



NCBJ Highlights

2016-2017



NATIONAL
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FOR NUCLEAR
RESEARCH
ŚWIERK

Category A+ Polish Scientific Institution



GENERAL INFORMATION

GENERAL INFORMATION

The National Centre for Nuclear Research is a Polish research institute that is a state legal entity. It is supervised by the Minister of Energy and subsidized by the Ministry of Science and Higher Education.

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DIRECTOR'S WORD

Director's word

The last two years have brought to fruition the efforts of the NCBJ team to ensure the success of the merger of the former Institute of Atomic Energy POLATOM with the former Andrzej Soltan Institute for Nuclear Studies in 2011. Participation in challenging R&D projects, expansion of the research infrastructure, an increase in the number of young, talented researchers and successful international and industrial collaborations have all contributed to the recognition of NCBJ as a leading research institution. In 2016, NCBJ was placed 10th in southern and eastern Europe in the "Nature Index Rising Stars" ranking. In 2017, as one of the few Polish research institutions, we received the highest A+ category in the assessment of the Ministry of Science and Higher Education. I hope that the brochure you hold in your hands will convince you that these high marks are fully deserved.

KRZYSZTOF KUREK
Director of NCBJ



NCBJ PERSPECTIVES FOR THE NEXT 10 YEARS

The National Centre for Nuclear Research is a leading research centre for basic and applied research, including interdisciplinary research, a centre of high European interest with a unique large research infrastructure. Research at NCBJ focuses on various aspects of ionizing radiation and related fields such as:

- ▶ Nuclear physics, high energy physics and particle physics, astrophysics, plasma physics and thermonuclear fusion;
- ▶ Materials physics, including both basic and applied research, focused on materials exposed to high levels of radiation, high temperatures or other destructive factors, and using nuclear physics methods to modify materials;
- ▶ Biophysics and biochemistry of radiopharmaceuticals, their design and research;
- ▶ Computer modelling of high complexity systems, design of materials, analysis of large, diverse data sets.

NCBJ develops and complements its competences through active collaboration with leading global and European research institutions both in terms of infrastructure construction and participation in experiments in international teams using this infrastructure. Examples of current research include work at CERN's European Laboratory for Particle Physics in Geneva, astrophysical experiments: sky surveys conducted in ground and space experiments, gravitational waves (LIGO / VIRGO), and neutrino experiments in Japan.

At the same time NCBJ seeks to achieve the status of Europe's most recognizable centre for nuclear and reactor technology development and fusion technology based on local European research infrastructures.

FOR THE ECONOMY

NCBJ actively co-operates with industry based on the close association of basic and applied research and new technologies and infrastructures. As a centre for nuclear research it offers services unique in the marketplace whether with analyses using X rays, electron beams, or radioisotope production. Research and implementation capacities are supplemented by the Science and Technology Park and the ecosystem of special purpose and employee companies. Research initiatives carried

out jointly with industry or focused on the demands of industry include such fields as:

- ▶ Design and testing of materials for use in high temperature, corrosive or radiation environments and for use in the nuclear, chemical or machine industries;
- ▶ Development, research into and production of radiopharmaceuticals;
- ▶ Development of accelerator and detector technologies for a wide range of applications: medical therapy and diagnostics, industrial radiography, border control and for innovative research infrastructures;
- ▶ Materials and R&D studies related to the development of fourth generation nuclear reactor technology, including HTR high temperature reactors, GFR gas-cooled reactors, nuclear cogeneration and thermonuclear fusion.

NCBJ is developing its competence in the field of industrial security research for electronic and information systems, in particular for key industrial infrastructures.

The economic effects of research and development and cooperation with industry can be realized in a variety of ways, responding to market requirements: from NCBJ's own production (as for example in OR POLATOM) to commercialization in cooperation with entrepreneurs, for example under licenses.

FOR THE COUNTRY

Because of its unique research infrastructures and specific competencies, NCBJ can support state institutions in carrying out key tasks connected with state innovation policy. In such a role NCBJ may provide:

- ▶ Expert Advisors for the TSO: Technical & Scientific Support Organization, providing comprehensive safety analyses for the Nuclear Energy Programme;
- ▶ Advanced training of personnel for state and national administration and institutions, in the domains of nuclear medicine, nuclear power and risk modelling and risk mitigation;
- ▶ Central competence in technology for the detection and control of goods at national borders;
- ▶ A high-power computation centre and technical facilities for tasks related to modelling of energy systems, ecological and industrial disasters.



Detection of gravitational waves: Algorithms and methods, modelling of the signal

Gravitational waves, in common with black holes, are solutions of Einstein's equations. Albert Einstein predicted the existence of gravitational waves in 1916, by linearization of the equations. However, for several years there were doubts as to whether gravitational waves are a real physical effect. Only a thorough analysis of Einstein's equations in the late fifties and sixties of last century showed that they allow gravitational radiation. Following this result, work began on the direct detection of these waves.

On 11th February 2016 the first direct detection of gravitational waves was announced. The detection was made on 14 September 2015 by the two detectors of the Laser Interferometer Gravitational wave Observatory – LIGO. The signal, registered in both detectors, is in perfect agreement with the signal of gravitational waves coming from the merger of a black hole binary with masses of 29 and 36 solar masses. In the following months two more registrations were made. On August 1 2017 VIRGO, the European detector of gravitational waves, officially joined Observational Run 2 to acquire data jointly with the two US-based LIGO detectors. All three detectors recorded a gravitational wave for the first time on August 14 2017. Three days later, scientists directly detected gravitational waves in addition to the light from a spectacular collision of two neutron stars. For the first time in history a cosmic event was observed both in gravitational waves and in light. A new scientific discipline was born - gravitational wave astronomy.

Employees of NCBJ - members of the POLGRAW research group - developed the foundations of

many of the algorithms and methods used to detect and estimate the parameters of gravitational waves from binary systems (Prof. dr hab. Andrzej Królak), contributed to the precise modelling of the signal of gravitational waves from compact binary systems (Prof. dr hab. Andrzej Królak), and searches for optical counterparts to gravitational waves (Dr. Adam Zadrożny). Andrzej Królak is a board member of the Virgo project and member of the Data Analysis team of the LIGO-Virgo Consortium. He contributed to the publication of the discovery. Dr. Adam Kutynia contributed to the development of the Virgo detector and Dr. Orest Dorosh is contributing to the search for gravitational waves from rotating neutron stars.

On October 3 2017 the Royal Swedish Academy of Sciences decided to award the Nobel Prize in Physics 2017 to Rainer Weiss, Barry C. Barish and Kip S. Thorne (all from the LIGO/VIRGO Collaboration) "for the decisive contribution to the LIGO detector and the observation of gravitational waves."

Members of the POLGRAW team who are co-authors of the publication of the discovery were honoured in 2016 by the Copernicus Medal of the Polish Academy of Sciences, the Rubinowicz Medal of the Polish Physical Society (team award), the Gruber Cosmology Prize and the Special Breakthrough Prize of the Milner Global Foundation. The Special Breakthrough Prize and the Gruber Prize were awarded to 1,015 scientists and engineers contributing to the detection of gravitational waves announced in February 2016.



Related highlight research:

The Quantum Mixmaster universe: no need for cosmological inflation?

The Quantum Mixmaster universe, a spatially homogenous cosmological model of general relativity, exhibits rich behaviour on the approach to the big-crunch/big-bang singularity. It describes a non-linear gravitational wave coupled to an isotropic background. The singularity of the Mixmaster universe can be resolved via affine quantization. A repulsive potential that issues from this quantization procedure generates a bounce, which replaces the classical Big Bang singularity. The studies in Refs. [1,2] extend the analysis of the quantum Mixmaster dynamics to the nonadiabatic

regime. They provide a complete and consistent set of equations of motion for the quantum Mixmaster universe within the so-called vibronic framework. A numerical study shows that the contraction and expansion phases are adiabatic, whereas the bounce can be nonadiabatic and excite anisotropy oscillations. The anisotropy oscillations can in turn produce an extended phase of accelerated expansion following the bounce which can last arbitrarily long. This finding suggests that perhaps one could reproduce the predictions of inflationary models without postulating the existence of inflation.

Related Activity:

International conference: Singularities of general relativity and their quantum fate

The conference was organized by NCBJ in Warsaw from 27 June to 1 July, 2016, together with the Institute of Mathematics of the Polish Academy of Sciences. 50 scientists discussed various aspects of

spacetime singularities: in particular both analytical and numerical treatments, both classical and quantum behaviour of spacelike, null, and timelike singularities.





VIPERS 3D map of the Universe: Studies of spectral lines, shapes and application of self learning sorting algorithms

VIPERS is the largest survey in history of galaxies at distances of at least 5 billion light years. The VIMOS multi-spectrograph mounted on one of the four 8.2-metre Very Large Telescopes operated in Chile by the European Southern Observatory (ESO) acquired data for nearly 8 years. Operating one of the largest telescopes on Earth for almost 500 hours, astronomers determined the distances of nearly 90,000 galaxies and learned their properties. The acquired data helped to chart the first detailed 3D map of that region of our Universe which is from 5 to 9 billion light years distant from us. Today we are looking at objects as they were when the Universe was half its present age.

The ESO telescopes were never involved in a galaxy survey bigger than VIPERS. The acquired information has helped scientists to understand how different types of galaxies and their stellar populations were and are evolving. Information on the distribution of galaxies helps to shed some light on the large-scale structure of the Universe composed of dark matter, and on the nature of dark energy, which makes the Universe expand at an ever increasing velocity.

Scientists from Poland involved in the project included Professor Agnieszka Pollo (Jagiellonian University in Cracow and NCBJ), Dr. Katarzyna Małek and Dr. Aleksandra Solarz (NCBJ), Dr. Janusz Krywult (the Jan Kochanowski University in Kielce) and Dr. Małgorzata Siudek (Center for Theoretical Physics Polish Academy of Sciences). Master's and PhD students from the Jagiellonian University

also participated. Polish team members studied in particular spectral lines in light emitted by the surveyed galaxies and the shapes of these galaxies. The results have proven that the distinction between the two main types of galaxies observed today (spiral galaxies, in which new stars are still created, and inactive elliptical galaxies composed of old stars) already existed when the Universe was half its present age. However, one part of the objects was still changing – a population of massive blue galaxies which turned red and changed their shapes somewhere between 6 and 7 billion years ago. These are likely the progenitors of today's lenticular galaxies. In addition, self-learning algorithms were adapted to sort the observed galaxies into various types – a very useful tool in the era of ever larger surveys of the sky – and the formation and evolution of the stellar population of red passive galaxies over the last 8 billion years were studied.

The VIPERS-produced map of the Universe shows compact large structures with collections of red (i.e. old) galaxies. Blue (active) galaxies dominate in the less crowded regions, just like in the present-day Universe which is almost 14 billion years old. It appears that all the basic galaxy types were already shaped in the much younger Universe. Cosmological measurements indicate that the cosmological constant remains the most likely explanation of the accelerated expansion of the Universe. Scientists hope that further analyses of the VIPERS data will bring other breakthrough results.



Related highlight research:

Machine-learning identification of galaxies

The two currently largest all-sky photometric datasets, WISE and SuperCOSMOS, were cross-matched to construct a novel photometric redshift catalogue of 70% of the sky. Usually galaxies are separated from stars and quasars through colour cuts, which may leave imperfections due to mixing of different source types which overlap in colour space. For the automated classification a support vector machine learning algorithm was used, employing SDSS spec-

troscopic sources cross-matched with WISExSuperCOSMOS as the training and verification set. The classifier was applied to the full-sky data and analysed the resulting catalogue of candidate galaxies. Application of the classifier to the all-sky WISExSuperCOSMOS data gives 15 million galaxies after masking problematic areas. The resulting sample is purer than that obtained with a simpler colour-based method, at the price of lower completeness over the sky.

Related highlight research:

Self-learning algorithm finds new extragalactic populations of sources

A novelty detection algorithm belonging to the type known as one-class support vector machines (OCSVM) has been applied to searches for anomalous patterns among sources preselected from the mid-infrared AllWISE catalogue covering the whole sky. It detects as anomalous those sources whose patterns - WISE photometric measurements in this case - are inconsistent with the expected data model, which was created by teaching the algorithm on a set of objects with spectroscopic

identifications from the SDSS database DR13, also present in AllWISE. Both previously undetected artefacts, such as objects with spurious photometry due to blending, and real sources of genuine astrophysical interest were found among the anomalies detected. OCSVM has identified a sample of heavily reddened AGN/quasar candidates distributed uniformly over the sky. It also enabled the detection of a specific group of sources of mixed types, mostly stars and compact galaxies.



T2K study of neutrino oscillations: Reducing errors, investigating the beam

T2K is a long baseline experiment using an (anti)neutrino beam sent from the J-PARC laboratory to Super-Kamiokande, a huge water Cherenkov detector. T2K is designed to probe precisely neutrino mixing parameters through measurement of oscillations of muon (anti)neutrinos. Currently running and planned experiments aim at the close investigation of the three-flavour oscillation paradigm, searching for CP violation in the lepton sector and measurements of the (anti)neutrino cross sections. In 2017, with nearly twice the neutrino data compared to their 2016 results, T2K performed a new analysis of neutrino and antineutrino data using a new event reconstruction algorithm for interactions in the far detector, Super-Kamiokande (SK). The analysis rejects the hypothesis that neutrinos and antineutrinos oscillate with the same probability at 95% confidence (2σ) level.

T2K uses a very pure muon (anti)neutrino beam produced using the accelerator complex at Tokai and sent towards the SK detector 295 km away. The experiment studies both disappearance of muon (anti)neutrinos and appearance of electron (anti)neutrinos thanks to the excellent capability of distinguishing the interactions of muon and electron neutrinos using the topology of the Cherenkov ring in the SK sector.

The NCBJ group is involved in the analysis performed by one of two Near Detectors located 280m from the neutrino production point which measure the unoscillated beam. The off-axis Near Detector, called ND280, is a multi-purpose magnetized detector able to measure the spectrum and flavour composition of the beam. ND280 provides samples of events enriched in different neutrino reaction types and sampling different neutrino energy ranges. Such samples are then used in the fit of the (anti)neutrino energy flux and cross section parameters used in models of neutrino interactions in Monte Carlo simulations. In this analysis the NCBJ group is responsible for the estimation of the external background and some of the systematic errors related to the ND280 detector. As a result of our efforts the systematic errors in the oscillation analysis have been reduced by a factor of 2. The group is also working on the measurement of cross sections for several (anti)neutrino interaction channels.

NCBJ scientists are also involved in experimental studies of hadron production in proton-carbon interactions at 31 GeV/c measured by the NA61/SHINE experiment at the CERN SPS aimed at improving the precision of calculations for the initial (anti)neutrino beam flux in T2K.



Highlight research:

Impact factor for dijet photoproduction

The impact factor for the dijet photoproduction transition has been calculated with one loop accuracy in arbitrary kinematics. The calculation was done within Balitsky's high energy operator expansion. Together with our previous result for the Born impact factor for dijet plus gluon photoproduction, it allows one to derive cross sections for 2- (one loop) and 3-jet (Born) diffractive electroproduction. Such cross sections for the 2 and 3 jet exclusive

diffractive electroproduction from a proton have been written in terms of hadronic matrix elements of Wilson lines. For the 2-jet cross section it was demonstrated that a cancellation of infrared, collinear and rapidity singularities occurs. This result can be directly exploited to describe the recently analyzed data on exclusive dijet production at HERA and used for the study of jet photoproduction in ultra-peripheral proton or nuclear scattering.

Highlight research:

Nonextensive Critical phenomena in the Nambu Jona-Lasinio model

Mutual interactions in dense nuclear matter (NM) have a long-range nature leading to correlations which become important with the increase of density and persist above the temperature of the phase transition from hadron matter to quark-gluon matter. One may distinguish two physical systems in which knowledge of the nuclear Equation of State for a density several times larger than the density of atomic nuclei is significant: the interior of neutron stars and high-energy scattering of heavy ions. Higher density and higher temperatures of NM occur in the scattering of heavy ions, where quarks and gluons are the basic degrees of

freedom of the description NM. Such a strongly correlated system can be well described using the nonextensive Tsallis statistics approach. The main result is the presentation of differences between the Nambu-Jona-Lasino calculations with different arrangements (entropies) of the quark system. With a better ordering there is smaller entropy of the quark system and NM is characterized by a lower pressure in the critical area. The expected phase transition is smoother compared to the system of higher entropy in which changes of such critical parameters, like specific heat or baryon susceptibility, have a more singular course.



Adiabatic fission barriers in superheavy nuclei

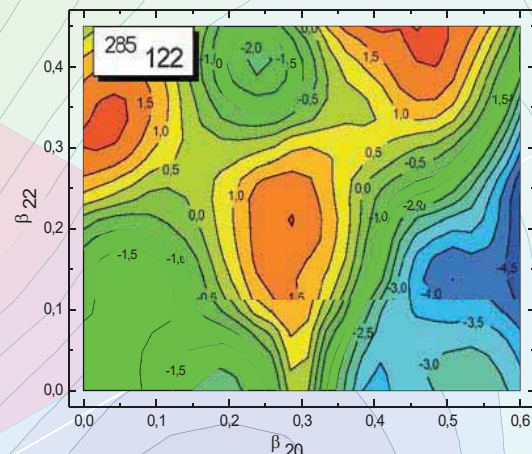
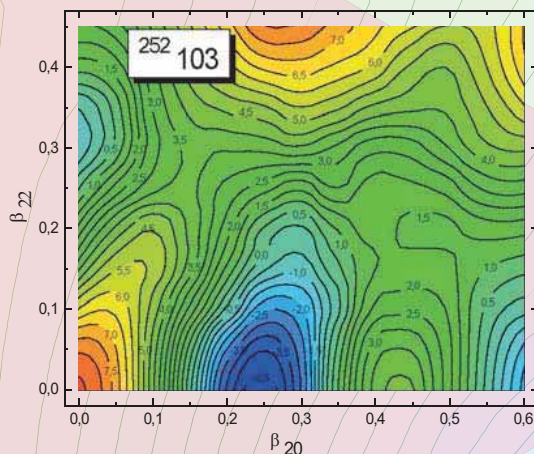
Although fission barrier heights are not directly measurable quantities they are very useful in estimating nuclear fission rates. The fission barrier gives the fission rate of an excited nucleus (as is usually the case in nuclear reactions). For example, knowledge of the fission barriers of possible fusion products helps in predicting the cross section for production of a given evaporation residue in a heavy ion reaction: one can determine whether neutron or alpha emission wins the competition with fission at each stage of the deexcitation of the compound nucleus. Moreover, one can try to understand the - experimentally established - intriguing growth of the total cross sections around $Z=118$.

Using the microscopic-macroscopic model based on the deformed Woods-Saxon single-particle potential and the Yukawa-plus-exponential macroscopic energy we calculated static fission barriers B_f for 1305 heavy and superheavy nuclei $98 \leq Z \leq 126$, including even-even, odd-even, even-odd and odd-odd systems. For odd and odd-odd nuclei, adiabatic potential energy surfaces were calculated by a minimization over configurations with one blocked neutron or/and proton on a level from the 10-th below to the 10-th above the Fermi level.

The parameters of the model - fixed previously by a fit to masses of even-even heavy nuclei - were kept unchanged. A search for saddle points was performed by the "Imaginary Water Flow" method on a basic five-dimensional deformation grid, including triaxiality. Two auxiliary grids were used to check the effects of mass asymmetry and hexadecapole non-axiality. The ground states were found by energy minimization over configurations and deformations.

It was found that non-axiality significantly changes the first and second fission barriers in many nuclei. The effect of the mass-asymmetry, known to lower the second, very deformed barriers in actinides, in the heaviest nuclei appears at the less deformed saddles in more than 100 nuclei. This occurs for saddles where the triaxiality does not play a role, which suggests a decoupling between the effects of mass-asymmetry and triaxiality. The influence of the pairing interaction strength on the staggering of B_f was also studied for odd- and even-particle numbers.

The results have been compared with other theoretical fission barrier evaluations and with available experimental estimates.





Research highlight:

Hot CNO chain study

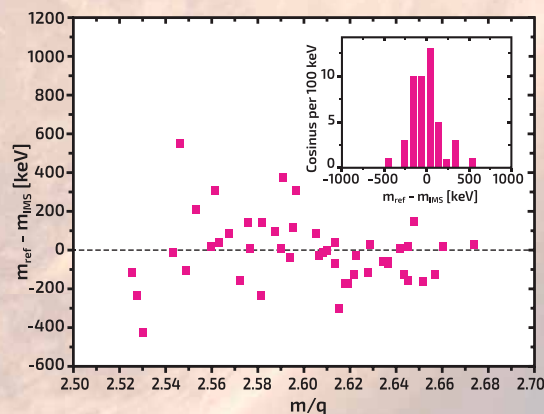
The carbon-nitrogen-oxygen (CNO) cycle is one of the fusion reaction chains by which stars convert hydrogen to helium. The hot CNO cycle occurs under conditions of higher temperature and pressure (novae, x-ray bursts). The $^{15}\text{O}(\alpha, \gamma)^{19}\text{Ne}(p, \gamma)^{20}\text{Na}$ reaction chain is an important break-out path from the hot CNO cycle, after which the rapid proton capture process can progress freely in a sequence of (p, γ) captures and β^+ decays. The spectrum of the low-

est proton-unbound states in ^{20}Na has been investigated experimentally (RESOLUT, FSU) in an effort to resolve contradictions in spin-parity assignments and extract reliable information about the thermal reaction rates. Three proton resonances with the ^{19}Ne ground state were observed and two with the first excited state. These observations allow the astrophysical reaction rate on an excited nuclear state to be quantified experimentally for the first time.

Research highlight:

Mass measurements of stored neutron-rich $^{129,130,131}\text{Cd}$ isotopes

The high sensitivity and selectivity of the method have given access to nuclides detected with a rate of a few atoms per week. Mass values for the $^{129,130,131}\text{Cd}$ isotopes were directly measured for the first time. The experimental mass values of cadmium as well as for tellurium and tin isotopes show a pronounced shell effect towards and at $N=82$. Shell quenching cannot be deduced from new mass values, nor by a better agreement with a theoretical model which explicitly takes into account a quenching feature. This is in agreement with the conclusions from γ -ray spectroscopy and confirms modern shell-model calculations.





European XFEL: Control and diagnostic parts, electronic systems

The European XFEL free electron laser is one of the largest research facilities in the world.

The facility, located at the Deutsches Elektronen Synchrotron (DESY) research centre in Hamburg, Germany, will generate ultra-short pulses of laser light of intensity billions of times higher than beams emitted by the best conventional sources of X rays. The project began in 2009 when a cooperation agreement was signed by 12 European countries. It is expected that European XFEL, a powerful new free electron laser, will open up many research opportunities for scientists and industrial researchers working in such fields as biology, medicine, development of new materials and environmental protection.

The Polish in-kind contribution has been estimated at 19 million Euro; more than 96% of the goods and services have already been delivered by research institutes and companies from Cracow and Wroclaw, as well as by NCBJ. NCBJ, a formal shareholder of the European XFEL GmbH company responsible for the development and subsequent operation of the European XFEL facility, coordinated all Polish deliveries.

NCBJ designed, coordinated the manufacture of, tested and delivered 1,700 couplers of higher

modes of the high frequency field within the superconducting resonators of the European XFEL accelerator, 850 field diagnostics antennas with external waveguides to be deployed inside the superconducting resonators (the so-called pick-up antennas), and 108 high frequency field mode absorbers whose task is to eliminate propagation of higher harmonics. The value of the deliveries amounted to more than 3.5 million Euro.

NCBJ also delivered 200 electronics modules for control circuitry to be deployed within the optical line / research stands area. The value of this contract amounts to 741,000 Euro. In July 2016 NCBJ reached another agreement with DESY on further cooperation in the development of European XFEL, mutual exchange of experience, and the projected use of the facility.

Development of the European XFEL laser infrastructure was finished in 2016; the start up process commenced immediately afterwards. The first beam is expected in 2017. Fascinating new research avenues that should be made possible by European XFEL include visualization of the detailed structures of viruses, observations of the molecular mechanisms that govern the functioning of living cells, recording video sequences showing how chemical reactions proceed.



New project:

In-kind contribution to the European Spallation Source

The European Spallation Source (ESS) which is now under construction in Lund (Sweden) will be the largest spallation-based source of neutrons in the world. In 2016 NCBJ began participation in this project. Up to the present time our scientists and engineers have been involved in the development of the electronics used to control the accelerating field in the ESS proton accelerator and have performed calculations essential for radiation protection. New fields of cooperation are planned. This

work forms part of the Polish in-kind contribution to the project.

The first ESS neutrons are scheduled for 2019. It is expected that beams of highly-energetic neutrons will help to discover important new phenomena in nanotechnology, pharmacology, materials science, the power industry, experimental physics and nuclear physics. Their availability will also be a milestone in the implementation of sub-critical nuclear reactors.



Accelerating structures for Linac 4 @ CERN

Linac 4, a nearly 90 m-long new linear accelerator, was designed to produce and initially accelerate particles subsequently fed to further accelerators of which the entire Large Hadron Collider facility is composed.

Linac 4 is composed of four accelerating stages that accelerate particles to higher and higher energies. The final stage is composed of 12 accelerating Pi-Mode Accelerating Structures (PIMS) which were constructed in a collaboration between CERN, NCBJ and FZJ started in 2011. While traversing this stage the particles gain energy from 102 MeV to 160 MeV. Each of the 12 accelerating structures is 54 cm in diameter and roughly 150 cm long. Each structure houses 7 resonating cavities carefully fabricated at NCBJ. 300 MHz microwaves propagating through the cavities accelerate bunches of charged particles traversing the cavities along their axes.

Several highest-level competences were needed to accomplish the Linac4 design requirements. Our CNC machines have machined 26 tons of copper to high accuracy reaching 20 microns. Similar precision was needed in various other operations, including the vacuum brazing of 12 input power resonators, each of a diameter exceeding 50 cm. Key operations were accomplished by operators wearing white latex gloves in order to exclude the pos-

sibility that any dirt deposited from their hands might change the electrical parameters of the work pieces being produced and/or the processed surfaces. Each of the manufactured components and the whole structure were extensively tested (metrology, vacuum, ultrasound, electromagnetic properties). It was very satisfying to learn in October 2016 (when the first Linac 4 run took place) that all the elements produced by NCBJ were working well and in perfect cooperation with the upstream structures of the Linac 4 machine.

The buncher, one of the first LINAC 4 structures, is another contribution made by NCBJ scientists and engineers to the development of the machine. The object of the buncher is to group particles into bunches which are then accelerated in subsequent stages of the machine. The use of PIMs would not be possible without the buncher.

Linac 4 will begin regular operations after the long technical break in LHC operations, planned for 2019-2020. It will accelerate hydrogen ions up to 160 million electron-volts kinetic energy, i.e. to an energy more than three times as high as the energy achievable by its predecessor, the forty-year-old Linac 2. At the same time the density of particle bunches will be increased by more than a factor of two, which will help the LHC detectors to acquire more data from the studied collisions.



New project:

QUACO @ CERN

The LHC will need a major upgrade in the 2020s to increase its luminosity by a factor of five beyond its design value. To fulfill these ambitions, the LHC needs new magnetic technologies that are not even being considered by commercial suppliers due to their novelty and low volume production. The QUACO project draws together several research infrastructures with similar technical requirements in magnet development. The partners in QUACO (CERN, CEA, CIEMAT and NCBJ) will act as a single buyer LHC group and the pre-commercial procurement (PCP) instrument will be used in order to develop and acquire the prototypes of

quadrupole corrector magnets for HL-LHC. NCBJ joined the consortium from its very beginning in early 2016 as one of the procuring agencies. NCBJ will contribute during the different phases with its specific know-how in precision mechanical engineering and in accelerators for medical applications to the follow-up of the production of the prototype magnets and in doing so will develop new in-house competence in superconductivity. We are the leader of WP7 "Pilots Evaluation and Recommendation." The QUACO project has received funding from the European Union's Horizon 2020 PCP programme under Grant Agreement no. 689359.



BIG SCIENCE BIG FACILITIES

Computing Centre Świerk (CIŚ) LHCb@CERN Tier-2



ŚWIERK COMPUTING CENTRE

The computing infrastructure of CIŚ consists of a 1 petaflop CPU and GPU cluster and 17 petabyte of disk storage. It is connected to the outside world by a redundant 10 Gbps link. Part of the processors are cooled using warm water, thus ensuring high power efficiency and environmental friendliness. The cluster is connected to three independent power lines and, in addition, has its own diesel generator, thus ensuring support of service machines in case of power cuts. The centre is located in a well-secured building with electronic security and fire control.

The staff pursue many projects in basic and applied science and engineering and are involved in a number of collaborations worldwide. In fundamental science these are: grid-computing support for CERN experiments in particle physics, LHCb and CMS at the Large Hadron Collider (Tier-2 level), astrophysics projects in extragalactic astronomy and high-energy astrophysics. In 2016 the CIŚ Tier-2 grid cluster for LHCb was the largest one in Poland. It was the 6th Tier-2 site in the world based on the fraction of analysed data on behalf

of the LHCb collaboration. Throughout the year 2016, CIŚ provided 244 millions of CPU hours for the LHC experiments' computing needs.

The activities of CIŚ also include computational molecular chemistry in the domain of radiopharmaceuticals (a unique competence in Poland), medical diagnostics using PET (signal and image reconstruction and data processing) and medical diagnostics using machine learning methods for textual information.

The other fields are management of radioactive and chemical hazards in the atmosphere, soil and water (chemicals and suspensions), security analyses and design of new nuclear reactors (collaborations with many nuclear centres, including Euratom projects), energy distribution in power networks (government supported National Centre of Energy Analysis), as well as processing of geo-location data from lidar and computational fluid dynamics applied to real systems (e.g. helicopters and nuclear reactors).



For IT technologies CIŚ is involved in engineering of file systems, grid middleware DIRAC, web services and cybersecurity.



The computing centre also offers rendering of 3D images for visualisation as well as for entertainment movies (sponsorship programme with the Polish National Film Institute).

In 2016, employees of CIŚ published 290 papers in journals on the Philadelphia list, about half of them in journals with impact factor above 5.

The goal:

100 Gbps link from Hamburg to Świerk

In 2017 NCBJ and European XFEL GmbH signed a framework agreement on cooperation. As specified, storage and processing of experimental data will be one of the major cooperation fields. Data acquired by international teams of researchers working at XFEL will be processed basically in two computer centres: the NCBJ Świerk Computer Centre (CIŚ) and the DESY Computer Centre in Hamburg. So far CIŚ has been processing data acquired

at the LHCb experiment run at CERN (Geneva). The stream of data from Hamburg is likely to be even larger, and will probably come in much larger packets. This calls for a larger bandwidth link between Świerk and PIONIER, the Polish optical Internet network. Therefore, one of the key tasks that must be accomplished to carry out the agreement will be to increase the link bandwidth. Scientists expect the bandwidth to reach 100 Gbps by the end of 2018.



New generation plasma source developed in Świerk

IBIS 2, a world unique plasma source developed at NCBJ, has started operation. The device opens up new development paths in pure research into high temperature plasmas, as well as making it possible to modify the surfaces of engineering materials for applications in technology in innovative ways.

Very high temperature (even as high as 100 million degrees) is an important feature of the plasmas generated by the IBIS 2 device. Also, intense turbulence in the plasma results in the generation of particles of even higher energies. The possibility of increasing the intensity of the plasma turbulence in order more cost-effectively to accelerate particles without the need to build and operate specialized accelerating structures will be one of the research topics to be studied. The device generates plasmas in high vacuum rather than in relatively dense gaseous media which is a very fundamental advantage, not featured in any of the other plasma generating devices operated elsewhere. Such conditions resemble those prevailing in deep space.

The interactions of plasmas with surfaces of solids at conditions far from thermodynamic equilibri-

um are another important field for future research based on IBIS 2. Such interactions usually produce modifications of surface properties unattainable with traditional methods. The topics explored at Świerk will include improvement of metal or ceramic surfaces and studies of materials that combine properties of semiconductor and ferromagnetic materials. Research is also aimed at improving methods for gluing together materials of different internal structures and considering other applications of intense pulsed ion-plasma beams.

The plasma source constructed and built at NCBJ is the seventh plasma-focus type research device created by scientists from Świerk in the last half century. It shows that Polish scientists do not confine themselves to purchasing equipment, but they can also develop their own original facilities.

Construction of IBIS 2 was part of the Development of Ionizing Radiation-Based Technologies project at NCBJ which was co-financed by the European Union from the European Regional Development Fund within the framework of the Regional Operational Programme for the Mazovia Voivodeship 2007-2013.



New superconducting photocathode Lab

The use of superconducting photocathodes avoids many technical problems associated with the presence of classic hot cathodes in a cryogenic environment. This is particularly important in the construction of superconducting free-electron lasers such as XFEL. A new laboratory dedicated to the study of supercon-

ducting photocathodes was created within the NCBJ Plasma/Ion Beam Technology Division. The installed equipment allows for laser smoothing of the surfaces of materials under test (in particular lead), which can then be accurately examined for the quantum yield of electron photoemission in ultraviolet radiation.

Highlight research:

Copper nitride unconventionally

Copper nitride (Cu_3N) is a metastable semiconductor which is an attractive material with vast application potential. The narrow range of its thermodynamic stability makes it decompose into metallic copper and nitrogen at 100-470°C. Decomposition can occur in a controlled manner, e.g. it can be induced by irradiation with electron and laser pulses. The Cu_3N then becomes a precursor for a complex structure composed of precipitates of metallic copper in a semiconducting matrix (Cu_3N).

Using specially constructed unique equipment scientists from NCBJ deposited Cu-N layers on

unheated substrates using plasma surface engineering techniques: pulsed magnetron sputtering (PMS) and the gas injection sputtering method (GIMS). On the basis of measurements of the Raman shift, X-ray diffraction and other studies, the researchers were able to classify the obtained coating material in terms of morphology, chemical and phase composition. They studied how various conditions of frequency modulation affect the mechanism of layer growth. The results obtained provide a way to optimize the synthesis of layers in an implementation based on the PMS and GIMS methods.



Advanced analyses for the energy market and energy distribution systems

Research conducted at NCBJ in the field of power systems both in Poland and in Europe is based on the computing power available in NCBJ's computer centre (CIŚ) and on the competences of analysts working in the Interdisciplinary Division of Energy Analyses (IDEA).

The National Centre for Power System Analyses (NCAE) is a research/industrial institution established in April 2016 with participation by the PSE Innowacje company and NCBJ/IDEA. The mission of the Centre is to support strategic initiatives for Poland to develop new regulations concerning both national and pan-European energy markets. Tasks of the Centre include the development of tools needed to prepare sound and fair socio-economic analyses as background for "policy papers" to be worked out by the ordering parties.

Some advanced solutions targeted at the energy markets have been devised within the framework of research conducted by both NCAE and NCBJ.

They include innovative functional solutions for the Demand Side Response service delivered by energy consumers acting for the benefit of the entire power system; the service helps to balance the system without the need to construct new power sources.

Possible ways in which the future pan-European energy market might be divided into several zones are studied. Two of the studied variants deal with clustering procedures developed at NCBJ. One is based on power grid topology and Energy prices in individual grid nodes (the LMP method), the other on commercial flows / grid properties (the PTDF method).

Energy market analyses and studies conducted at NCBJ are focused on several topics, including profitability of projects aimed to increase interconnection capacity, ability of the Polish system to meet national demand for power in subsequent years, mutual interaction of solutions implemented better to control energy flows, and optimization of the solutions.



European projects

NCBJ/IDEA participate in the LitPol Link project (Cost benefit analysis of the consequences resulting from the installation of a second back-to-back converter on the Polish-Lithuanian interconnection) and the SysFlex-H2020 project (a Pan-Eu-

ropean system with efficient coordinated use of flexibilities for the integration of a large share of RES). In the latter project IDEA is responsible for the development of PST, XBR and RMA coordination mechanisms and cost sharing methodologies.

AXA project

The original project "Protecting Power Supply with Better Risk Management" was the winner in an AXA company-organized contest. The project objective is to develop a methodology capable of estimating risks on the basis of continuously mon-

itored operating points of the power units in question. It is expected that an optimization methodology based on current readings of active/passive power generated by the units will be developed and implemented.

IAEA project:

CyberLAB – a PLC testing laboratory for the energy industry

The research contract "Testing of PLCs used in nuclear installations by Bug Fuzzing Search for Cyber Vulnerabilities" was started at Świerk as part of the IAEA Coordinated Research Project "Enhancing Computer Security Incident Analysis at Nuclear Facilities." It is based on active testing of Programmable Logic Controllers (and their software environment) by a combination of various Bug Fuzzing methods. PLCs often control various crucial hard-

ware used in nuclear installations and are prone to cyberattacks. NCBJ scientists have built a dedicated test-bed and will test the vulnerability of typical PLCs and study their response under heavy attack, trying to determine corresponding criteria and limits. The current project will also develop the concept of a full scale laboratory to test cybersecurity of PLCs used in emerging NPPs and energy sector installations.



BRILLIANT: **Baltic Region Initiative for Long Lasting InnovActive Nuclear Technologies**

Building new NPPs affects the whole region not only in the technological but also in the macroeconomic field. Different levels of nuclear safety and radiation safety knowledge and different R&D infrastructures exist in the countries of the Baltic Sea Region. BRILLIANT – a H2020-EURATOM project continued in 2016 – was developed to create a cooperation platform for modern electrical power solutions. The project will support the exchange of knowledge, competence and infrastructure between the countries of the Baltic Region – Estonia, Latvia, Lithuania, Poland and Sweden. Hitachi-GE, developer of the ABWR reactor, is an industrial partner in the project providing valuable insights and information.

The main objective of the BRILLIANT project is the identification of barriers to nuclear power development in the countries of the Baltic Region and the preparation of the ground for overcoming them. Regional cooperation will enable development of synergies with on-going and future EURATOM projects, in particular those offering access to research infrastructures in conjunction with education and training. The project addresses the issues surrounding the building of nuclear R&D capacity in the region, Regional cooperation on education and training, nuclear waste treatment and the fuel cycle, NPP in-

tegration in relatively small power systems, Nuclear energy influence on national and regional security of energy supply, Macroeconomic impact of nuclear programmes, public awareness of the benefits deriving from nuclear energy and from the creation of a strong local and regional basis for the development and use of new technologies.

The tasks of NCBJ within the programme concentrate on Nuclear Research Capacity building. The Institute is responsible for an analysis of the existing research potential in the Baltic Region and the development of research capabilities: we are preparing an inventory of the existing research infrastructure and associated access rules, working on the concept of as well as the education and training programme of a EuroBaltic Centre for Nuclear Research and Technology. In particular, the education and training courses developed in participating countries are being reviewed and compared. A list of courses will be prepared and made available to the public. Special emphasis will be given to the training of young scientists. It is expected that an extensive regional educational programme will contribute to the creation of strong links between the next generations of scientists and will contribute to more efficient and stronger collaboration in the region.



European Nuclear Conference 2016

The largest European nuclear science conference, ENC 2016, was held in Warsaw between October 9 and 13, 2016. The conference was a forum where experts, decision-makers and representatives of the nuclear industry from all over the world could share their experience and discuss innovations, nuclear safety issues, applications and the future of the nuclear industry in general. This prestigious event was principally organized by the European Nuclear Society with NCBJ, IAEA Vienna, the American Nuclear Society and the Polish Nuclear Society as co-organizers. The conference was held under the honorary patronage of the Minister of Energy.

Key themes of ENC 2016 included state-of-the-art research and development in areas such as: nuclear science applications for industry and society, life science applications, advanced reactor technologies, current reactor technologies and new build, plant operations, nuclear fuel, waste management,

dismantling and decommissioning, safety and security, education, training and knowledge management, and public engagement in nuclear power.

One of the conference topics was the project to develop HTR reactors in Poland. This project has placed Poland among those countries implementing state-of-the-art nuclear technologies. A dedicated committee appointed by the Ministry of Energy is currently studying the feasibility of a successful implementation of HTR technology in the national economy. Experts agree that HTR reactors may significantly reduce consumption of natural gas used as a source of heat needed by the chemical industry. Co-generation of electricity and high-temperature heat is also commercially viable. The HTR programme in Poland may profit from a synergy with the construction of large light water reactors, necessary to increase the power generation capacity of the country by 6,000 MW.





Functional properties studies of materials exposed to severe exploitation conditions.

The Materials Research Laboratory (MRL) which is home to the Hot Cell laboratory is the only facility in Poland able to handle active (neutron irradiated in nuclear reactor) samples and perform mechanical, structural and chemical investigations. All studies conducted at the Materials Research Laboratory are performed according to a Quality Assurance Programme confirmed by the accreditation of the National Accreditation Centre and the Office of Technical Inspection. Standard mechanical tests conducted at the MRL facility are focussed on studies aiming to determine the "life time of the material." These tests are very useful to the energy industry because they help in the estimation of the operation time of technological installations.

The best example of research related to modern nuclear power engineering are the nanomechanical studies of ion implanted ODS RAF steels, conducted jointly with the Institute of Electronic

Materials Research. Experiments have proved that new types of steels reinforced with nano-ceramic particles exhibit better mechanical properties and corrosion resistance in radiation environments than standard stainless steels (i.e. 304 or 304L) currently used in industry.

In addition to standard research, MRL employees are involved in several European programmes aimed at the development of new, highly resistant materials dedicated to Generation IV nuclear reactors. Among many projects funded by the European Commission are: NOMATEN, M4F, VINCO and GEMMA. The overall goal of these projects is to develop the necessary materials competences in the area of nuclear engineering and create a so-called regional Centre of Excellence in materials research. Beginning in 2016 MRL employees published over 20 scientific papers and participated in over 10 international conferences and symposia.



Research:

Gamma detectors

In 2016 we delivered to the Joint European Torus (JET) a new detector for the Gamma-ray Spectrometer based on a 3"×3" CeBr₃ scintillator coupled to a photomultiplier tube. A dedicated active voltage divider was designed at NCBJ for this detector. In test measurements at NCBJ a strong ¹³⁷Cs source with an activity of ~400 MBq was used to check the stability of the detector performance at high count rates. The results of tests already performed at NCBJ and JET have shown that the new detector based on CeBr₃ with the active voltage divider is well suited to measurements at rates of up to ~1 Mcps. The studies at JET will prepare detectors for the International Thermonuclear Experimental Reactor (ITER) as well as the DEMOnstration Pow-

er Plant (DEMO). At JET the α particle diagnostics are based on the ⁹Be(α ,n)¹²C nuclear reaction occurring between confined α particles and beryllium impurity ions typically present in the plasma. A 4.4 MeV gamma line is emitted as a result of this reaction. Gamma-ray diagnostics of magnetically confined plasmas provide information on runaway electrons (fast electrons that often appear during plasma disruptions), fusion products and other fast ions due to nuclear reactions with fuel ions or main plasma impurities such as carbon and beryllium.

This research is part of the EUROfusion_NCBJ_JET4 Project of H2020-EURATOM.



9th INTERNATIONAL SCHOOL ON NUCLEAR POWER MIĘDZYNARODOWA SZKOŁA ENERGETYKI JĄDROWEJ

Warszawa – Świerk – Różan
14-17 listopada 2017

9th International School on Nuclear Power

The Ministry of Energy and NCBJ, in cooperation with the Faculty of Physics of Warsaw University and the State Enterprise Radioactive Waste Management Plant organized the 9th International School on Nuclear Power, which took place in Warsaw, Świerk and Różan on November 14-17 2017. The School dealt with the problems of the future of nuclear power, the nuclear fuel cycle, the influence of low radiation doses on human health, management of radioactive waste, safety issues in III generation nuclear power plants and nuclear power applications for the propulsion of rockets to Mars. Most of the lectures

were delivered by international experts from many countries. Since 2017 marked the 150th anniversary of Maria Skłodowska-Curie's birth Professor Andrzej K. Wróblewski (Faculty of Physics, University of Warsaw), author of the book "*Historia Fizyki*" (History of Physics), gave a celebratory lecture on the famous winner of two Nobel Prizes. In addition to lectures, special workshops took place at the NCBJ premises in Świerk (the MARIA research reactor and some research labs), the State Enterprise Radioactive Waste Management Plant premises in Świerk, and the National Nuclear Waste Repository premises in Różan.



ERMSAR2017:

Nuclear reactor safety experts convention in Warsaw

More than 160 experts from around the world discussed how to keep nuclear power plants safe even in the case of extremely improbable failures during the prestigious ERMSAR2017 international scientific conference, organized by NCBJ in Warsaw. Attendees included representatives of the nuclear science community, industry, regulatory bodies and technical support organizations from Europe and other parts of the world involved in studies on preventing severe accidents in nuclear reactors and mitigating the consequences of any accidents that do occur. Since 2011 international collaboration in

this field has intensified considerably and Polish scientists actively participate. NCBJ scientists have conducted advanced analyses of power reactors operated in other countries. The conference organized in Warsaw brought numerous opportunities to extend cooperation and gain new partners. The ERMSAR conferences are a joint initiative of NUGENIA (the NUClear Generation II & III Association) and SARNET (the European Severe Accident Research NETWORK of Excellence). For the first time Poland was entrusted with the task of organizing such an important scientific conference on nuclear reactor research.

Quality test guidelines for NPP builders

The NCBJ Materials Research Lab has worked out guidelines for Polish companies involved in the construction of nuclear power plants (NPPs). Guidelines on how to conduct non-destructive and destructive tests of elements to be deployed in such plants have been compiled into a 50-page report. The document gives descriptions of the methods used to assess the quality and nuclear safety of individual elements to be deployed in NPPs. It is also a guide to domestic

and foreign technical standards applicable in this area. NCBJ is the sole centre in Poland in which a nuclear reactor is operated. The quality of reactor systems and subassemblies is tested systematically. The NCBJ Materials Research Lab is a certified body. It conducts research for NCBJ's own needs as well as accepting external assignments. The Guidelines have been prepared under an assignment from the Polish Ministry of Energy.



Five NCBJ projects accepted in the H2020 Euratom call

NCBJ coordinates R&D work on High Temperature Reactors (HTR) conducted within the “GEMINI+” European-US cooperation project. GEMINI+ is one of the five projects from Świerk accepted in 2017 for financing in the Horizon 2020 EURATOM call for proposals.

GEMINI+ is an extension of a cooperation agreement reached in 2014 between the NGNP Industrial Alliance formed by the US nuclear industry and the Nuclear Cogeneration Industrial Initiative (NC2I) European consortium. Almost thirty institutions from several European countries and the USA, Japan and South Korea will be identifying prerequisites/licensing methods indispensable in implementing the HTR technology and looking for potential consumers of the industry-grade heat produced by HTRs. They are also to work out recommendations concerning the development of a European demonstrator of the HTR technology and to indicate directions for further development. In Poland HTRs could be used as sources of industrial-grade heat for chemical industry plants and oil refineries.

NCBJ scientists are also involved in research projects concerning engineering materials for future nuclear reactors. New solutions are being searched for in view of the extremely harsh environments in which these materials will be used: extremely high temperatures, exposure to very high-intensity radiation, and all the ensuing chemical and physical factors. The GEMMA project is focused on new

materials for 4th generation reactors already in the design phase; therefore, many industrial partners interested in fast applications are involved in the project. In particular, reactor constructional materials and protective coatings used in nuclear facilities are being tested. All the tested materials are to be surface-modified by means of ion implantation in order to increase their resistance to external factors.

Solutions applicable in future thermonuclear (fusion) reactors are also included within the scope of another project, M4F. NCBJ-assigned sub-tasks include the study of the evolution of tribological properties of engineering materials under the influence of factors possibly present in their operational environment. The NCBJ Materials Research Lab plays a key role in this research. The FOREVER project is aimed at securing supplies of nuclear fuel for European research reactors. Probabilistic methods applicable in safety analyses of nuclear facilities are being improved/extended within the NAR-SIS project aimed at developing new tools in order to deal with multi-hazards, effectively to support the management of severe nuclear accidents (like the failure of the Fukushima power plant as the result of a tsunami) and to find optimal solutions to minimize the potential consequences of such accidents. Bayesian network techniques are being extensively studied to this end. Unique competences in this area acquired over many years in the NCBJ MANHAZ Excellence Centre will be utilized to the maximum possible extent.



A Centre for future materials in Świerk?

Scientists from NCBJ have launched the NOMATEN project to establish in Świerk a Centre of Excellence with the mission to develop new materials for medicine, chemistry, the nuclear industry and Hi-Tech applications. The project was granted funding for one year by the European Union Teaming for Excellence programme. This funding will be used to develop a detailed research agenda and a business plan for the Centre. The NOMATEN consortium was founded by NCBJ Świerk, the French Alternative Energies and Atomic Energy Commission (CEA) and the VTT Technical Research Centre of Finland. Consortium partners also include the National Centre for Research and Development (NCBiR), a Polish government agency that may co-fund the NOMATEN CoE project, if approved. The authors wish to develop new materials capable of performing in extremely harsh environments in the NOMATEN Centre of Excellence. New engineering

materials are in particular needed for the construction of new generation nuclear/thermonuclear reactors. Such materials must be robust, durable, and resistant to high temperatures/corrosion/strong radiation fields. New materials of unique properties are also needed in several branches of industry, such as: aviation/space, electronics, household appliances and others. In specialized labs at Świerk, NCBJ scientists have been researching methods to modify materials for almost twenty years using the MARIA nuclear reactor and various plasma ion implanters. Project objectives will be pursued using a range of approaches, from atomic scale computer simulations based on molecular dynamics methods, through diverse analytical methods helping to determine the internal structures and radiation defect concentrations of materials, to measurement of tribological properties (hardness, strength, brittleness, corrosion resistance).

JRC Collaboration partner

In 2017 NCBJ signed an agreement on collaboration with the Joint Research Centre (JRC), one of the Directorates General within the European Commission. Scientists employed in the JRC's six research centres and the Brussels-located headquarters carry out research to provide European Commission, European Parliament, Council of the European Union, and EU Member States with independent advice and sup-

port for EU science & technology policy. Within the framework of the agreement, NCBJ scientists will be co-authoring JRC research programmes and will thus participate in coordinating EU science & technology policy, in particular in such fields as the development of nuclear technologies for power generation and other industry sectors, cyber-crime security and medical applications of ionizing radiation.



Maria refreshes its research apparatus. HZB helps

Four modern instruments used in materials research performed with thermal neutrons will be moved from Ber-II to the Maria reactor under an agreement between NCBJ and the Helmholtz-Zentrum Berlin (HZB). The instruments will increase the scope of neutron investigations carried out at NCBJ.

The instruments will be transferred from the BER II reactor operated by HZB. The list of instruments includes a diffractometer for neutron diffraction measurements for evaluation of the quality of single crystalline samples. NCBJ also hopes to obtain a diffractometer used in the generation of 3D maps of plane-to-plane distances in crystals. The possibility of transferring additional equipment for sample environment definition (including cryostats for measurements at extremely low temperatures as well as equipment for experiments in magnetic fields) has been negotiated.

The necessary re-arrangement of the Maria research reactor hall in Świerk where the new instruments are to be installed was started in 2017. In particular, the elevations of the instruments must match the elevations of the existing Maria horizontal neutron beams. The floor must be very

rigid and accurately levelled and smooth since the instruments will move on air cushions; therefore, it is planned to make it out of granite tiles. NCBJ experts estimate that some of the new equipment will be ready for experiments in 2020.

Some of the neutrons produced as a result of uranium fission within the Maria research reactor core exit the reactor through eight horizontal channels. Each exit will be endowed with specialized experimental equipment. Examples of research include studies of diffraction patterns to analyse crystal structure and its change with environmental parameters such as temperature, magnetic field or pressure. The Maria reactor is currently one of the few strong neutron sources available in Europe, while demand for neutron beams for research on new materials is steadily growing. The capacity of the HZB lab is fully booked till its scheduled closure in 2019. HZB's capacities are used by scientists from all over the world, including Poland. The NCBJ authorities wish that the thermal neutron scattering facility at Świerk will be available to scientists from all parts of the world and that it will effectively support the Polish nuclear technologies development programme.



Maria's new research division for biomedical studies

A new Division of Radiological Metrology and Biomedical Research is being established at the National Centre for Nuclear Research. The establishment of the new division was influenced by the development of interests in the field of biological and biomedical research. At one of the horizontal channels of the MARIA research reactor there is a stand for the development of research on Boron Neutron Capture Therapy. This therapy, currently experiencing a renaissance throughout the world, is a method of treating brain, head and neck cancer, and above all, non-surgical and disseminated cancers. Members of the Neutron H2 project operating at the National Centre for Nuclear Research are among the creators of the "NeoBor" scientific platform, the main task of which is to

create an interdisciplinary research team. The second major project in the field of biomedical research concerns the development of Y-90 microspheres used in liver radioembolisation. It is hoped this technique will provide the possibility of a longer life for patients with liver cancer, the treatment of which is currently a challenge for chemotherapy and classic radiotherapy. As part of the operation of the branch it is planned to extend the scope of biological research using various types of ionizing radiation, covering a wide range of medical research on cell lines. This division will also include studies from the mixed radiation dosimetry section, radiation transport calculations, natural radiation geophysics, medical physics and nano-development, and biomedical research.

CENTRIX: a new complex of materials research labs

The aim of the CENTRIX project is to create a complex of industrial radiography and non-destructive testing laboratories dedicated to the needs of the fuel, transport, mechanical, military and special production sectors. The project is based on many years of NCBJ experience in research using gamma and X rays, electrons and neutrons in the implementation of dedicated imaging systems. Four new laboratories will be created under the project.

The Fast-X lab will be equipped with an electron accelerator with an energy of 6-9 MeV for multi-pulse scanning of steel objects up to 350 mm thick. An additional acceleration segment will allow conversion to a neutron beam with a yield greater than currently available fast neutron generators. The laboratory will also receive a set of detectors (including 1Mfps high speed radiography), X-ray equipment and manipulators.

The second lab, for detection systems, will allow the testing of new detectors and work on the development of imaging methods. The third dedicated laboratory will allow the study of accelerating structures for radiographic linacs, including optimization of the RF conditioning process, testing of high frequency power sources, examination of electron guns and quality control of ionization chambers. Finally, the materials testing lab will enable, among others, surface tests using Raman spectroscopy, thus complementing the palette of research methods used so far by NCBJ.

It is anticipated that the CENTRIX labs will begin operation in 2021. The project was included in the list of ventures designated for co-financing by the Regional Operational Programme of the Mazowieckie Voivodship 2014-2020.



In vitro evaluation of biological activity of radiopharmaceuticals

Radiolabelled monoclonal antibodies (mAb) and peptides are powerful tools for tumour imaging or targeted radiotherapy. However, before they are used in humans it is of major importance to assess their biological activity and characterize their properties in pre-clinical studies. The immunoreactivity of mAbs or the receptor binding affinity of peptides after conjugation of the chelator for radiometal labelling need to be assessed before in vivo studies.

In our laboratory we evaluated the biological activity of antibodies and peptides that are under development at RC POLATOM using in vitro assays in dedicated cancer cell lines. All the studied radiopharmaceuticals were obtained with high radiolabelling yields of over 90%.

The specific binding of ^{177}Lu -DOTA-Rituximab and ^{90}Y -DOTA-Rituximab directed to CD20 antigen was evaluated by in vitro studies carried out on Raji cells. The IRF (Immunoreactivity Fraction assay) was determined by the Lindmo *et al.* (1984) method.

Immunoreactivity Fraction Assay: Around 22% of ^{177}Lu -DOTA-Rituximab and 26% of ^{90}Y -DOTA-Rituximab was bound to the Raji cells. Very

small differences were observed in the IRFs of ^{177}Lu -DOTA-Rituximab and ^{90}Y -DOTA-Rituximab.

The receptor binding affinity of the CP04 peptide radiolabelled with ^{177}Lu and ^{68}Ga towards CCK2R (gastrin/cholecystokinin receptor) was defined according to the method of Khaloudi *et al.* (2016), using A431(CCK2R(-)) cells and A431(CCK2R(+)) cells which had been transfected with the plasmid pCR3.1.

The binding and internalization assay: ^{177}Lu -CP04 and ^{68}Ga -CP04 showed a specific binding at the level of about 4% with a high internalization rate (over 70%) for both radiolabelled peptides, with no significant differences between the two of them.

In vitro studies such as the immunoreactivity determination for monoclonal antibody-based tracers or binding and internalization for peptide-based radiopharmaceuticals are important tools for evaluation of potential drug candidates in the pre-clinical phase, giving essential information regarding their biological activity. The results of such studies are starting points for further comprehensive in vivo evaluation using specific animal models.



POLATOM in brief

POLATOM is a world-famous supplier of high quality radiopharmaceuticals and diagnostic kits for nuclear medicine and an important manufacturer of radiochemical products for customers all over the world. Our products are exported to more than 80 countries. POLATOM is Poland's main producer of radioactive preparations and radiopharmaceuticals.

POLATOM's current commercial package includes:

- ▶ A wide range of scintigraphic kits for ^{99m}Tc labelling for the examination of organs and cancer diagnoses,
- ▶ Preparations of radioactive iodine-131 for the diagnosis and treatment of thyroid diseases,
- ▶ Preparations for the palliative treatment of bone metastases,
- ▶ Radionuclide $^{99}\text{Mo}/^{99m}\text{Tc}$ generator,
- ▶ Precursors for the preparation of therapeutic radiopharmaceuticals,
- ▶ Industrial sealed sources,
- ▶ Radioactive standard solutions,
- ▶ Radiochemical reagents,
- ▶ A wide range of special customised radioactive preparations,
- ▶ Accessories for nuclear medicine units,
- ▶ The calibration and servicing of dose calibrators,
- ▶ The installation and maintenance of isotopic equipment,
- ▶ The handling and transportation of radioactive materials.

POLATOM's activities in all areas meet European and international standards; with regard to its quality-assurance system, POLATOM holds the PN-EN/ISO 9001:2009 Certificate of Compliance for the trading of dual use items and technology - the Internal Control System Certificate. Its standard of radiopharmaceutical production is confirmed by the GMP Certificate and its qualifications in the area of the ionising radiation metrology laboratory are confirmed by the Accreditation Certificate of the Calibration Laboratory in compliance with PN-EN/ISO 17025:2005.





New radiopharmaceuticals and radiopharmaceutical kits

The R&D Department of the Radioisotope Centre POLATOM carries out research programmes related to the application of radioactive isotopes and radiolabelled compounds in various fields of medicine, research and industry. The results of our investigations are directly implemented in the technologies at POLATOM. The vast majority of POLATOM commercial products on offer, including approximately 150 items, are the results of its own work.

In recent years POLATOM has launched the manufacture of several innovative products, among them ^{99m}Tc -Tektrotyd - a radiopharmaceutical kit for diagnostic imaging of tumours expressing somatostatin receptors useful in oncology, Tchim-muna - a radiopharmaceutical kit for the detection and localization of inflammatory lesions or ItraPol (^{90}Y) and LutaPol (^{177}Lu) as radiopharmaceutical precursors for radiolabelling of peptides and other biomolecules for cancer therapy. In 2016 marketing authorization for Tektrotyd was granted in several EU countries.

POLATOM has gained permission from the Polish, Austrian and Slovenian Authorities to conduct a phase I clinical study for ^{111}In -CP04 preparation under the ERA-NET TRANSCAN project. The product is a novel CCK-2/gastrin receptor-localizing radiolabelled peptide probe for personalized diagnosis and therapy of patients with progressive metastatic medullary thyroid carcinoma.

In 2016 POLATOM developed research on the PSMA-11 (Prostate Specific Membrane Antigen) peptide. It is characterized by high affinity for prostate cancer cells. Its usefulness for the diagnosis of metastatic prostate cancer, in combination with ^{68}Ga , has been confirmed in many publications. A suitable PET tracer can be obtained by labelling the kit under hospital conditions with an isotope from the radionuclide generator. Ultimately, the combination of isotopic techniques with molecular disease markers should enable earlier detection of diseases and implementation of relevant therapeutic procedures (personalised medicine).



Research/Applications:

Targets for Mo-99

The main objective of ^{235}U irradiation in the Maria research reactor is to produce the $^{99\text{m}}\text{Tc}$ isomer, widely used in medical diagnostics. The decisive factor determining its availability, despite its short life time, is the radioactive decay of ^{99}Mo into $^{99\text{m}}\text{Tc}$. One possible source of molybdenum is the ^{235}U fission reaction. Extracting ^{99}Mo from fission products is one of the most effective methods for obtaining this isotope.

The ^{99}Mo deficit which occurred on the global market, and the pressure of international organizations for fuel conversion of nuclear reactors using highly enriched ^{235}U to low enriched uranium (LEU) fuel, forced the development of new technology for the production of ^{99}Mo based on LEU targets.

The technology proposed to irradiate uranium targets in the reactor in a relatively simple and at

the same time very effective way utilizes both the structural possibilities of the MARIA reactor and the fundamental relationship between the fission power generated in the targets and the activity of the ^{99}Mo created as one of the ^{235}U fission products. The technology implemented in the MARIA reactor employs a specific construction of fuel channels with the cooling system, mechanical hardware and measuring system.

A test irradiation of a set of 8 LEU uranium targets ($^{235}\text{U} < 20\%$) inducing an average fission power of 165- 175 kW over hours yielded an activity of 5690 Ci (210.5 TBq) of ^{99}Mo at the end of irradiation. It showed that the technology to obtain ^{99}Mo in the MARIA reactor satisfies the procedure for determining and checking the activity of this isotope in the process of irradiation of uranium targets and creates unique manufacturing possibilities.



APPLICATIONS *for* MEDICINE RADIOPHARMACEUTICALS

CERAD: cyclotron and laboratories for design and synthesis of new molecularly targeted drugs



A modern centre for the design and synthesis of new radiopharmaceuticals will begin operation at Świerk in 2021. Scientists working in the centre will have at their disposal a new 30 MeV cyclotron, the Maria research reactor, a group of research labs and the CIŚ supercomputer. NCBJ, representing a consortium of six research/academic institutions, has reached an agreement on co-financing the CERAD project from EU funds allocated to the Smart Growth Operational Programme 2014-2020 (SGOP). It is expected that the existing resources of NCBJ (including the Maria research reactor, the Radioisotope Centre POLATOM and the CIŚ supercomputer) in conjunction with the in-kind contributions and expertise of other members of the CERAD consortium will help the new centre to attain the status of a truly European-class unique research infrastructure.

The most important new equipment in the centre will be a cyclotron capable of accelerating protons (to an energy of 30 MeV), deuterons (to 15 MeV) and alpha particles (to 30 MeV). Such energies are sufficient to produce radioactive isotopes needed in nuclear medicine; radioisotopes are produced in this way in only a very few institutions worldwide. New labs built within the CERAD project framework and existing labs currently run by the NCBJ Radioisotope Centre POLATOM will be combined into a comprehensive infrastructure necessary to synthesize and study new radiopharmaceuticals

based on radioisotopes produced by the cyclotron and Maria reactor. The CIŚ supercomputer operating at Świerk and the competences of the CIŚ staff will assist researchers in making comprehensive simulations of new radiopharmaceuticals. The CERAD centre's mission is to develop original, effective and safe drugs. The wide range of radioisotopes available from the cyclotron/reactor combination will enable us to design numerous isotope markers capable of diagnosing various diseases sooner and more accurately, and hence more promptly implementing proper treatment of the disease. Scientists want to combine radioisotope techniques with other diagnostic methods, such as those based on disease molecular markers and magnetic resonance imaging. A wide range of available radioisotopes will also enable them optimally to match radiation energy and biological half-life to the nature/advancement of the disease and individual situation of a given patient. They intend to develop both final drugs and drug precursors necessary in the production of radiopharmaceuticals.

The members of the CERAD consortium are NCBJ, the University of Warsaw, the Institute of Nuclear Chemistry and Technology in Warsaw, Warsaw Medical University, Collegium Medicum of the Jagiellonian University in Cracow and the Medical University of Białystok. The work of the consortium is coordinated by NCBJ.



RESEARCH/APPLICATIONS:

Techetium-99m from accelerators

A proprietary method to produce targets suitable for the production of technetium-99m in accelerators has been developed at the NCBJ Radioisotope Centre (POLATOM). Technetium-99m is one of nuclear medicine's more important radioisotopes. Technetium-99m is usually obtained from generators as a decay product of molybdenum-99, which is produced in large amounts in nuclear reactors. The alternative route for production of ^{99m}Tc is in accelerators using reactions of protons with ^{100}Mo , a stable molybdenum isotope. The targets of ^{100}Mo must be mechanically strong enough to survive bombardment by intense proton beams but also

porous enough to enable quick dissolving after irradiation. Finally, their thermal conductivity is crucial. For ^{100}Mo target preparation NCBJ scientists have proposed to press molybdenum-100 enriched molybdenum powder into 12 mm dia and less than 1 mm thick pellets, then to sinter the pellets under appropriate conditions in a hydrogen atmosphere. The mechanical properties of the pellets were successfully tested in the NCBJ Materials Research Lab and the targets were irradiated with protons from the cyclotron operated by the University of Warsaw. The proposed method of producing molybdenum targets is the subject of a Patent Application.

^{177}Lu labelled radioligands for targeted radiotherapy

Minigastrin (MG) analogues specifically target cholecystokinin-2 receptors (CCK2R) expressed in different tumours and enable targeted radiotherapy of advanced and disseminated disease when radiolabelled with a beta emitter such as ^{177}Lu . Especially truncated MG analogues missing the penta-Glu sequence are associated with low kidney retention and seem therefore most promising for therapeutic use. Scientists from NCBJ POLATOM together with researchers from the Medical University of Innsbruck and the "Frédéric

Joliot-Curie" National Research Institute for Radiobiology and Radiohygiene in Budapest have developed a freeze-dried kit formulation that allows the straightforward preparation of two ^{177}Lu radiolabelled MG derivatives with high RCP acceptable for clinical use. Preclinical studies confirm the promising properties of ^{177}Lu -labelled cyclic MG analogues for clinical translation and support further studies to introduce this new therapeutic approach for patients with advanced and disseminated CCK2R related tumours.



APPLICATIONS *for* MEDICINE INSTRUMENTS

IntraLine-IOERT

NCBJ, together with the Greater Poland Cancer Centre (WCO Poznań), has constructed IntraLine, a new electron accelerator dedicated to intra-operative treatment.

The technique of irradiating after-tumour cavities with electrons during surgery, referred to as intra-operative irradiation treatment, is one of the most modern methods of tackling malignant cancers. Intra-operative accelerators are capable of delivering therapeutic beams to the lesion area easily, quickly and accurately. Physicians can more easily carry out the procedure and adverse side effects for patients can be minimized. The electron irradiation technique combines the advantages of photon irradiation and irradiation with massive charged particles.

The IntraLine medical linear accelerator was built as part of the INTRA-DOSE project. The device, suitable for use in sterile conditions, serves to irradiate tissues and organs with a spatially homogeneous and time-stable beam of electrons of high energy and intensity, administered directly to an open operating field. The task of the apparatus is to destroy – at the stage of the surgical operation – those tumour cells that may remain in the patient's body despite the resection of the tumour.

The exceptional mobility of the IntraLine accelerator head makes it possible to deliver the therapeutic beam rapidly and comfortably directly to the area at risk. Since the radiation does not pass through healthy tissues and organs its dose may be safely increased. This sort of irradiation is more effective,

reducing the risk of complications and shortening the treatment period by up to several weeks. The whole system is easily relocatable due to the integrally built-in trolley and the surgeon can move the IntraLine accelerator to a standard operating table solely for the time of the irradiation.

The innovative technical solutions of the electron accelerating systems, beam formation and positioning developed at NCBJ and covered by patent protection, guarantee the creation of a uniform and stable therapeutic beam of a high quality. The accelerating structure itself is short and lightweight.

The range of available electron energies (4-12 MeV) makes it possible to carry out virtually any of the procedures of today's intra-operative radiation therapy. The profile of the beam, verified in dosimetric measurements, is flat over a range corresponding to international standards and guarantees the uniform irradiation of tissues within the volume of a cylinder of height up to 6 cm with a high radiation dose (5 or 15 Gy/min). At the same time the level of scattered X-ray radiation is 500 times less than that required by the relevant standard.

The INTRA-DOSE project ended on December 31, 2016 and was supported by the National Centre for Research & Development within the framework of the Basic Applied Research programme, path B.



Research:

Innovative method for designing beam forming systems

Passive beam forming systems transform the “pencil” beam extracted from a particle accelerator into a beam that is spread uniformly over a large area of an irradiation field. Such systems are employed in all medical linacs currently serving electron beam therapy, as well as in some proton therapy facilities (particularly for treatment of eye cancers). In a passive system the primary beam is scattered and subsequently collimated to the area of a designated field.

At NCBJ passive systems were recently designed and constructed for the prototype of a novel mobile linac for intraoperative electron radiation therapy and for an experimental high dose-rate irradiation facility at Wroclaw Technology Park (WPT).

Despite the conceptual simplicity, designing an actual passive beam forming system can be a rather challenging task, often taking months. Thus a new, efficient design method was developed. The new method is based on research tools developed in modern subatomic physics, particularly Monte Carlo simulations. The new method can deliver better results compared to previously used methods in a much shorter time. It allows, practically for the first time, for simultaneous optimization of multiple objectives (e.g. dose uniformity and dose rate). By providing insight into system behaviour the method allows for educated and well balanced decisions on difficult design issues that often demand a compromise between contradictory requirements. Finally, the designer is able, also practically for the first time, actually to prove that the proposed solution is truly optimal under given constraints.



Signal and image reconstruction for J-PET, a novel type of PET scanner.

Computer scientists and physicists from the NCBJ Świerk Computing Centre have contributed to the development of a J-PET scanner constructed by a consortium led by the Jagiellonian University in Cracow. Novel plastic detectors employed in the scanner make it possible to diagnose the entire human body at once. The scanner is capable of recording patient body images with three times as large a field of view and with better resolution than offered by traditional (commercially available) solutions. In addition, the scanner under development is much less expensive than traditional PET based on inorganic scintillator crystals.

The new type detectors required a dedicated image reconstruction system. The task of developing such a system was accomplished by scientists from NCBJ. The set of detectors used in the scanner was precisely simulated, with all geometrical details taken into account. The model and the simulations made it possible to optimize such detector parameters as shape, situation with respect to radiation origin, sensitivity etc. Scientists were also able to analyse and understand the impact of the background level and sources of potential interferences with the signal. This was a key factor in obtaining

maximum clarity and spatial resolution in the ultimately reconstructed images.

Signals produced by detectors need to be correctly interpreted and this is the crucial element of analyses conducted both in physical experiments in laboratories and in diagnostic systems such as PET scanners. The shape of the signals produced by the J-PET detectors is reconstructed from the signal amplitude/leading edge/trailing edge read out by timing modules. An image of the object that has emitted the radiation is finally reconstructed by filtered backprojection from signals produced by the entire set of detectors. The analyses for the J-PET signal reconstruction were carried out in the Complex Systems Department of NCBJ.

Other tasks accomplished by NCBJ for the J-PET project include measurements and calculations aimed at determining the compatibility of the J-PET scanner with NEMA (National Electrical Manufacturers Association) standards. This work is in progress.

The Świerk Computing Centre is also storing/computing data acquired by the scanner prototype.



Research:

HPC analyses of medical histories and symptom correlations

A collaboration with the Bielański Hospital in Warsaw, which concentrated on the analysis of anonymized data from the HIS (Hospital Information System) was continued. The analysis is focused on two goals: the probability of hospital readmission (return of the patient within a specified time interval) and finding similarities in patients' symptoms

using graph theory methods. The analysis, apart from well-defined input data like ICD-10 codes or numerical results of medical tests, also takes into account unstructured textual data, like doctors' notes. The data are analyzed using machine learning methods and High Performance Computing (HPC) algorithms.



APPLICATIONS *for* INDUSTRY

Online chemical analysis: cement raw materials

The level of impurities and quality of materials used for cement production are key factors in determining its class. The aim of this project carried out by NCBJ together with two Polish companies: SysKon - Control Systems of Industrial Processes and POLON Nuclear Technology Centre in Wrocław, Ltd. was to create a system for controlling the chemical composition of the raw materials used in cement production. The system operates in continuous mode and monitors a stream of material moving on a conveyor belt. The principle of operation is based on prompt-gamma neutron activation analysis (PGNAA) and the key part is a deuterium-deuterium neutron generator emitting particles with an energy of 2.45 MeV. The generated neutrons, after thermalisation, are absorbed (captured) by the inspected material resulting in its activation and the emission of characteristic prompt

gamma rays. Detection and analysis of this radiation with scintillation detectors allows the determination of the chemical composition of the raw materials, in particular the content of such compounds as: CaO , SiO_2 , Al_2O_3 , Fe_2O_3 , SO_3 and others.

The test installation of the RaM-scaN system demonstrator was mounted on a conveyor belt in the "Folwark" mine in Poland. The mine supplies raw materials to the largest cement plant in Europe - Góraźdże. At present the RaM-scaN system is operating under real industrial conditions and is installed in series (on the same conveyor belt, at a distance of around 10 m) with another commercial system from the Sodern company (France). The comparative tests have proven the high performance of the RaM-scaN analyzer.

and minerals

Cooperation between NCBJ and our client from Lubin, KGHM "Polska Miedź" S.A. was continued in 2016. We signed two contracts that mark progress in the industrial applications of Neutron Activation Analysis and X-Ray Fluorescence for ap-

praising the quality and composition of copper ore at various stages of mining. Both branches of this project have their roots in the Accelerators and Detectors project and contribute to the commercialization of its results.



Commercialization:

CANIS

In 2016 NCBJ and the PID Polska company reached a cooperation agreement on the commercialization of the NCBJ-developed CANIS Cargo Scanning System. CANIS is a radiographic device, i.e. it scans the cargo to be checked with high energy X-ray beams. The well-known principle of operation of a radiographic scanner was improved by NCBJ scientists by introducing two X-ray energies in alternating pulses of radiation; in the CANIS case the two energies are 4 MeV and 6 MeV. Two radiographic images taken virtually simultaneously at two different X-ray energies dramatically improve the ability of the scanner to differentiate cargo objects in the displayed images.

The feasibility of CANIS was originally demonstrated within the framework of the “Development of Specialized Systems Based on Accelerators and Detectors of Ionizing Radiation for Medical Therapy and in Detection of Hazardous Materials and Toxic Wastes” project run at NCBJ under the EU Innovative Economy Operational Programme. According to the commercialization agreement the PID Polska company will be the exclusive supplier of the CANIS Cargo Scanning Systems for the next 5 years. The agreement may be extended for any period in the future.



▶ Tap Water Radioactivity Real Time Monitor

The quality of water supplied for daily consumption is one of the key issues in ensuring the health of a population. One of the factors that need to be controlled is the content of radioisotopes in drinkable water. A project named TAP Water Radioactivity Real Time Monitor (TAWARA_RTM) was started with the aim of developing a scalable platform providing online inspection of radiological contamination of water processed in water treatment plants (WTP). The prototype of the TAWARA_RTM system was installed in the North Plant of the Warsaw Waterworks Company located in Wieliszew by Lake Zegrzyńskie. The trials were carried out between June and August 2016.

The prototype of the TAWARA_RTM platform comprises three monitoring nodes. One of them, the Early Alarm Detector (EAD), was installed close to the water intake, just after sedimentation tanks that are used to remove large size impurities that constitute humus in the raw water. The detector is supposed to protect further installations of the WTP in the case of a large scale radioactive contamination. Since water at the intake contains many impurities, the EAD was designed as a large size γ -ray detector.

The second detector, the Real Time Monitor (RTM), performs continuous scanning of water just before the last treatment process (disinfection with $\text{Cl}_2 + \text{ClO}_2$) that precedes the distribution of water to

the consumers. It measures the α and β radioactivity from contamination potentially present in purified water. The detector required a special construction allowing for constant water flow around the detector surface immersed in the monitored water.

A Reverse Osmosis Concentration System (ROCS) installed in front of the RTM supplied the detector with water that contained concentrated impurities in order to increase the sensitivity of the RTM device. A by-pass pipeline was used to feed the third monitoring node, namely the spectroscopy detector (SPEC) that was intended for identification of radioisotopes that would have been eventually detected by the RTM. SPEC was also equipped with a concentration system based on ion-selective resins to speed-up identification of potentially detected radioisotopes.

The monitoring nodes and concentration systems were connected using a custom designed hydraulics system. All the devices and their electronics were steered and controlled by a central server (CS) that was also used for data collection and analysis.

The project “TAP Water Radioactivity Real Time Monitor” was funded by the EU FP7 Security Programme under grant agreement no. 312713 and by the Polish funds for science for 2014-2016 allocated to co-funded international projects – contract 3036/7.PR/2014/2.



For Security:

C-BORD

Efficient non-intrusive inspection of containerised freight is critical to trade and society. The aim of the C-BORD project of the H2020 EU programme is to prepare a universal inspection Toolbox that will include 5 complementary innovative detection technologies: delivering improved X rays, Target Neutron Interrogation, Photofission, Sniffing and Passive Detection. In 2016 NCBJ participated in the development of the relevant inspection technologies, in particular in the design and integration of equipment for inspection of containers in seaports:

passive gates, X-ray radiography and neutron activation systems. The NCBJ team contributed to the construction of the Rapidly Relocatable Tagged Neutron Inspection System (RRTNIS) for the detection of illicit goods and dangerous materials inside containers transported through sea-ports. Threshold Activation Detectors containing fluorine and intended for the detection of fissile materials by means of photofission have also been developed in Świerk. NCBJ experts coordinate the testing of four of the five inspection systems at the Gdańsk port.

For Heritage:

Materials research for archaeometallurgy

Based on materials research, modern archaeometallurgy gives answers about the technological and deposit provenance of archaeological objects, especially the methods of ancient and historic metallurgical workmanship and the conditions of ancient and historic casting and ornamentation techniques. Researchers from NCBJ participated in studies of the elemental and structural composition of silver coins and jewelry from the X and XI century and gold and silver artifacts of probable Eastern Mediterranean provenance found in the archaeological site within the area of the former lake Nidajno (north-eastern Poland). Scanning electron microscopy with X-ray microanalysis (SEM-EDX), energy dispersive X-ray fluorescence (ED-XRF) and laser inductively coupled plasma mass spectrometry

(LA-ICP-MS) were used in these studies. SEM-EDX allows morphological changes to be studied and the quantitative elemental composition to be determined. ED-XRF gives information about the alloy matrix due to the deeper penetration of the X rays. In order to obtain the lead isotope concentration LA-ICP-MS was used with a specially constructed statistical method (Kernel Density Estimation) which recalculates the data and gives the average value of the lead isotope ratio.

The applied techniques gave information about the types of solders used, i.e. mercury amalgam and indium binders. They have also shown that the nielium technique and the fire-gilding process were used in the treatment of the artifacts examined.



FOR BUSINESS *and* LOCAL GOVERNMENT

Seven Labs of the Science and Technology Park (PNT)



The mission of the Science and Technology Park Świerk (PNT) is to support the incubation and development of small and medium size enterprises (SMEs), particularly those operating in High-Tech business sectors compatible with the NCBJ profile. PNT offers some privileged term services (de minimis assistance), making available its own specialized laboratories, lab/office/warehouse/conference rooms and conference facilities.

The biggest advantage of PNT is the seven specialized laboratories, where entrepreneurs can carry out research themselves or commission it from experienced workers. 2016 was the first full year of activity of the seven labs.

The **Nanoscale Materials Laboratory** is the main reason to be proud of PNT. By using atomic force microscopes it allows a wide range of nano- and micro-tests of materials to be carried out, at temperatures up to 750 degrees Celsius. The lab offers the opportunity to study numerous materials with different physicochemical properties - from super hard coatings, through steels and alloys, to soft polymers.

The **Advanced 3D Printing Laboratory** allows metal powder prints to be produced using the SLM (Selective Laser Melting) technique. They can be up to 90 mm in diameter and geometrical accuracy can reach as much as 50 microns. This is where, based on the transmitted geometry, fully functional metal parts with complex shapes can be produced.



The **Tomography Laboratory** has an advanced CT scanner that produces radiographic images and delivers full three-dimensional images. In the laboratory objects measuring up to several centimetres can be X-ray checked with an accuracy of several micrometres.

The **Spatial Scanner Laboratory**, equipped with a state-of-the-art optical scanner, is able to scan the surface of small and medium-sized objects with micrometre accuracy. Based on the collected scans, reverse engineering is carried out to obtain full technical documentation of the scanned item.

The **Electronic Lab** has about ten Top-Class electronic devices including a real-time spectrum ana-

lyzer, arbitrary waveform generator and high frequency generator and oscilloscope.

The **Climate Research Laboratory** allows studies and tests to be carried out under controlled environmental conditions (with precisely defined temperature and humidity). This infrastructure is usually used to study the stability of electronic equipment.

The Park also has an **ISO 8 Cleanroom Cleanroom Laboratory**, as well as general purpose laboratory rooms that can be arranged to meet the needs of even the most demanding clients.

PNT was founded at NCBJ Świerk within the framework of a project co-financed by the Mazovia Voivodship Regional Operational Programme.



FOR BUSINESS *and* LOCAL GOVERNMENT

PNT support and consulting

In 2016 more than 20 companies used PNT's services. a commercialization strategy.

An experienced team of specialists supports companies operating in the Park. Lawyers help entrepreneurs establish and operate their businesses and verify contracts they sign.

Counsellors with extensive market and project experience help them to acquire funds for the business, to create business plans, and to form

Customers can also get help in establishing business contacts and finding partners both in Poland and abroad. PNT can also act as an interface between business entities and NCBJ scientists helping these entities to establish international contacts based on the broad network of international scientific cooperation relations and partnerships already established by research teams of the Institute.

Space for Business

In the modern Park building users have at their disposal dozens of office, laboratory, workshop and storage rooms. A total of more than 3500 m².

The Park provides fully equipped office space with access to the media necessary to run a business.

Companies operating in the Park have richly equipped conference facilities. The largest room of the Park is able to accommodate over 300 people. Several smaller rooms provide full flexibility in organizing meetings, trainings, workshops or symposia.



PNT Meetings:

The 2016 International Symposium on Reliability of Optoelectronics for Systems (ISROS 2016)

ISROS 2016 was hosted by PNT in June 2016. The Symposium focused on a technical programme dedicated to quality and reliability assessment of optoelectronic devices and systems in severe environments, not limited to space, but also including aeronautics, telecommunications, nuclear, automotive, and defence applications.



PNT Meetings:

INNOMAZ meeting in PNT Świerk

INNOMAZ 2017, the 1st Forum for cooperation between local authorities/science/business, was held at the NCBJ premises in Świerk. The Forum was organized by the Innomaz Association for Mazovia Region Development in cooperation with the Warsaw University of Technology Faculty of Materials Science and Engineering and the Świerk Science & Technology Park. The agenda of the Forum included case studies of innovation transfers from science to business, discussions on the role played

by local authorities in the development of local entrepreneurship, and opportunities for cooperation between local authorities, the scientific community, and businesses.





Education and Training Division: Trips, Lectures, Competitions

In 2016 the Division moved to a new location in the building of the Science and Technology Park. At the new site the Division has at its disposal 2 lecture halls, an exhibition hall, laboratory space and staff offices. Each lecture room was designed for 40 - 50 people. They are adapted to present physical phenomena related to non-ionizing and ionizing radiations, including cosmic rays, and natural radioactivity and everyday radioactive substances. The exhibition hall is dedicated to popularizing knowledge about nuclear reactors and nuclear power. There is information on the construction and operation of nuclear reactors, as well as information on the management of radioactive waste. In addition, the exhibition hall is equipped with a conceptual layout showing the use of high temperature reactors in industry and agriculture. A separate display part of the Division is a mock-up of the WWER-440 reactor together with a light table showing its performance.

The Atomic and Nuclear Physics Laboratory was prepared and equipped to start work in 2017. It is intended for more advanced high school students and university students and it is a Z class isotopic laboratory (work with closed sources) and an X-ray lab. In a surface of 140 m² there are more than 20 measuring stations which can simultaneously be used by up to 20 people (including service). Many demonstrations have the potential to replicate physics-relevant experiments such as the photoelectric effect, the Rutherford experiment, the Thomson lamp, the Michelson interferometer, but also measure the various properties of ionizing radiation (alpha, beta, gamma, X ray). In total, the Laboratory offers the possibility to perform more than 30 different experiments.

In 2016 the Division hosted 7200 visitors from high schools, universities, and industrial and scientific institutions from many towns and villages.

Among these visitors one may list students from the Medical Universities of Białystok and Gdańsk, Warsaw and Gdańsk Technical Universities, the Academy of Mining from Cracow, the Marie Curie University of Lublin. The Department also hosted film makers, participants in the European Nuclear Conference, firemen, military personnel, not to mention organised groups of senior citizens.

The Division was very active during the Science Picnic and the Science Festival, both held in Warsaw. In addition, our group popularised elements of nuclear science in the villages of Gniewino and Choczewo, where the construction of nuclear power plants is planned. It also organised (in collaboration with the Institute of Physics and the Polish Academy of Sciences) the annual high-school student competition "The Paths of Physics". This was the 12th edition of this competition.

The Division organised regular Radiological Protection courses and a special course for future nuclear reactor operators. It also participates in two EU Projects: BRILLIANT (Baltic Region Initiative for Long Lasting Innovative Nuclear Technologies) and VINCO (Visegrad Initiative for Nuclear Cooperation). A semi-popular brochure "Paving the Way to Gen IV Nuclear Reactors" was prepared and published as part of our obligations within this latter project.

Some of Division's employees are active scientists in the field of high-energy physics, and the influence of low dose radiation on organisms - modelling of the transformations of irradiated cells in particular. The Head of the Division, professor L. Dobrzyński, served as an expert in the preparation of the IAEA report on the Fukushima event and was a member of the Polish Delegation to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).



International project:

D-shuttle

In 2016 the results of the D-shuttle project were presented. The project was carried out over the preceding two years and involved hundreds of students from Japan, France, Poland and Belarus. The Education and Training Division of NCBJ was the coordinator of the Polish part of the project, which was attended by students from eight high schools. The other scientific institutions involved were the Institute for Radiation Protection and Nuclear Safety (IRSN), The University of Tokyo, Fukushima Medical University and the Centre d'étude sur l'évaluation de la Protection dans le domaine Nucléaire (CEPN). The purpose of the project was to compare the level of radiation backgrounds in Japan, especially around Fukushima, with the natural radiation background in European countries. Students participating in the project received specially prepared radiometers that

collected radiation during two weeks. Each participant had to create a logbook in which he/she had to write his/her place and type of building, if indoors, every hour. The values obtained were not known to the participants until the radiometers were read out in Japan. The results published in a professional scientific journal showed that the differences in radiation levels were statistically insignificant and are within the limits of natural fluctuations due to geological and geographic conditions. It is worth pointing out that in Poland this was probably the first project implemented in a full scientific research regime in which so many students from vocational and technical schools participated.



EDUCATION NEW OFFER

Unique Lab: Towards teaching standards for raising awareness of nuclear science

The Education and Training Division of NCBJ offers high school and university students as well as science teachers the opportunity to perform unique experiments at the Laboratory of Atomic and Nuclear Physics, which was modernized in 2017. In the new premises over 30 experimental stations are available. Students working alone or in two-person teams can perform measurements of alpha, beta and gamma radiation as well as light and X rays. The experiments concern the penetration and absorption of radiation, diffraction and interference of light and X rays, and spectral analysis of atomic and nuclear radiation. Among the prepared experiments are the classic experiments of Rutherford and Franck-Hertz, measurements of the Compton effect, electron diffraction, laser and microwave interference by the Michelson method, studies of luminescence, decay time measurements, studies of the external and internal photoelectric effect, and even experiments with a hydrogen cell. For each proposed experiment and measurement, a special didactic manual has

been prepared describing both the course of the experiment and the analysis of its results. Students' work is constantly supervised by dedicated teaching staff. Instructors are always available for individual help. Usually groups of 16 or 30 people are involved in classes. All-day classes last 6.5 hours and end with a reporting seminar during which the participants report the work done and discuss the results obtained.

This laboratory launched at NCBJ is unique not only in Poland but in the whole of Europe. It is dedicated to young people learning in schools with specialized profiles related to the practical use of radiation and nuclear techniques. It gives students the possibility of encountering important phenomena already at high school or basic university course level. One of the aims of the laboratory is to develop teaching standards and methods for education in the importance of nuclear technology in our lives, including the Polish nuclear power plant construction programme.

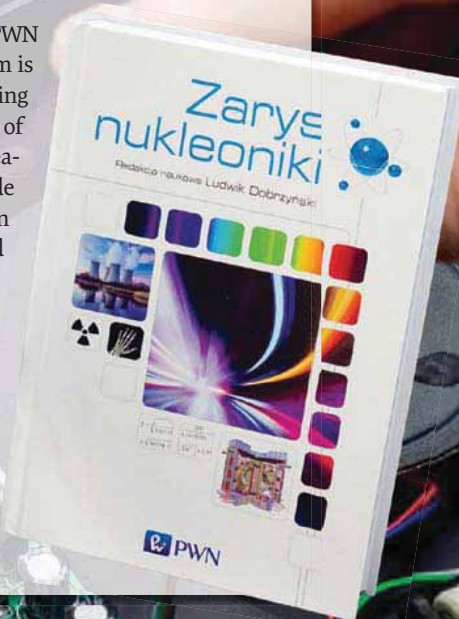


The term “nucleonics” generally tells people little ...

“Nucleonics” is the science of the properties of the atomic nucleus, the search for methods to study these properties and their application in science, industry, agriculture and medicine. These applications are related to the use of various properties of nuclear (ionizing) radiation. Unfortunately, the term “nuclear radiation” raises in society a completely undeserved reluctance, often resulting from ignorance of the importance of ionizing radiation in our daily lives. We do not know or forget that our life on Earth is to a large extent conditioned by the existence of this radiation.

A monograph entitled “Zarys nukleoniki” (“The Outline of Nucleonics”) has been prepared by authors from the Education and Training Division of NCBJ and was

published in 2017 by the PWN publishing company. Its aim is to show the nature of ionizing radiation and the diversity of its applications. For this reason it should serve as a guide to problems discussed in detail in the specialized scientific literature. The authors would like it to become a guide for teachers, natural science students, and even high school students and anyone interested in the issues raised in the book.



Instruments for schools:

Didactic radiation detectors

NCBJ researchers have developed and launched a pilot production of Geiger-Muller counters for didactic demonstrations and exercises in secondary schools. A discharge tube with a length of approximately 180 mm and a diameter of approximately 18 mm forms the heart of the device. The electronics supply and pulse reading system as well as batteries are placed in a small box with a transparent lid, which allows easy visibility of their construction and operating principles. The counter counts high-energy gamma and beta particles (up to several hundred counts per second). Each count is accompanied by a sound signal, and information about their number and frequency is presented on a built-in display. The system can work with a computer. The developers have prepared special

software to facilitate the use of the instrument for teaching purposes. The first copies have already been sent to teachers, and NCBJ is trying to obtain funds to start a programme of short-term loan of equipment sets to interested schools.

Simultaneously with the Geiger-Muller counters, NCBJ actively recommends schools to use the cosmic muon detectors called CosmicWatch, based on plastic scintillators and designed by the Massachusetts Institute of Technology graduate student Spencer Axani. Twenty such detectors were tested at the Education and Training Division of NCBJ and are currently being used in work with teachers. Teaching materials that can help in the effective use of the instruments have also been prepared.



NCBJ DEPARTMENTS AND DIVISIONS

DEPARTMENT OF FUNDAMENTAL RESEARCH

NUCLEAR PHYSICS DIVISION
THEORETICAL PHYSICS DIVISION
HIGH ENERGY PHYSICS DIVISION
ASTROPHYSICS DIVISION

MATERIALS PHYSICS DEPARTMENT

MATERIALS TESTING LABORATORY
NUCLEAR METHODS IN SOLID STATE PHYSICS DIVISION
PLASMA/ION BEAM TECHNOLOGY DIVISION

NUCLEAR TECHNIQUES & EQUIPMENT DEPARTMENT

PARTICLE ACCELERATION PHYSICS & TECHNOLOGY DIVISION
RADIATION DETECTORS DIVISION
ELECTRONICS AND DETECTION SYSTEMS DIVISION
PLASMA STUDIES DIVISION

NUCLEAR FACILITIES OPERATIONS DEPARTMENT

MARIA REACTOR OPERATIONS DIVISION
REACTOR RESEARCH AND TECHNOLOGY DIVISION
RADIATION PROTECTION MEASUREMENTS LABORATORY

DEPARTMENT OF COMPLEX SYSTEMS

LABORATORY FOR INFORMATION TECHNOLOGIES
DIVISION OF NUCLEAR ENERGY AND ENVIRONMENTAL STUDIES

INTERDISCIPLINARY DIVISION for ENERGY ANALYSES

DIVISION OF NUCLEAR EQUIPMENT HITEC

EDUCATION AND TRAINING DIVISION

SCIENCE AND TECHNOLOGY PARK

RADIOISOTOPE CENTRE POLATOM

TRANSPORT DIVISION

Radiation Protection Measurements Laboratory

In 2016 the Radiation Protection Measurements Laboratory successfully continued its activities concerning the improvement of measuring procedures within two domains of the Laboratory which are accredited by the Polish Centre for Accreditation (PCA), namely:

- ▶ The determination of internal body contamination (whole body counter, thyroid counter and radiological analysis of excretions) – Accreditation No. AB 567.
- ▶ Calibration of dosimetric instruments in reference gamma and neutron radiation fields and surface contamination monitors – Accreditation No. AP 070.

Materials Research Laboratory (MRL)

The MRL holds Accreditation Certificate No AB 025 issued by the Polish Centre for Accreditation which permits the performance of destructive and non-destructive tests of materials. Granted in 1995 the Certificate confirms the fulfillment of ISO / IEC 17025: 2005 standards and is continually renegotiated. In addition, MRL holds the second degree Approval No LB-038/27 granted by the Office of Technical Inspection. These certificates confirm the highest qualifications of the employees and the technical reports which they prepare. It should be emphasized that MRL is the only laboratory in Poland which is able to provide accredited measurements in the field of fracture mechanics according to ASTM E399-09, ISO 12108:2011, BS 6835-1: 1998, BS 7448-1:1991 and PN-EN ISO 12737: 2011 standards. The MRL consists of four independent sections: the Hot Cell Laboratory, the Non-Destructive Testing Laboratory, the Laboratory of Mechanical Research and the Laboratory of Structural Research, Corrosion and Chemical Investigation.

Laboratory of Radioactivity Standards (LRS) of POLATOM

The LRS is the competent metrological laboratory in Poland calibrating radioactive solutions of alpha-, beta- and gamma-emitting radionuclides by the use of absolute measuring methods. Calibrated radioactive materials are made available to users in the form of radioactive standards. Absolute measuring methods worked out in the laboratory and unique systems for the measurement of radioactivity make it possible to produce many types of radioactive standards. The LRS has implemented and maintained a quality management system compliant with the international standard ISO / IEC 17025:2005. Confirmation of technical competence as a calibration laboratory is provided by the accreditation certificate awarded by the Polish Centre for Accreditation in December 2008.

The Regional Laboratory of Neutronography

The X-ray Diffraction Laboratory

Laboratory of Spectrometry and Nuclear Electronics

Laboratory of Environmental Protection Physics

Laboratory of X-ray Radiation Physics

Accelerating Structures Laboratory

Radiographic Laboratory

7 labs of PNT



Category A+ scientific unit

In accordance with the recommendations of the Committee for the Assessment of Scientific Units in 2017, the Polish Minister of Science and Higher Education awarded NCBJ the category A+ for scientific units. This highest category was awarded to a group of just 47 units selected from around 1000 rated in all fields of science. There are only four R&D institutes among all 47 scientific units in the A+ category in Poland.

Publications

- ▶ over 500 peer-reviewed publications in 2017
- ▶ h-index 140 (without self-citations)
- ▶ 10 th place in southern and eastern Europe in the “Nature Index 2016 Rising Stars”

Projects and grants (December 2017)

NCBJ participates in 84 projects co-financed from international and domestic sources:

- ▶ 15 projects under the Horizon 2020 programme of the European Union
- ▶ 27 grants from the National Science Centre
- ▶ 8 grants from the National Centre for Research and Development
- ▶ 24 projects financed by the Ministry of Science and Higher Education
- ▶ 3 projects under the European Regional Development Fund
- ▶ 6 projects financed from other sources

Employees, scientific staff (December 2017)

- ▶ over 1100 persons
- ▶ over 200 with a PhD degree
- ▶ over 60 professors and associate professors
- ▶ over 200 with an engineering degree
- ▶ about 300 under 35 years of age

NCBJ main site in Świerk (20 km south-east of central Warsaw)

- ▶ area of approximately 45 ha
- ▶ nuclear research reactor Maria – 30 MW, $>10^{14}$ neutrons/cm²s
- ▶ Świerk Computing Centre (CIŚ) – over 1 petaFLOPS, over 180 terabyte RAM, over 18 petabyte disk storage
- ▶ Science and Technology Park – usable area of 3500 m²
- ▶ research and construction labs with unique devices
- ▶ radiopharmaceutical production plant
- ▶ accelerating structures production plant

COLLABORATIONS

