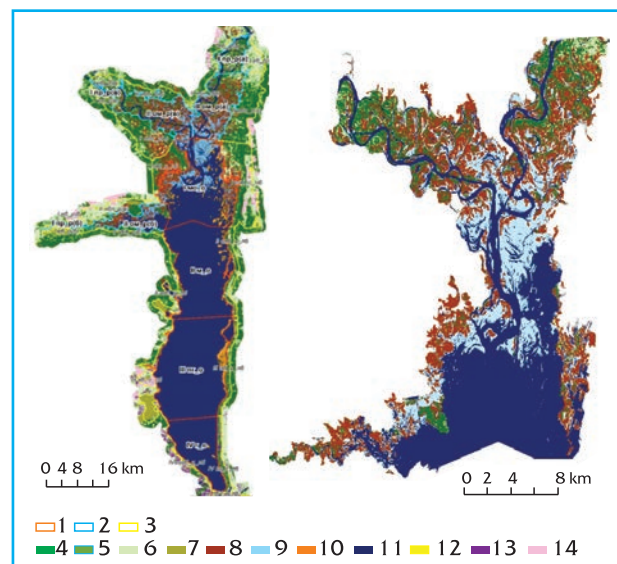
Institute's scientists were actively involved in designing and starting pilot operation of the HPPO-based installation having production capacity of 2,000 tons per year. The future annual production of 130 thousand tons is planned.

Propylene oxide is one of the organic synthesis products obtained in large amounts — nearly 8 million tons is produced annually in the world. It is used in the synthesis of oligomers necessary for manufacturing rigid and flexible polyurethane foams that provide heat-insulating and sound-isolating properties of the materials used in construction industry, for cushioned furniture etc., as well as for producing propylene glycol and pluronics.

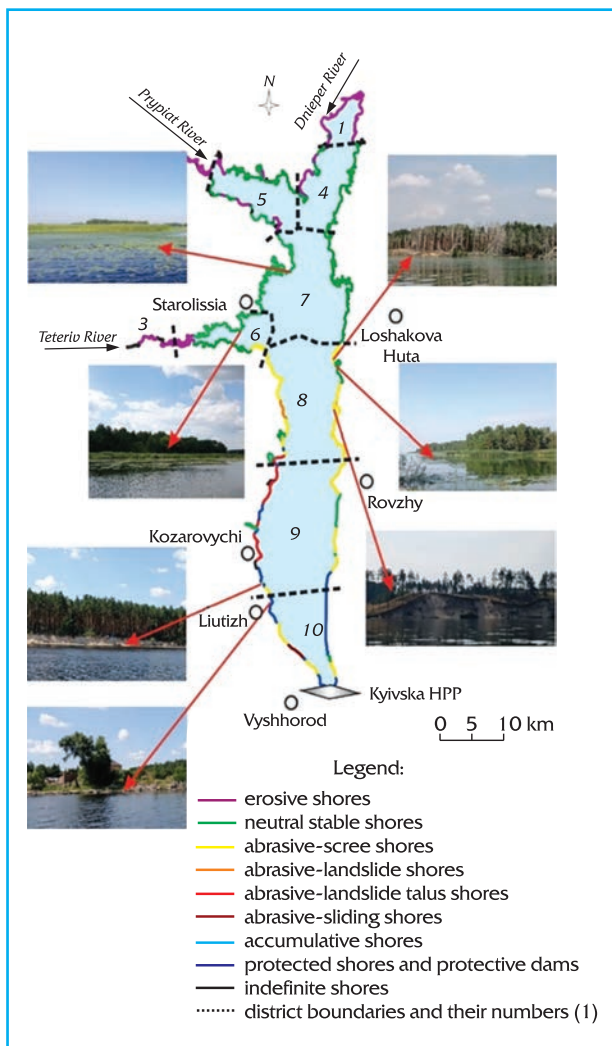
*V. Brei*

### Determining the ecological potential of the Dnieper water-storage reservoirs

Scientists of the Institute of Hydrobiology, the NAS of Ukraine, developed a methodology of determining and classifying biological hydromorphological and hydro-



General scheme showing the distribution of the principal biotope types of the Kyiv Water-Storage Reservoir and its waterside areas as of 2020 (Left), the map of Kyiv Water-Storage Reservoir headwaters and their waterside areas (Right): 1–3 – borders of oblasts, districts, and areas of influence; 4–14 – biotope types (4 – forests, 5 – shrubs and sparse forests, 6 – meadows, 7 – tallgrass bogs, 8 – waterside waterlogged biotopes, 9 – phytal biotopes, 10 – uncovered shallow-water biotopes, 11 – uncovered deep-water biotopes, 12 – sand massifs, 13 – residential biotopes, 14 – agriculture biotopes)



Ecological and hydromorphological zoning of the Kyiv Water-Storage Reservoir

chemical indicators of the ecological state of the Dnieper basin's reservoirs and waterstreams.

Taking into account European approaches to assessing the state of hydroecosystems, summarized were the results of multi-year studies of the biodiversity, biota state, oxygen regime, correlation of principal ions, concentration of nutrients in the Dnieper water, that became the basis for defining reference values and compiling classification tables of biological and physicochemical elements of water quality for assessing the ecological potential of the Dnieper water-storage reservoirs.

New approaches to ecological and hydromorphological zoning of large flatland water-storage reservoirs (exemplified by the Dnieper ones) were developed with a view to further mapping, determining hydromorphological and biotopic characteristics, revealing the course of exogenous processes in these reservoirs.

Recommendations regarding the state-run monitoring of water in the Dnieper basin, taking into account the EU Water Framework Directive and measures for

biodiversity restoration and conservation, as well as sustainable use of the Dnieper Cascade were implemented by the Ministry of Environmental Protection and Natural Resources of Ukraine.

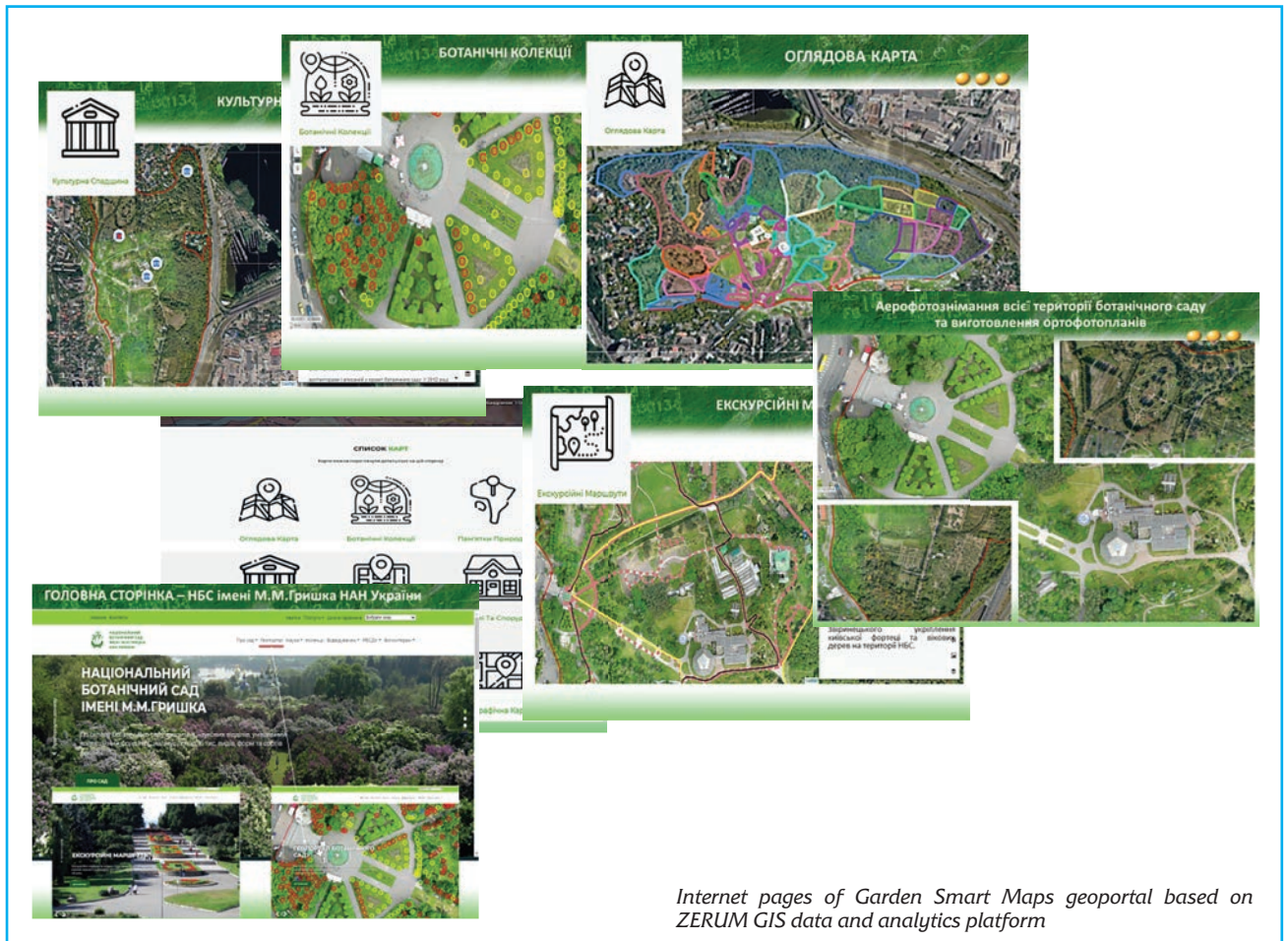
*S. Afanasyev*

### Open geoinformation system for preserving the natural and cultural heritage of M.M. Gryshko National Botanical Garden

Having ratified the Convention concerning the protection of world cultural and natural heritage, Ukraine assumed the commitment to detect, protect, and popularize objects of cultural and natural heritage, promote the studies of Ukraine's landmarks of culture and nature.

Scholars of the M.M. Gryshko National Botanical Garden of the NAS of Ukraine, which is an object of the nature reserve fund of Ukraine, have accumulated and processed historical information on the objects of natural and cultural heritage, prepared their photographs, created objects' visual panoramas, compiled schematic plans and maps of some objects, and developed excursion routes. In particular, the cultural heritage objects included in the State register of immovable landmarks of Ukraine and situated on the territory of the National Botanical Garden are: the cultural layer of 'Prince Vsevolod's grand courtyard' of XI—XII centuries; the cultural layer of Vydubychi tract of IX—XIII and XII—XVII centuries; Zvirynetski Caves of XI—early XVII centuries, Zvirynetskiy blockhouse of Kyiv Fortress of 1810; St. Trinity Church of St. Jonas Monastery of XIX century. Local botanical landmarks include Lypsky's Sycamores, Gryshko's Chestnut Trees, Bohun's Linden Trees, Shevchenko's and Stus' Mulberry Trees etc.

On the basis of *ZERUM GIS* data and analytics platform, Botanical Garden's associates constructed Geoportal (*Garden Smart Maps*) and created spatial sets of vector data for collection and exposition plots, ecology trails and excursion routes, along with those for nature landmarks, cultural heritage objects, terrain, road network, infrastructure, and buildings located on the territory of the institution. Such Geoportal is to become an advanced instrument for publications and online work with scientific documentation, as well as for publicizing the information that is of public interest. The employed methods of remote sensing of the Earth surface help assess the state of vegetation and its development dynamics with various degrees of information generalization — from global studies covering the entire country to small vegetation areas. Besides, information stands and special information signs were elaborated for interactive excursions "Secrets of Kyiv Fortress Zvirynetskiy blockhouse" and "Natural heritage of the



Internet pages of Garden Smart Maps geoportal based on ZERUM GIS data and analytics platform

National Botanical Garden”, which provide access to geoportal materials through scanning QR codes.

The launch of Garden Smart Maps resource is expected to provide positive socio-cultural, educational

and scholarly influence on the society, and on the image of Kyiv and Ukraine.

*M. Gaponenko, L. Buyun, D. Rakhmetov, M. Shumyk, A. Gnatiuk, V. Pylypchuk*

# SCIENTISTS OF THE NAS OF UKRAINE IN INTERNATIONAL PROGRAMS AND PROJECTS

**In** 2021, despite the limitations introduced due to anti-epidemic measures for preventing the spread of COVID-19 in the world, the National Academy of Sciences of Ukraine continued to effectively fulfill the task of international and S&T collaboration. Its purpose was to enhance the presence of Academy's institutions in international and European scientific programs, further advancement of international cooperation with the institutions it had the experience and good working results: CERN, IAEA, EC Joint Research Centre, the International Institute for Applied Systems Analysis.

The work on the projects started earlier in the framework of the previous EU research and innovation programme "Horizon 2020" was going on. In general, Ukraine took the seventh place among the associated countries in terms of the funds allocated from the overall budget of the programme. As of October 2021, Ukrainian participants signed 228 grant agreements for the total amount about €45.8 million, of which NAS institutions were involved in the implementation of nearly 50 projects with the total funding over €5.5 million. NAS institutions joined the implementation of both research projects, e.g., *PREDIS* (the Institute of Environmental Geochemistry), *STRUMAT-LTO* (Institute for Nuclear Research), *Flintstone 2020* (V. Bakul Institute for Superhard Materials) and coordination projects, e.g., *VACTRAIN* (R.E. Kavetsky Institute of Experimental Pathology, Oncology and Radiobiology), *UAIinEuratom* (National Science Center 'Kharkiv Institute of Physics and Technology').

Late in 2021, at the 23<sup>rd</sup> EU-Ukraine Summit the Agreement on Ukraine's participation in the "Horizon Europe" Research and Innovation Framework Programme, which is the largest EU program for research and innovation funding with the total budget over €90 billion, and in the European Atomic Energy Community's "Euratom" Research and Training Programme. Taking into account new opportunities with regard to receiving access to the instruments of support and raising grant funds, Academy focused its efforts on ensuring the participation in these programs. In spite of the late start of Ukrainian scientists in applying for com-

petitive projects of "Horizon Europe" programme, NAS institutions were admitted to several consortiums that submitted applications for the funding of respective projects in the framework of competitions announced by the European Union.

The National Academy of Sciences of Ukraine is active in popularizing and supporting the participation of its institutions in "Horizon Europe" programme. Since 1 January 2021, the NAS of Ukraine has been involved in the implementation of *FIT-4-NMP* project under "Horizon 2020" programme, which will last till the end of 2023 and provides for stimulating and enlarging the involvement of talented new innovation actors in the projects under this program in the areas of nanotechnologies, novel materials and production technologies, and cutting-edge production processes.

An important role in the international collaboration of the NAS of Ukraine was played by the participation of its scientists in multi-year projects in the framework of NATO program "Science for Peace and Security". Marked for their new accomplishments were Academy institutions that took part in implementing projects of this program, in particular, O.Ya. Usikov Institute for Radio Physics and Electronics, I.M. Frantsevich Institute for Problems of Materials Science, B. Verkin Institute for Low Temperature Physics etc., whose researchers carried out concurrent studies under several projects of this program. Altogether, 11 projects were financed in the framework of NATO program "Science for Peace and Security". Scientific collaboration with NATO broadens the opportunities for upgrading the research infrastructure of Academy's institutions, establishing new international contacts, involving additional funding sources etc.

In 2021, the Federal Ministry for Education and Research of Germany announced and held a contest of projects "Establishing German-Ukrainian Cores of Excellence", CoE). In accordance with its results, 12 applications were chosen, four of those were submitted by scientific institutions of the NAS of Ukraine.

The collaboration of Kyiv Academic University (KAU) and the Leibniz Institute for Solid State and Materials (*IFW Dresden*) under *UKRATOP* joint project of topological materials studies was also fruitful. In the framework of this project, in July 2021, KAU received unique equipment from *IFW Dresden* — an optical furnace for growing single crystals and equipment for specimen preparation, as well as helium cryostat with 16-tesla superconductor magnet, which is a record for Ukraine. This equipment is German colleagues' contribution to the development of Joint Ukrainian-German Laboratory for studying quantum materials and the KAU Center for quantum materials and technologies, which is based in G.V. Kurdyumov Institute for Metal Physics of the NAS of Ukraine, and is to become a center of joint



Coordinator of EEN-Ukraine Consortium Olena Fecenko (Center) at the ceremony of awarding for the first place in the European Best Practice Contest

research for other Academy institutions and an attractive center of involving young scientists.

Researchers of B. Verkin Institute for Low Temperature Physics of the NAS of Ukraine, in collaboration with their Ukrainian, German and Israeli colleagues, carried out experimental observations of electromagnetic microwaves emitted by moving vortices in superconducting nanostructures. The scientific result of this collaborative effort was published in the prestigious scientific journal *Nature Communications*, which belongs to the Publishing Group *Nature Research*.

Scientists of Pidstryhach Institute for Applied Problems of Mechanics and Mathematics, NAS of Ukraine, and Palermo Astronomical Observatory (Italy) jointly modeled the evolution of the most important Supernova SN 1987A. Relying on novel mathematical analytical and numerical methods, they constructed polarization maps, which has opened the way to detailed understanding of how stars end their lives.

Researchers of V.I. Vernadsky Institute of General and Inorganic Chemistry of the NAS of Ukraine and their Slovak colleagues, dealing with the therapy of Alzheimer's disease and other cognitive disorders resulting from brain damage, synthesized and investigated inorganic particles of cerium dioxide ( $\text{CeO}_2$ ), which are promising for the treatment of neurodegenerative diseases.

The collaboration of Ukrainian scientists with the European Center for Nuclear Research (CERN) continued. With the active contribution of Ukrainian physicists to designing and implementing experiments at the Large Hadron Collider, proofs of the existence of odderon quasi particle were found, though the first hypothesis of its existence had been advanced nearly 50 years ago. This discovery is a revolutionary breakthrough in physics.

The Institute for Scintillation Materials of the NAS of Ukraine joined one of the four central experiments at the Large Hadron Collider — *LHCb* (*Large Hadron Collider beauty*). In the framework of this collaboration, *PLUME* detector update is planned, with using new scintillators developed at the Institute.

On 28 May, a video conference of the members of working groups for studying *COVID-19* pandemic was held; the groups are operating under the National Academy of Sciences of Ukraine and the inter-disciplinary *COVID-19* advisory group of the Polish Academy of Sciences. The participants of the meeting analyzed the current epidemic situations in their countries and agreed to collaborate in examining *COVID-19* pandemic development, in particular, its pace and ways of pandemic spreading in the two countries. Developing this collaboration, in August 2021 the presidents of the NAS of Ukraine academician Anatolii Zagorodny and of the Polish Academy of Sciences professor Jerzy Duszyński held a meeting, discussed bilateral cooperation, in particular, in the investigations of *SARS-CoV-2* coronavirus, and signed a protocol to the Cooperation Agreement between the NAS of Ukraine and the PAS for 2022—2024, which provides for the implementation of 49 mobility projects in this period.

In July 2021, in the NAS Presidium, a meeting headed by academician V.P. Gorbulin, the First Vice-President of the NAS of Ukraine, and the delegation of the Scientific and Technological Research Council of Turkey (TÜBİTAK), headed by its President professor Hasan Mandal took place. During it, the parties determined promising lines of further collaboration that are of common interest and signed the updated Collaboration Agreement, which provides for the support of joint projects selected on the competitive basis.

With active NAS participation, "botanical diplomacy" was brought to life. In August 2021, in the framework of



Signing the Agreement between the NAS of Ukraine and TÜBİTAK at NAS Presidium

the international environmental project *Greening of Ukraine*, diplomats from Cuba, Slovakia, Croatia, Montenegro, the South African Republic and other countries congratulated Ukraine on the 30th anniversary of its independence and took part in planting the symbolic Independence Alley of 30 linden trees in the M.M. Gryshko National Botanical Garden.

The intergovernmental organization *Group of Earth Observation (GEO)* awarded the *GEO* honorary prize *Individual Excellence Award 2021* to professor Natalia Kussul, Dr. of Engineering, deputy director of the Institute for Space Research of the NAS of Ukraine and the SSA of Ukraine, head of the department of space information systems and technologies of this institute, for her outstanding personal contribution to the activities of this organization. She is representing Ukraine in the High-Level Working Group of the European regional center *EuroGEO*, and as a member of Ukrainian representation in *GEO*, she made considerable efforts for transferring Ukraine from the post-Soviet to the European regional sector and for including Ukraine in the

European research area in the sphere of Earth observation from space.

The ties with Ukrainian scientific diaspora were strengthened. Due to the initiatives of such its pro-active representatives as doctor of science, professor Olga Garaschuk (FRG), foreign members of the NAS of Ukraine, doctors of science Yuriy Gamota (the USA) and Ihor Huk (Austria), the fruitful collaboration with compatriots is gaining momentum. E.g., in 2021 a video conference was held that was concerned with further development of ties between NAS scientists and Ukrainian scientific diaspora in Europe and the USA. German–Ukrainian academic society started to create cooperative information platform *UKRAINet* (Ukrainian international academic network). Its principal tasks are: to promote scientific collaboration with Ukraine; enhance the awareness of Ukraine abroad and vice versa; raise the visibility of Ukrainian scientists and their achievements; support career development of network members and researchers who start their careers in Ukraine; support reforms in Ukrainian science.

# SCIENCE AND SOCIETY

The enhancement of the NAS communication activity in the information space, informing the broad public on the decisive role of science in today's world and nation's life, important results of Academy institutions' work and the challenges of domestic scientific sphere remain important tasks. The incessant work towards organizing the effective interaction of scientists with media and the public is going on. Media representatives are invited to take part in important scientific events, NAS scientists regularly participate in TV and radio programs, issue articles on the pages of printed editions and Internet sites, are active social network contributors on scientific issues, organizers and participants of popular-science projects etc. The Academy is taking resolute steps for its activities to become more public and comprehensible for society every year. One of the instruments of achieving this aim is the regular work of filling and updating the official Internet site of the NAS of Ukraine and its Facebook web page with materials on the Academy's life and activities that are of public interest.

Last year, quite a few events aimed at the widest possible coverage of the results of Academy's work, its achievements and problems were carried out with the involvement of its leadership. On 21 January 2021, an online briefing of NAS President academician Anatolii Zagorodny for media was held. During it, the NAS leader told media representatives about the main implemented measures for reforming the NAS of Ukraine, priority plans and tasks, presented his vision of the ways of Academy's future development, while journalists had an opportunity to ask questions and get answers on the issues that were the most interesting for them.

A large-scale event that attracted a broad circle of representatives of state power bodies, business, educators, scientists, public figures, journalists and was widely covered in media was the all-Ukraine forum "Ukraine 30. Education and Science", which took place in Kyiv from 31 May to 2 June 2021 on the initiative and with the participation of the President of Ukraine. Academician Anatolii Zagorodny and scientists of various NAS institutions became speakers at this event and participated in discussions addressing the general trends

of the development of education and science in Ukraine and the world.

During the three days of forum's work, its participants could visit an exhibition of S&T developments of NAS institutions, where scientists demonstrated their latest achievements in information technologies, novel materials, energy engineering, ecology, medicine and health protection, defense industry etc.

In 2021, the pages of renowned printed and Internet editions (*Dzerkalo tyzhnia* weekly, the newspaper of the Cabinet of Ministers of Ukraine *Uriadovi Kurier*, newspaper *Svit*, journal *Visnyk NAN Ukrainy* (*Herald of the NAS of Ukraine*)) presented broad public with several extensive interviews of NAS President academician Anatolii Zagorodny addressing various aspects of Ukrainian science life.

As in the previous year, quarantine restrictions due to the coronavirus disease prevented full-fledged large-scale activities aimed at science popularization: the All-Ukraine Science Festival, traditionally held in May, "Science Days" — the project launched by young NAS scientists, whose purpose is to inform wide circles of Ukrainian society on scientists' work, as well as the achievements of Ukrainian and world science.

COVID-19 pandemic also made organizers of other popular-science events change their modes: reduce the number of live event participants, use mixed (online and offline) or fully online modes. All events (presentations, master classes, lectures, exhibitions, contests for the public), which were traditionally held in the framework of the Brain Awareness Week, had to be postponed. The 2021 event program was limited to a cycle of online lectures delivered by scientists. Listeners from all over the country could join them, which also demonstrated the advantages of this way of communication.

The work of YouTube Channel of the NAS of Ukraine became more proactive. Last July, the project "About science. Competently" was launched. In the framework of that, leading Academy's scientists in the interviews given to NAS academician Volodymyr Semynozhenko speak about the most relevant and the most interesting outcomes of scientific research along with S&T developments that are of considerable importance for the life of each person and the whole country. This project has become a useful place of scientific communication for scholars themselves and the society in general. Over the time of project existence, invited to conversation were well-known experts in biology, genetics, medicine, chemistry, physics, astronomy, mathematics, optoelectronics, aircraft construction, political science, economics, demography, sociology etc. The program is going on the air on a regular basis and is winning ever more popularity among TV viewers.

In 2021, the Academy joined the celebration of the event of utmost importance for our country — the 30th

anniversary of its Independence. On this occasion, a jubilee session of the NAS General Meeting was held, where accomplishments of Ukrainian academic science, as well as scientists' contribution to the development of Ukraine were presented. Institutions of the NAS of Ukraine also organized a number of other events — conferences, round table discussions etc. E.g., on 24 August, the Institute of Mathematics of the NAS of Ukraine, jointly with Kyiv Academic University, organized and held an online mathematical marathon "Ukraine is  $3^3+3$ ", whose aim was to acquaint a broad circle of TV viewers with prominent mathematicians, present interesting facts about today's mathematics, show this science at different angles.

In 2021, the NAS of Ukraine became a partner of the international project "Musical tribute to COVID-19 health care workers", supported by WHO and UNESCO, — the event intended to draw the attention of the Ukrainian society and the whole world to the difficult work of medical workers and scientists who are fighting against COVID-19 pandemic. The opening night of the project took place on 16 September at the National Opera of Ukraine.

Significant interest was generated by the action "We open «Science for everyone»", initiated and implemented by NAS Publishing House *Akademperiodyka* with the support of the NAS Council for Scientific Publishing. Every week since May 2021, *Akademperiodyka* has been giving public access to another book from the general academic book series "Science for everyone" by placing the full text of the edition on its Web resource. Over the time of this action, 23 popular-science editions were placed in the open access.

Last year, lecture series provided by NAS scientists were continued. Among them were online lecture cycles under "Real science" and "Scientific meetings" projects.

In April 2021, the authors of scientific initiatives "Science Days" and "Scientific Picnics in Ukraine" launched a new popular-science video project "NaukuYimo", whose active participants are scientists of the NAS of Ukraine.

"Science is cool!" — for many years, under this slogan the State Scientific Institution 'Institute for Single Crystals' has been providing study tours for high-school and university students, and for all those who are interested in science. Last year was not an exception. Scientists of the Institute welcomed guests and told them about the directions of research conducted there, demonstrated specimens of scientific developments and advanced equipment.

Traditionally, the National Museum of Natural History of the NAS of Ukraine, which is situated in Kyiv, invited its visitors to take part in various interesting events — excursions, exhibitions, demonstrations, quests,



President of the NAS of Ukraine academician Anatolii Zagorodny during his speech at the All-Ukraine Forum "Ukraine 30. Education and Science"



Scientists of the NAS of Ukraine present their state-of-the-art developments during the All-Ukraine Forum 'Ukraine 30. Education and Science'



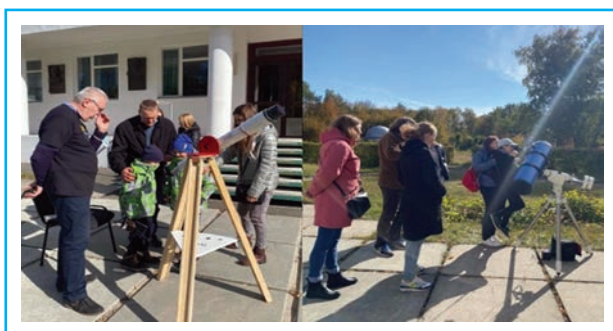
Young scientists of the NAS Institute of Mathematics inaugurate mathematical online marathon "Ukraine  $3^3 + 3$ " (24.08.2021)



Pupils of a Kharkiv school at the educational excursion at S&T Complex 'Institute for Single Crystals' of the NAS of Ukraine



*Open Doors Day at the Institute for Nuclear Research of the NAS of Ukraine*



*Daytime observations of the Sun during Autumn Astronomy Day at the Main Astronomical Observatory of the NAS of Ukraine*

lectures, interactive programs. The program proposed by the Museum every month was designed in such a way that it was fit for absolutely different groups of visitors: preschoolers, schoolchildren, adults.

General public did not miss popular-science events organized by the scientific associates of the NAS Main Astronomical Observatory in 2021. Among those were Spring Astronomy Day, International "Observe the Moon" Night, Autumn Astronomy Day, Astro Autumn in Holosiiv etc.

In June 2021, the "old ground" of the National Science Center 'Kharkiv Institute of Physics and Technology' became the center of the international research-and-artistic residence "Our School KHTZ". For a month, artists from Ukraine, Belarus, Moldova, Georgia, Kazakhstan, and Tajikistan investigated Institute's history, visited laboratories where prominent scientists had conducted experiments and worked, communicated with research associates.

A remarkable event was the 2021 Open Doors Day at the NAS Institute for Nuclear Research, which was held last summer on the initiative of the Council of young scientists and supported by the leadership of this Academy institution. During the excursion, all those willing had an opportunity to learn about Institute's

research areas and get acquainted with its nuclear physics installations.

In September 2021, the traditional autumn popular-science lecture tour — this time in the National History and Ethnography Reserve "Pereiaslav" (Pereiaslav town, Kyiv Oblast) — started a new season of the archeology lecture series "What archeology tells us about", functioning within the Archeology Museum of the NAS Institute of Archeology. In 2021, scholars of the NAS of Ukraine continued their close collaboration with Ukrainian media, in particular, TV channels *Rada*, *Priamyi*, *Inter*, *5 Channel*, *TRK Kyiv*, *Ukraina24*, *Espresso TV*, *Apostrof TV*, Internet channels: *Hromadske telebachennia*, *I-UA.TV*, radio stations UA: *Ukrainske radio (UR-1, Promin, Kultura)*, *Hromadske radio*, *Radio Svoboda*, *Radio NV*. Collaboration with printed editions *Den*, *Holos Ukrainy*, *Uriadovyi Kurier*, *Svit*, *Ukrainskyi Tyzhden*, *Vechirniy Kyiv*, *Fakty*, popular-science magazine *Kunsht*, Internet editions: *Dzerkalo tyzhnia*, *Ukrainska pravda*, *BBC NEWS Ukraina*, *Tsenzor.NET*, *Zakhid.net*, *Hlavkom*, *Gazeta.ua*, *Apostrof*, *Livyi Bereh*, *Wonderzine*, *LIGA.Life*, *Telegraf*, information agencies *Ukrinform*, *Unian*, *RBK-Ukraina* etc.

Especially proactive in the work with media were Academy scholars whose research was concerned with counteracting COVID-19 pandemic. Collaborating with various media, scientists of the NAS of Ukraine conducted continuous educational work in society: explained coronavirus nature, spoke about the mechanisms of disease spreading, the measures necessary to avoid it, the importance of vaccination, informed about the emergence of new strains etc. Prognoses of pandemic development in Ukraine, which Academy scientists regularly prepared and promptly publicized on its information resources, were quickly circulated and used by media.

In 2021, the NAS Commission for communicating with society and popularizing scientific activities continued its work. An important result of its functioning was establishing NAS Prize "For popularizing science". The prize will be awarded annually to media and their representatives, scientists, and organizers of independent projects for the best publication about scientists' accomplishments, the activities of research institutions and the NAS of Ukraine as a whole, as well as for promoting science popularization and raising the prestige of scientific professions.

An important step towards enhancing the communicative activity of the NAS of Ukraine was to identify among associates of NAS research institutions the persons responsible for the popularization of scientific activities and relations with the Press Service of the NAS of Ukraine.

# DISTINCTIONS AND AWARDS

**A**warded with V.I. Vernadsky Gold Medal of the NAS of Ukraine were academician A.G. Naumovets — for his outstanding accomplishments in nanoelectronics and surface physics, as well as professor Anton Zeilinger (Austria) — for prominent achievements in quantum electronics and photon teleportation.

For considerable contribution to the development of international scientific collaboration, the title of Honored Doctor of the National Academy of Sciences of Ukraine was bestowed on L.V. Huberskyi, Rector of Taras Shevchenko National University of Kyiv; Josef Eberhardsteiner, Vice-Rector of Vienna Technological University; Herbert Mang, research associate of the Institute for Mechanics of Materials and Structures, foreign member of the NAS of Ukraine.

In 2021, 29 associates of NAS institutions, organizations and enterprises were honored with state awards of Ukraine. For his personal contribution to the state development, strengthening the system of state security and defense, multi-year fruitful scientific activities, academician V.P. Gorbulin, First Vice-President of the National Academy of Sciences of Ukraine, was honored with the title "Hero of Ukraine" with the presentation of Order of the State.

For significant personal contribution to state establishment, strengthening state security, socio-economic, S&T, cultural and educational development of Ukraine, significant labor achievements, multi-year conscientious work marked were:

NAS corresponding member Ye.R. Bersheda; NAS academician V.V. Morgun, director of NAS Institute of Plant Physiology and Genetics, — with Order of Yaroslav the Wise IV Class;

NAS corresponding member I.S. Kosenko, director of "Sofiivka" National Dendrological Park of the NAS of Ukraine; Mykola Mushynka, foreign member of the NAS of Ukraine, — with Order of Prince Yaroslav the Wise V Class;

NAS academician A.G. Zagorodny, President of the National Academy of Sciences of Ukraine, director of Bogolyubov Institute for Theoretical Physics; NAS academician G.G. Pivnyak — with Order of Merit I Class;

NAS corresponding member V.M. Danylenko, department head of the NAS Institute of the History of Ukraine — with Order of Merit II Class.

Awarded for considerable personal contribution to the advancement of Ukrainian science, strengthening S&T potential of Ukraine, conscientious work of many years and high professionalism were:

NAS academician V.G. Koshechko, Vice-President of the NAS of Ukraine, director of L.V. Pisarzevsky Institute of Physical Chemistry of the NAS of Ukraine — with Order of Prince Yaroslav the Wise III Class;

NAS corresponding member V.A. Kordium, department head of the NAS Institute of Molecular Biology and Genetics, — with Order of Prince Yaroslav the Wise IV Class;

NAS corresponding member C.V. Vidnianskyi, department head of the NAS Institute of the History of Ukraine; NAAS academician M.M. Gavryliuk, deputy director of the NAS Institute of Plant Physiology and Genetics; Yu.Zh. Shaigorodskyi, principal researcher of Kuras Institute of Political and Ethnic Studies of the NAS of Ukraine, — with Order of Merit III Class.

For considerable personal contribution to state establishment, strengthening defense potential, socio-economic, S&T, cultural and educational progress of the Ukrainian state, essential labor achievements, multi-year conscientious work awarded were:

NAS and NAPS academician V.G. Kremen, President of the National Academy of Pedagogical Sciences; NAMS academician and NAS corresponding member V.V. Lazoryshynets, Vice-President of the National Academy of Medical Sciences of Ukraine, director of the state institution "Amosov National Institute of Cardiovascular Surgery" of the National Academy of Medical Sciences of Ukraine; NAS academician V.D. Pokhodenko, adviser of the NAS Presidium, emeritus director of L.V. Pisarzevsky Institute of Physical Chemistry of the NAS of Ukraine — with Order of Prince Yaroslav the Wise III Class;

M.V. Yurzrenko, department head of E.O. Paton Electric Welding Institute of the NAS of Ukraine — with Order of Merit III Class;

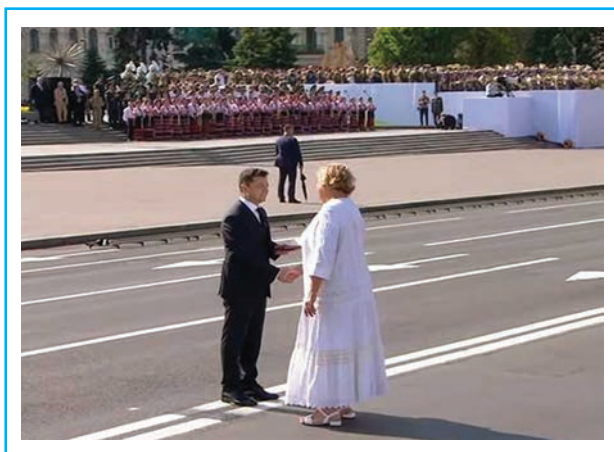
NAS academician E.M. Libanova, academician-secretary of the NAS Department of Economics, director of Ptoukha Institute for Demography and Social Studies of the NAS of Ukraine, — with Order of Princess Olga I Class;

G.V. Nikitiuk, librarian, tour organizer of "Sofiivka" National Dendrological Park of the NAS of Ukraine, — with Order of Princess Olga III Class.

Awarded for significant personal contribution to the socio-economic, S&T, cultural and educational progress of Ukraine, considerable labor achievements and multi-year conscientious work were:

NAS academician Yu.S. Shemshuchenko, director of the NAS Institute of State and Law, — with Order of Prince Yaroslav the Wise I Class;

NAS corresponding member V.M. Shapoval — with Order of Prince Yaroslav the Wise II Class;



*President of Ukraine Volodymyr Zelensky hands the Order of Princess Olga I Class to NAS academician Ella Libanova*



*Winners of the 2021 State Prize of Ukraine in Science and Technology*



NAS academician B.V. Grynirov, director of the Institute for Scintillation Materials of the NAS of Ukraine, — with Order of Prince Yaroslav the Wise IV Class.

For outstanding personal contribution to scientific activities in the Antarctic, distinguished were:

NAS academician S.V. Komisarenko, director of Paladin Institute of Biochemistry of the NAS of Ukraine, — with Order of Prince Yaroslav the Wise III Class;

NAS Academician P.F. Gozhik, director of the Antarctic Research Center in 1993—1999, — with Order of Prince Yaroslav the Wise V Class (posthumously);

O.V. Budanov, research associate of the NAS Institute of Radio Astronomy — with Order of Merit III Class.

Marked for her considerable personal contribution to the socio-economic, S&T, cultural and educational progress of the Ukrainian state, exemplary performance of official duties and multi-year conscientious work was NAS academician H.V. Yelska, adviser to the directorate of the NAS Institute of Molecular Biology and Genetics, — with Order of Princess Olga I Class.

Distinguished for essential personal contribution to the progress of national education, training of highly qualified specialists, multi-year fruitful pedagogical work and high professionalism were:

Onishchenko N.M., department head of Koretsky Institute of State and Law of the NAS of Ukraine, — with Order of Merit I Class;

V.B. Dunets, department head of the National center “Junior Academy of Sciences”; Ye.V. Kudriavets, deputy director of the National center “Junior Academy of Sciences”, — with Order of Merit III Class.

For significant personal contribution to the mitigation of Chernobyl accident consequences, dedication, high professionalism, and multi-year fruitful social activities, V.Ye. Khan, department head of the NAS Institute for Safety Problems of Nuclear Power Plants, was awarded with Medal “For Labor and Victory”.

For essential personal contribution to the development of military industry and strengthening the defense potential of Ukraine, the National Defense and Security Council of Ukraine awarded NAS corresponding member V.I. Grytsenko, director of the Research and Training Center for Information Technologies and Systems under the MES and the NAS of Ukraine, and young scientist O.Ye. Volkov, head of intelligent control department of the same institute, head of Young Scientists’ Council of the NAS of Ukraine, with Distinction of III Class.

The honorary title “Merited Figure of Science and Technology of Ukraine” was bestowed on eleven scientists, the title “Merited Education Worker of Ukraine” — on two scientists, “Merited Environmentalist of Ukraine” — on one scientist.

The State Prize in Science and Technology of Ukraine went to 6 NAS scientists for the work “Control of materials’ properties under extreme conditions”; for the work “Discovery and investigation of new phenomena for light beams with wave front singularities” — to 2; for the work “Analytical methods of functions theory” — to 7; for the work “Development of functional vacuum plasma and diffusion coatings for wide application” — to 5; for the work “Technologies and equipment for producing and consuming alternative fuels” — to 5; for the work “Innovative nano-biotechnologies for early diagnostics and chemical therapy of pathological states”— to 6; for the work “Disaster medicine in battlefield’ — to 2 researchers.

The National Borys Paton Prize for the work "Dynamic interaction of solid and deformable bodies with fluid" was awarded to 5 NAS associates; for the work "Physical and technological fundamentals of developing controllable nano- and microstructures on solid surfaces" — to 4; for the work "Electrochemistry of functional materials and systems" — to 3; for the work "Novel multi-component high-entropy materials of constructional and functional purposes" — to 7; for the work "Physical fundamentals and innovative technologies of ultrasonic processing of materials" — to 3; for the work "Development of high-efficiency hydro units for hydro power plants of Ukraine" — to 1; for the work "Conservation and recovery of plant diversity in Ukraine" — to 8 researchers.

41 researchers of the Academy became laureates of Ukraine President's Prize for young scientists, and the Prize of the Verkhovna Rada of Ukraine for young scientists was awarded to 27 researchers. 12 researchers won personal stipends of the Verkhovna Rada of Ukraine for young doctors of sciences. 16 Academy associates were marked with the diploma of the Verkhovna Rada of Ukraine and the honorary diploma of the Verkhovna Rada of Ukraine, while 3 associates of the NAS of Ukraine received valuable presents from the head of the Verkhovna Rada of Ukraine. 9 scientists were awarded with the honorary diploma of the Cabinet of Ministers of Ukraine, and 4 Academy associates were marked with the Commendation of the Prime Minister of Ukraine.

47 researchers won NAS prizes named after prominent Ukrainian scientists and scholars, 15 scientists received prizes of the NAS of Ukraine for young scientists. Academician Borys Paton stipend for young scientists of the National Academy of Scientists of Ukraine was awarded to 15 scholars, and certificates of honor went to 7 young researchers for their achievements in studying important scientific problems.

46 Academy associates were marked with the jubilee medal on the occasion of the 75th anniversary of ANTONOV State Enterprise for multi-year conscientious labor, considerable personal contribution to the progress of aircraft construction and high professionalism.

By a resolution of the General Meeting of the National Academy of Agrarian Sciences of Ukraine, the ti-

tle of its Honorable Member was bestowed on NAS academician V.V. Morgun for his outstanding contribution to the development of genetics and plant breeding.

Researcher of NAS Institute for Scintillation Materials I.I. Bespalova, senior research associates of V.Ye. Lashkaryov Institute of Semiconductor Physics V.V. Nosenko and of Chuyko Institute of Surface Chemistry I.Ya. Sulym became the laureates of the IV Ukrainian L'ORÉAL-UNESCO Prize "For Women in Science".

In the framework of XII International exhibition "Modern education institutions — 2021", which was organized by "Vystavkovy Svit" company with the information, methodological and organizational support of the Ministry of Education and Science of Ukraine, as well as the National Academy of Pedagogical Sciences of Ukraine, Kyiv University of Law of the NAS of Ukraine was awarded the gold medal in the nomination "Innovations in promoting international collaboration at an educational institution" and a diploma in the nomination "For active participation and professional presentation of educational and scientific achievements". Yu.L. Boshytskyi, the rector of this institution, received the Honorary certificate "For considerable personal contribution to ensuring modern progress of the national education and science".

NAS associates V. Nepran, O. Zakletsyky, Yu. Krasylenko, O. Gubin, S. Yesylevskyi, O. Tomchenko, and K. Terletska became the winners of the scientific photographs contest held by *Vikimedia Ukraina* — a non-profit organization, whose mission is to promote free flow of knowledge, in the categories "People in science", "Microscopy", "Living organisms", "Non-photographic imagery", and in "General category".

224 people were awarded with NAS honors: "For Scientific Achievements" — 30 associates, "For Training Young Scientists" — 48, "For Professional Accomplishments" — 95, "For Promoting Science Advancement" — 10, with "Talent, Inspiration, Work" prize for young scientists — 38.

288 people and labor collectives received NAS acknowledgements.

141 people and labor collectives were awarded with certificates of honor by NAS Presidium and the Central Committee of NAS Trade Unions.

# BACKGROUND INFORMATION. STATISTICAL DATA

## Structure of the NAS of Ukraine

The structure of the NAS of Ukraine includes 3 sections and 14 departments, which incorporate 147 research institutions. Research-and-production organizations (design offices, pilot production facilities etc.) operate within some scientific institutions, while within some research institutions function scientific objects that have the status of National Asset (nuclear, physical, and astronomical research facilities, complexes of testing equipment, archive scientific collections and museum displays, plant genetic funds, collections of microorganism strains and plant lines, cell banks, landmarks of history and culture etc.), as well as centers for shared use of scientific equipment.

### Research organizations that have the National Institution status:

- V.I. Vernadsky National Library of Ukraine;
- National Science Center "Kharkiv Institute of Physics and Technology";
- "Olbia" National Historical and Archeological Reserve;
- M.M. Gryshko National Botanical Garden;
- "Sofiivka" National Dendrological Park;
- National Museum of Natural History;
- V. Stefanyk National Scientific Library of Lviv;
- National Center "Junior Academy of Sciences" of the MES of Ukraine and the NAS of Ukraine.

Functioning in the Academy are **five regional science centers** of dual subordination to the Ministry of Education and Science of Ukraine:

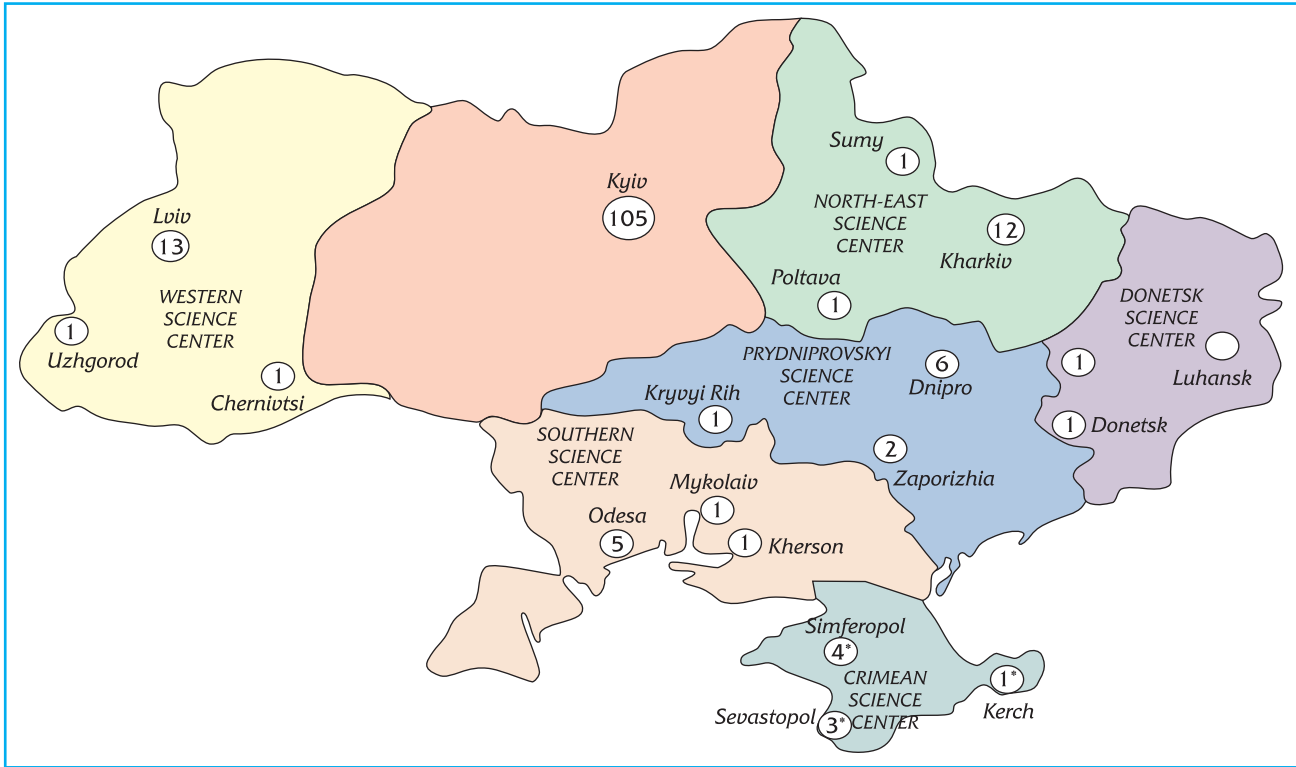
- Donetsk Science Center (Kramatorsk, Donetsk Oblast)
  - Western Science Center (Lviv),
  - Southern Science Center (Odesa),
  - North-East Science Center (Kharkiv),
  - Prydniprovskiy Science Center (Dnipro),
- as well as the Center for evaluating research institutions and scientific support to regional development (Kyiv).

The statutory activities of Crimean Science Center and its funding by the NAS budget were suspended in 2014.

## DISTRIBUTION OF INSTITUTIONS ACROSS SECTIONS AND DEPARTMENTS

Department	Scientific institutions	R&D organizations	Objects that have National Asset status	Centers of the shared use of equipment
<b>Section of Physical, Engineering and Mathematical Sciences</b>				
Mathematics	3	—	—	—
Informatics	8	—	—	—
Mechanics	7	3	3	7
Physics and Astronomy	15	2	9	16
Earth Sciences	14	1	—	5
Physical & Engineering Problems of Materials Sciences	12	19	1	12
Physical & Technological Problems of Energy Engineering	10	1	2	4
Nuclear Physics & Energy Engineering	5	2	2	6
<b>Section of Chemical and Biological Sciences</b>				
Chemistry	13	6	—	11
Biochemistry, Physiology & Molecular Biology	8	2	5	9
General Biology	21	1	19	12
<b>Section of Social Sciences and Humanities</b>				
Economics	9	—	—	—
History, Philosophy & Law	15	3	5	—
Literature, Language & Art Criticism	7	—	4	—

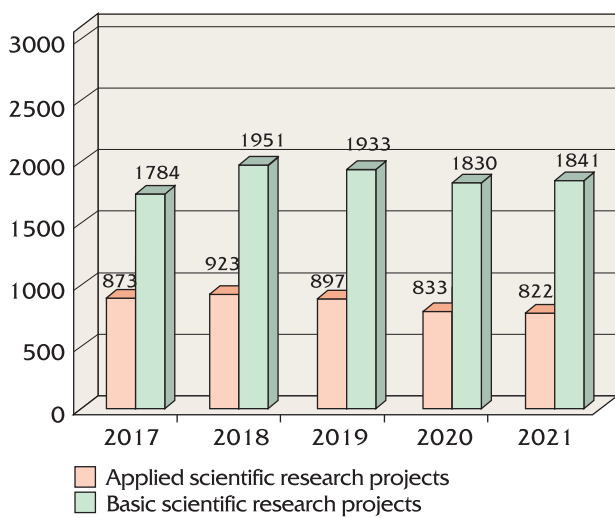
### Regional structure of the NAS of Ukraine



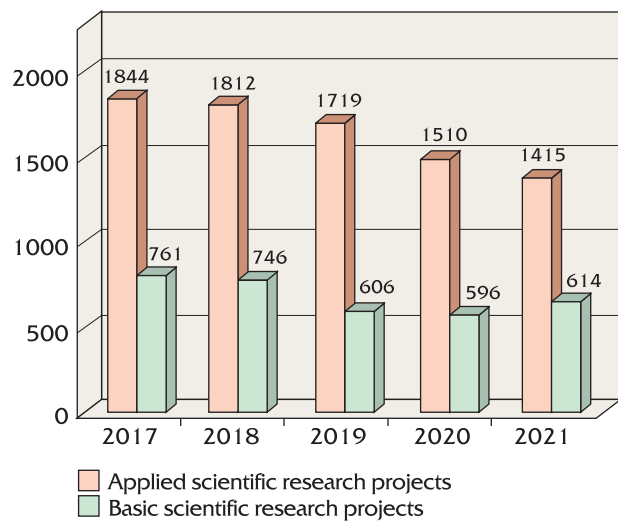
The figures in the map show the number of research institutions

\* The status of NAS institutions located in the Autonomous Republic of Crimea is defined by the Law of Ukraine “On guaranteeing the rights and freedoms of citizens and legal regime on the temporarily occupied territories of Ukraine”

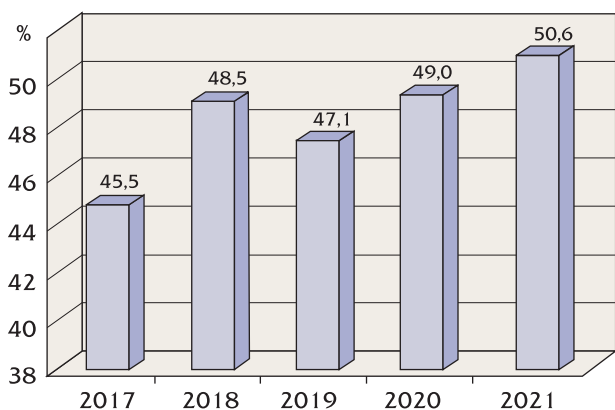
### Conducting scientific research



The number of implemented research projects financed from the general fund of the State Budget



The number of implemented research projects financed from the special fund of the State Budget

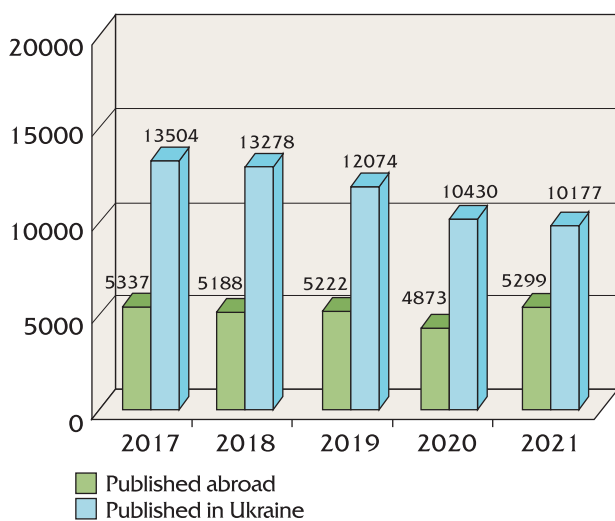


The part of targeted-program and competitive projects of NAS institutions in the total number of scientific research works

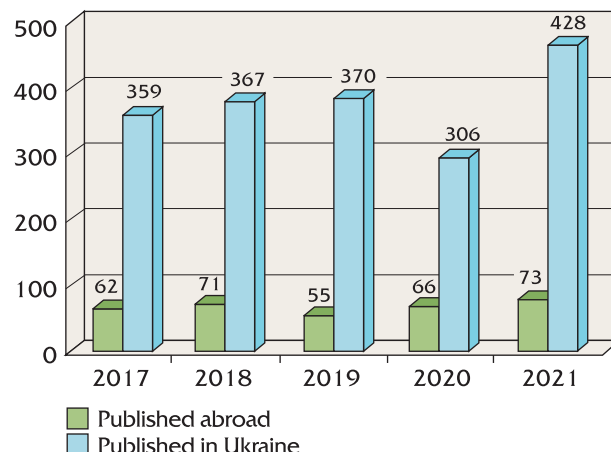
In 2021, targeted-program and competitive NAS topics consisted of research projects implemented under:

- 9 targeted programs of NAS basic research;
  - 14 targeted programs of NAS applied research;
  - 2 separate targeted projects;
  - 15 scientific programs of NAS departments;
- and were based on the results of:**
- joint contests with foreign and international organizations;
  - the contest of S&T (innovative) projects;
  - the contest of scientific and S&T projects implemented in the framework of the state-prioritized program "Support to scientific research and R&D (experimental) projects";
  - the contest of research projects in socio-humanities;
  - the contest of scientific research projects of young NAS scientists.

### Publication activity



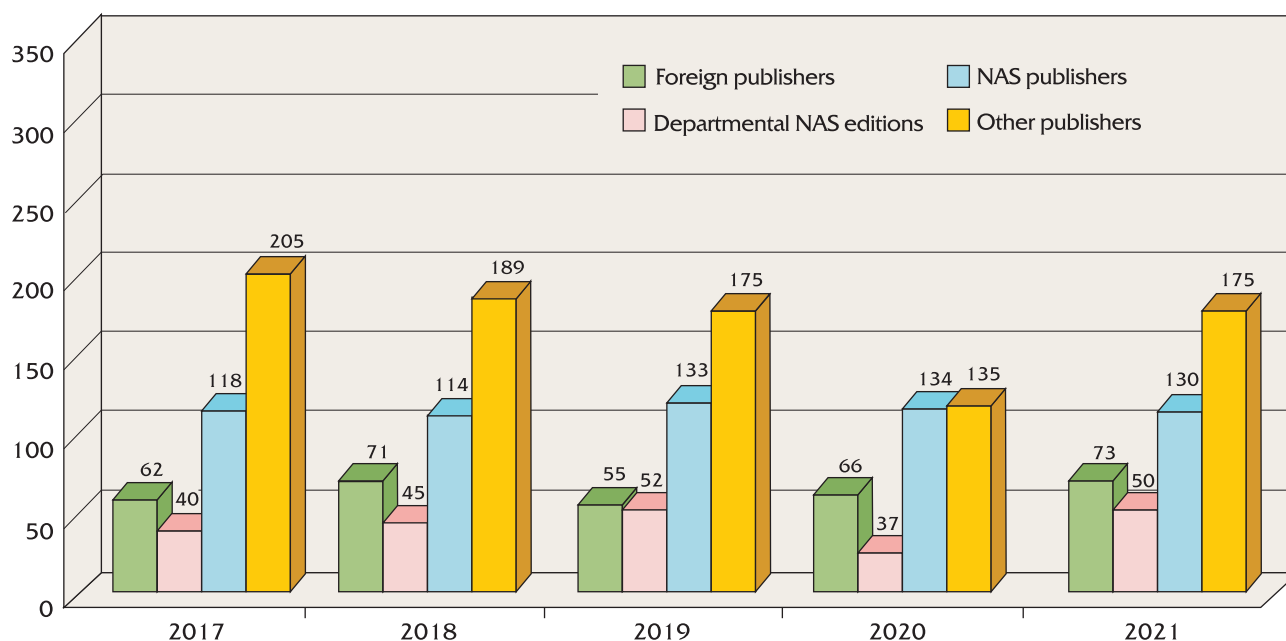
The number of papers by NAS scientists in periodicals



The number of scientific monographs

### Publishing activities

- **The total number of Academy journals:** 87 scientific journals, 1 popular-science journal (*Svitohliad*), and *Dzherelelo* abstract journal in four series;
- **10 journals are published in English in Ukraine:**
  1. Science and Innovation
  2. Semiconductor Physics, Quantum Electronics & Optoelectronics
  3. Journal of Mathematical Physics, Analysis, Geometry
  4. The Paton Welding Journal
  5. Journal of Thermoelectricity
  6. Ukrainian Journal of Physics
  7. Functional Materials
  8. Biopolymers and Cell
  9. Experimental Oncology
  10. Problems of Cryobiology and Cryomedicine
- **15 journals are published in English abroad:**
  - by Springer Publishers*
    1. Ukrainian Mathematical Journal
    2. Cybernetics and Systems Analysis
    3. International Applied Mechanics
    4. Strength of Materials
    5. Materials Science
    6. Theoretical and Experimental Chemistry
    7. Neurophysiology
  - by Allerton Press, Inc.*
    8. Kinematics and Physics of Celestial Bodies
    9. Journal of Superhard Materials
    10. Journal of Water Chemistry and Technology
  - by Begell House Inc. Publishers*
    11. Cytology and Genetics
    12. International Journal on Algae
    13. Hydrobiological Journal
    14. International Journal of Physiology and Pathophysiology
  - by other publishers*
    15. Low Temperature Physics (American Institute of Physics)



Distribution of scientific monographs across publisher groups

## Activities in scientific expertise

### In 2021, experts of the NAS of Ukraine were involved in preparing:

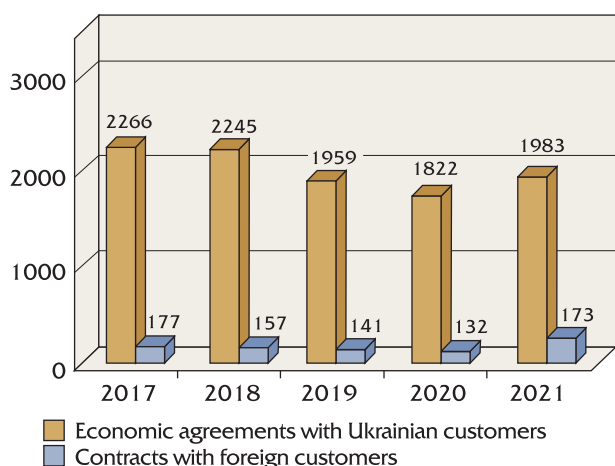
- Strategy of developing the industrial complex of Ukraine till 2030;
- Strategy of developing the defense industry complex;
- Strategy of developing higher education in Ukraine for 2021—2031;
- State strategy of ensuring equal rights and opportunities for women and men till 2030;
- Strategy of reforming local self-government and public authority decentralization in Ukraine;
- Strategy of economic development of Donetsk and Luhansk oblasts;
- National report "Ukraine as a civilizational subject of history and contemporaneity".

### Expert conclusions, notes, proposals were prepared, in particular, those to legislation drafts:

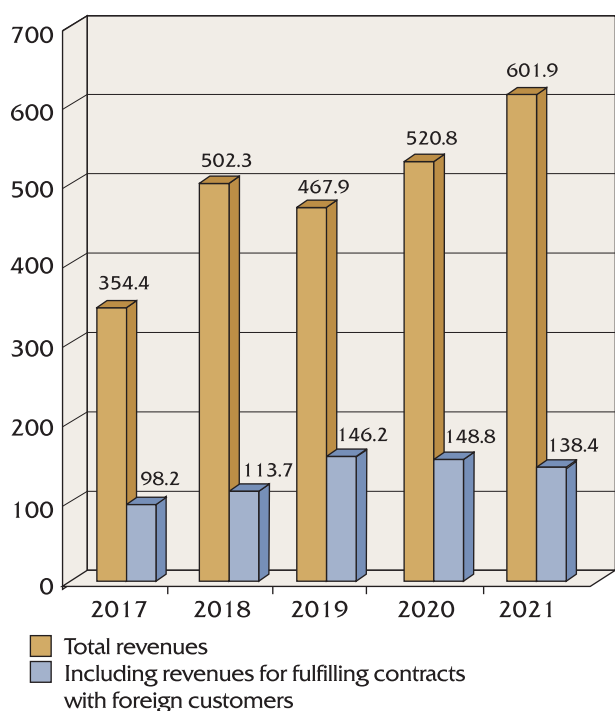
- On state industrial policy;
- On industrial parks of Ukraine;
- On the principles of state anti-corruption policy for 2021—2025;
- On Security Service of Ukraine;
- On state-supported targeted programs;
- On scientific and S&T expertise;
- On state support to families with children;
- On introducing amendments to the Law of Ukraine "On state support to business entities";
- On the main principles (strategy) of low-carbon development of Ukraine (Climate Law of Ukraine);
- On state environmental control;
- On introducing amendments to the Law of Ukraine "On the Red Data Book of Ukraine".

Expert conclusions	2017	2018	2019	2020	2021
Conclusions concerning normative legal acts and program documents, information and analytics materials on various issues of socio-economic development provided for state power bodies	2200	2320	2330	1850	1900
Conclusions concerning the expediency of carrying out basic research projects at the expense of the State Budget	393	378	428	1081	440

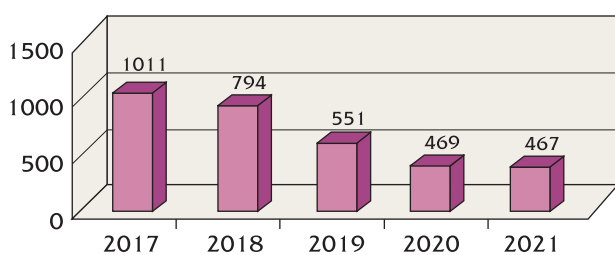
### Innovation activities



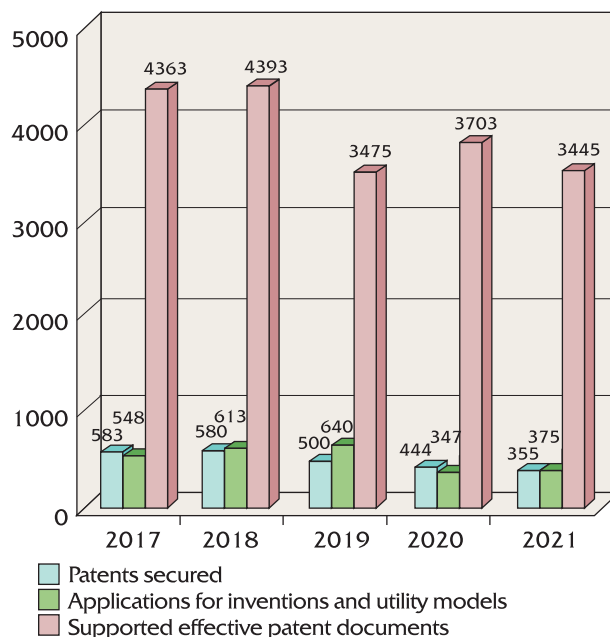
Economic agreements and contracts, the number



Revenues received by NAS institutions for fulfilling economic agreements and contracts, \$ million



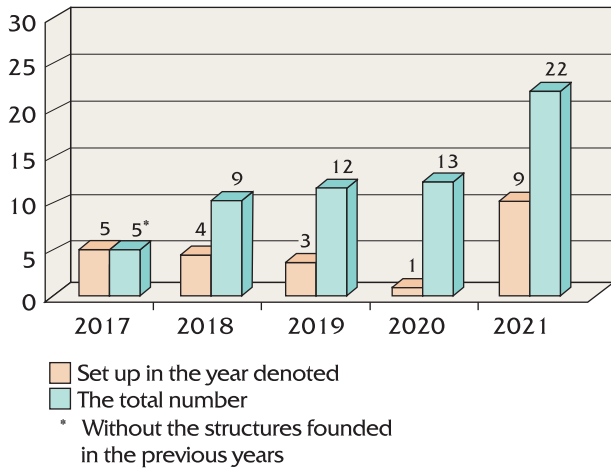
The number of implemented developments



Protection and use of intellectual property objects, the number

### Collaboration between institutions of higher education (IHE) and institutions of the MES of Ukraine

Collaboration agreements concluded by research institutions and IHE	217
Research topics and projects implemented collaboratively with academics	195
Published monographs co-authored with academics	117
Research scientists who worked in education:	1206
including:	
NAS academicians	47
NAS corresponding members	93
Published textbooks and manuals for institutions of higher education	97
Scientists at the head of chairs in IHE	60
Students of higher education institutions who pursued/are pursuing Master's degree programs at joint research-and-training agencies hosted by scientific organizations:	
in academic year 2020/2021	315
in academic year 2021/2022	328
Students who wrote their graduate papers at research institutions	798
Academics incorporated to specialized academic councils of research institutions	552
Scientists of research institutions incorporated to specialized academic councils of IHE	536



Joint research-and-training structures

Newly employed graduate specialists who attended study groups of the Junior Academy of Sciences in their school days 5

Research scientists and lecturers of IHE and MES organizations who upgraded their professional skills at research institutions 280

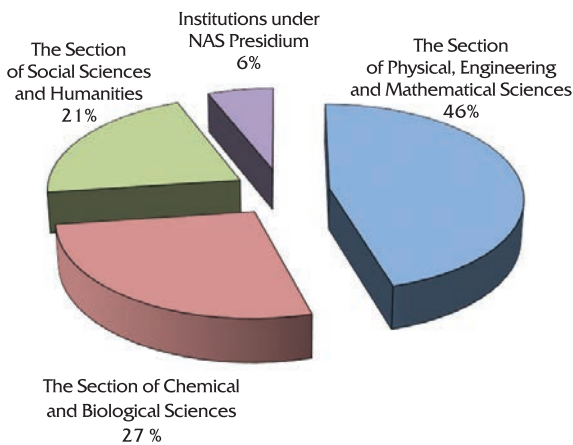
Theses of academics defended at specialized academic councils of scientific research institutions 143

**International ties**

**Legal contractual framework for the international collaboration of the NAS of Ukraine** (effective agreements, contracts, memorandums etc.) — the total of 139 documents.

**In 2021, the Academy signed:**

- Memorandum of the scientific and technological collaboration between the NAS of Ukraine and the Administrative Committee of Guangzhou High-Tech and New Technologies Zone (PRC).

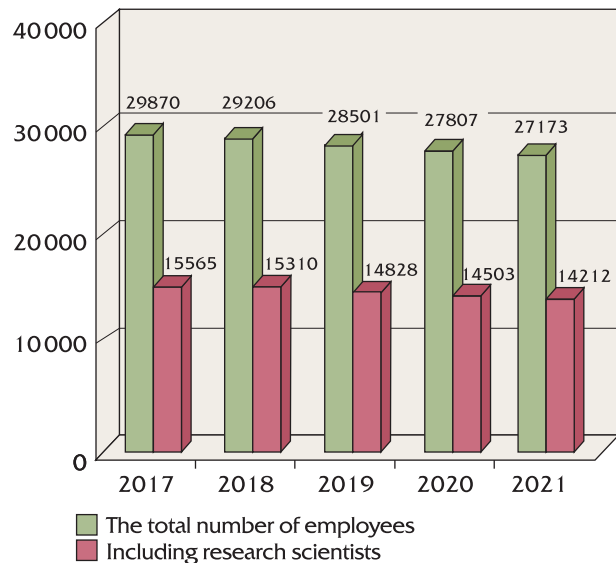


Distribution of direct agreements and contracts across the institutions of NAS sections

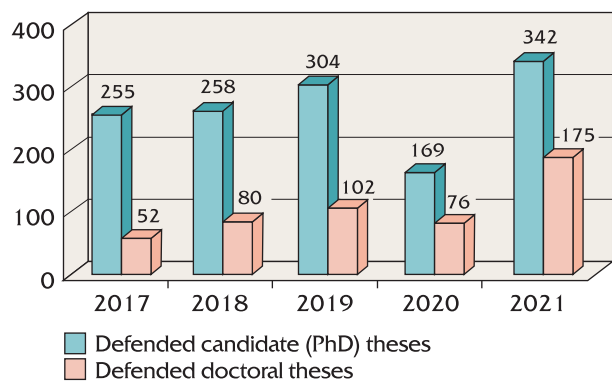
**Over 700 direct agreements and contracts**, concluded by NAS institutions with international partners are in force. Of them 321 — concluded by institutions of the Section of Physical, Engineering and Mathematical Sciences, 193 — by institutions of the Section of Chemical and Biological Sciences, 148 — by the Section of Social Sciences and Humanities, 43 — by institutions operating under the Presidium of the NAS of Ukraine

**Employment figures (as of 01.01.2022)**

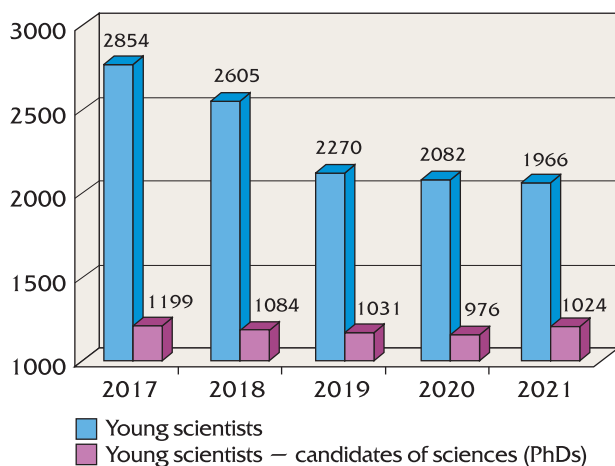
<b>The total number of employees</b>	27173
of them:	
in research institutions	25867
in research-and-production facilities	1033
in service organizations	227
<b>The number of research scientists</b>	14212
of them:	
doctors of sciences	2485
candidates of sciences (PhD)	6598
researchers without an advanced degree	5129
The number of young specialists recruited in 2021	281
The number of those who pursued post-graduate studies	1119
including full-time studies	977
Defended Candidate theses (including 55 PhD)	342
Doctoral fellowships	89
Defended doctor-of-science theses	175



The number of employees

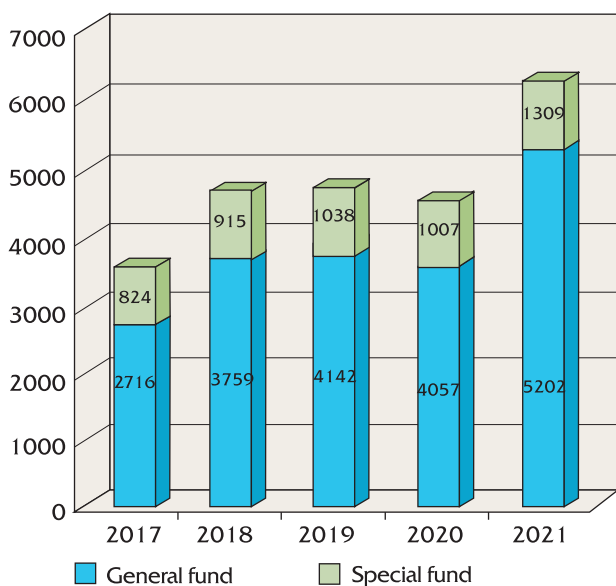


Training of scientific personnel, the number of people

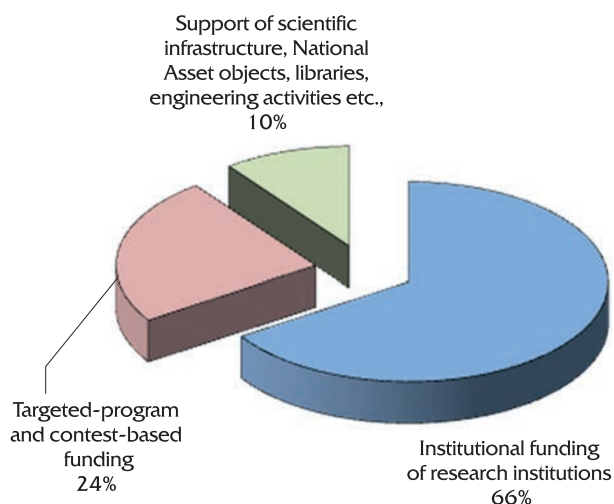


The number of young scientists

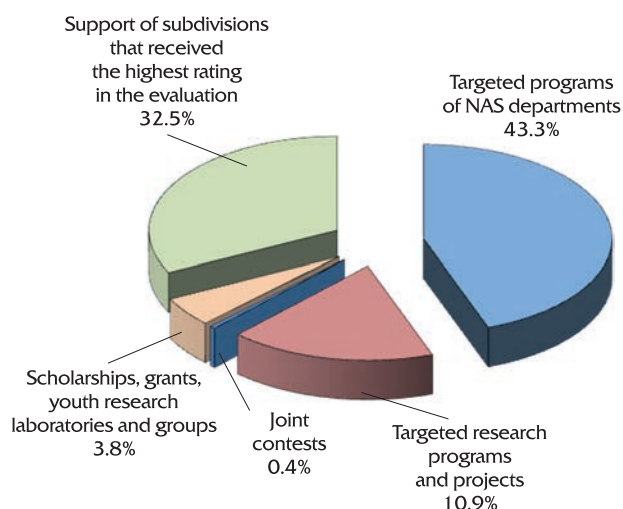
### Financial provision



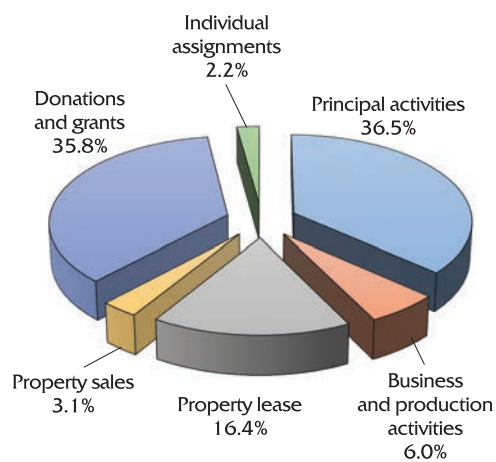
The total amount of NAS funding, € million



Distribution of general fund for conducting scientific research



Targeted-program and contest-based funding



Structure of revenues to the special fund