Centre for
Energy Research

Challenges in nuclear energy, energy security,
environmental protection and materials science
R & D & I Strategy 2020-2025

2020.

Research strategy of the institutes of the Centre for Energy Research

January 2020

In 2020, the Government published the National Energy Strategy, which aims at the full decarbonisation of energy production by 2050, in line with European aspirations. One of the main pillars of the strategy is security of sustainable energy supply and reduction of dependence on imports. To achieve the goals, the combined use of nuclear energy and renewable energy sources will be emphasized. Environmental protection and materials science like energy are priority areas. With the environmental issues related to energy production, it is expedient to expand the framework of energy research. On the one hand, it is very important to form an objective opinion on the environmental and health effects of energy production and on the disposal and recycling of waste generated during energy production. A reassuring settlement of these issues is not only important for the future of nuclear energy but is important in all sectors of energy. On the other hand, the basic part of energy management is the search for energy-saving and environmentally friendly solutions, the development of related new materials and technologies, for which the use of the results of materials science research is essential.

However, materials science, chemistry and analytical research, new functional materials, sensors exploration of the Research Centre a significant contribution to solving societal challenges in health preservation, smart urban development, new to the earlier production and finally, more useful products of cultural assets preservation and origin learn about. One of the important analytical tools for the development of materials science is the study of the interaction between radiation and matter, for which the centre operates a significant research infrastructure (RI) both domestically and internationally. These are the Budapest Research Reactor (BRR), a laboratory based on several electron microscopes, a microelectronics laboratory and laboratories dealing with the biological and chemical effects of radiation. Of these, the BRR is an international RI based on an open application system that implements research proposals from anywhere in the world.

The activities of the Centre for Energy Research are organized around three scientific institutes: i) Institute for Atomic Energy Research (AEKI), ii) Institute for Energy Security and Environmental Safety (EKBI), iii) Institute of Technical Physics and Materials Science (MFA)

1. Energy, environment, and non-destructive analytics

Institute director: Dr. Tamás Belgya

The activities of Institute for Energy Security and Environmental Safety spread out in non-nuclear energy research directions, which can be reached with decades long existing competencies. The Institute has many decades of experience in catalytic chemistry, radiochemistry, nuclear analysis, and environmental physics. Based on the medium- and long-term research strategy renewed in 2012, the Institute's main tasks in response to societal challenges are:

- Research on the transmission and distribution systems and environmental impacts of heat and electricity generation, in which one of **our important goals is to assist in the preparation of energy policy decisions;**
- Experimental research of environmentally friendly, economical and energy-saving chemical methods of energy production and storage processes with the involvement of renewable energies.
- Research on radiochemical and high-efficiency oxidation methods of innovative oxidation and water purification processes;
- Continuous development, refurbishment, and high-level utilization of analytical and imaging experimental equipment operated at the Budapest Research Reactor (BRR) with the **involvement of international and domestic researchers, providing open and excellence-based access** coordinated by the Budapest Neutron Centre (BNC) Executive Board. The necessary renovations, which will allow even an order of magnitude increase in power, are summarized in the Neutron Research Roadmap completed by the end of the previous year, which also proposes a new neutron source after the reactor is shut down;
- Access to the CERIC-ERIC (Central European Research Infrastructure Consortium) distributed infrastructure analytical research work;
- Active participation in university education, using research infrastructure, training of TDK, BSc, MSc, PhD students, as well as foreign researchers delegated by the International Atomic Energy Agency.

Detailed environment of the strategy, domestic collaborations, industrial relations:

BNC is collaborating with Atomki's researchers in the E-RISH PP project, which aims to create a cultural heritage ERIC. In 2018, a new collaboration agreement was reached between the Ecological Research Centre for radiochemical research on drug residues. A relationship will be established with the University of Pannonia for the development of a biofuel reactor system. With TTK AKI, we carry out largely complementary research in the field of renewable energies. Fuel cell electrocatalysts are being developed at AKI, where it is possible to diagnose electrodes containing catalysts (membrane electrode assemblies - MEAs). The latter two connections will take us one step closer to building a link between Energy Research Infrastructures in the National Infrastructure Roadmap.

We cooperate with the University of Pécs in the sub-theme Biomedical Engineering, which is also related to the capacities of the Research Reactor. Our researchers participate in the university education of ELTE, BME, ÓE, PTE, DE, SZTE and SZIE, and contribute to the doctoral training of foreign universities by providing BNC open infrastructure access.

The institute has several domestic and foreign industrial relations, in which measurements based on individual agreements are usually carried out in the framework of R&D.

Research groups implementing the strategy:

The scientific activities of the Institute of Energy and Environmental Safety are organized around five research groups.

Laboratory of Environmental Physics (Applied Physical and Chemical Research in Energy and Environment)

The simultaneous achievement of the climate targets set for 2030 and 2050 and the energy supply targets is a great challenge for Hungary, and these can be achieved mostly through significant electrification of building energy and transport. The laboratory's energy simulation team has achieved outstanding results in recent years by assessing the technical needs for energy storage and network development required to accommodate the periodic surplus production of weather-dependent renewable electricity generation. In the future, stochastic simulations using medium-voltage distribution network type models will be able to determine the receiving capacity of Hungarian network topologies and set requirements for more resilient network topology types, which is an essential condition for further efficient expansion of renewable capacities.

In addition to this research, research on the environmental impacts of energy production and the minimization of these impacts has an important role to play. Therefore, they intend to continue research into the safe disposal of high- level radioactive waste, as well as the impact of radioactive materials released into the air and harmful substances released into the atmosphere during energy production. They are involved in the development of the ESS detector and radiation protection.

Laboratory of Surface Chemistry and Catalysis (Chemical Research of Energy and Materials)

(1) Clean H_2 produced by water decomposition is an excellent source of energy that can make a significant contribution to the stability of a renewable energy economy. We are researching new, cost-effective (photo) electrode catalysts to aid in the production of a H_2 using common chemical elements. (2) Greenhouse CO_2 can be converted into useful products by means of CH_4 or H_2 using appropriate heterogeneous catalysts, the composition-dependent behaviour of which is further investigated. (3) By measuring the ^{14}C content of bio-based (fuel) materials, the biomass component (as opposed to the complex and expensive methods currently used) can be successfully determined by a direct method, which is being further developed and used more widely at international level.

Laboratory of Nuclear Analysis and Radiography (Applied Physical and Chemical Research of Materials and Energy)

The aim of the laboratory is to solve applied research tasks in the fields of materials science, archaeometry, geochemistry, chemistry, and nuclear technology, as well as to fulfil special industrial assignments requiring non-destructive testing with neutron analytical and structural measurement stations and additional X-ray-based techniques. Continuation of internationally recognized research work in the fields of related nuclear physics, nuclear data of reactor materials, methodology, measurement technology and computer simulation, as well as the optimal combination of individual methods. Participation in the CERIC-ERIC distributed research infrastructure and other individual or consortium in the context of the already awarded H2020 IPERION HS (Archaeometry), H2020 ARIEL (Nuclear Data Education), H2020 TOURR (Optimizing the Operation of EUs Research Reactors), H2020 EURAD (Nuclear Waste Management) and V4-Korea-RADCOM (Testing Concrete Raw Materials from V4 countries), and other research and education applications, as well as the work of IAEA, the League of Advanced European Neutron Sources (LENS).

Laboratory of Neutron Spectroscopy (Basic and Applied Physical Research of Material)

The task of the laboratory joining the Institute in 2020 is to operate the existing basic and applied research neutron equipment fleet – six spectrometers – efficiently and to a high standard. In connection to this, both the equipment control and data collection and data processing systems will be gradually renovated. In the medium term, the relocation of two equipment from the decommissioned HZB neutron centre in Berlin, the development and commissioning of a new cold neutron moderator, and a comprehensive upgrade of the neutron control system are expected. At the same time, efforts are being made to implement the Open Data and Display Standards and Open Access standards advocated by the LENS, the user representatives (ENSA) and the CERIC-ERIC. The staff of the laboratory is in intensive contact with MIRROTRON Ltd. in the development of neutron optical products and measuring stations, as well as in the development of ESS measuring equipment. Furthermore, the laboratory participates in the H2020 IPERION HS and H2020 CREMLIN+ (Development of Russian reactor and accelerator research infrastructures) projects.

Radiochemistry Laboratory (Basic and Applied Chemical Research of the Environment)

Maintaining the purity of our freshwater property is a key task, so experimental research into the decomposition of organic matter in wastewater by ionizing radiation will continue. The method under development could be a complementary step to traditional wastewater treatment processes, for which a scientific background is being established. This additional method is particularly important for stable organic matter that cannot be degraded or decomposed using the traditional methods or create resistant bacteria. These include e.g. drug molecules or dyes.

2. Physical materials science

Institute director: Dr. Béla Pécz

The main task of the EK Institute of Technical Physics and Materials Science (EK MFA) has not changed in the recent years: conducting research on nanoscale functional materials, exploring their physical, chemical and biological properties, and harnessing knowledge in integrated nano / micro devices, sensors and non-destructive testing methods. Added to this are materials science studies that belong to the topic of renewable energy. An important task is to help SMEs and university in education, the utilization of the RIs in the higher education (TDK, BSc, MSc and PhD) with Open Access Scheme.

- Demonstration of new sensing devices using basic research results, semiconductor nanofibers, ferroelectric oxides, piezoelectric layers.
- Development of integrated, wearable sensor systems and implantable microsystems for medical purposes. Microfluidic systems for chemical and cell analytical purposes.

- Development of unlabelled optical methods for the study of individual cells. Investigation of cellular responses to drug stimuli by developing sensors.
- Production of new two-dimensional materials, exploration of their atomic and electronic structures, planned modification of their properties with self-developed nanotechnological processes.
- Chemically selective optical vapor detection with bioinspired nanoarchitectures.
- Structural research of modern semiconductor devices, transmission electron microscopy. Development of graphene-doped ceramics and bio ceramics.
- Development of non-destructive material testing procedures for industrial applications.
- Application of the methods of physics to multiplayer biological and social systems.

The strength of the area is indicated by the running ERC grant with Graphene Flagship participation, the 3 Momentum grants and a Leading-edge grant, and several EU H2020 projects. Their infrastructure has significantly improved thanks to the VEKOP project. This will make it possible to achieve new scientific results of international significance.

In 2019, five EU proposals had already been submitted. One of them, an M-ERA.NET applications has just won. Their involvement in international research networks is clearly expanding.

They are carrying out joint developments with industry partners in the field of electronics and sensors for modern healthcare. They transfer results to technology-oriented Hungarian companies.

Their activities are tailored to both economic and social challenges. Their activities primarily related to the industry and digitization issue which belongs to a technical science and physics, but it touches on the topics of energy and health. At the same time, innovations and measurement services are available to industry in the field of Innovation for Competitiveness, a challenge for international scientific success and career guidance (summer school, women in science).

Materials science research is organized around the following seven research groups:

Nanostructures Laboratory

The main research directions of the Nanostructures Laboratory are defined by an ERC Starting Grant, a Graphene Flagship, a running and finalized Momentum project and a Korean-Hungarian Joint Nanosciences Laboratory with a decade-long history in two-dimensional (2D) materials. Activity comprising preparing 2D various materials, structures atomic level characterization and nanotechnology methods of modification, and the exploration of formed nanostructures properties. All this is based on the low temperature scanning tunnelling microscope equipment which is unique in Hungary. In addition to more than ten years of graphene research, today the focus is on new 2D materials as well as on the research of topological insulating crystals. In addition to research on 2D materials, they are still actively researching biologically derived and bioinspired photonic nanostructures.

Their medium-term strategy: To produce new two-dimensional crystals and to explore their electrical, magnetic, optical, and catalytic properties. Atomic precision modification of the structure of these materials to target tuning of said properties. Production of 2D hetero-structures, arrays (artificial crystals) built in layers from different 2D crystals. To achieve the desired properties, the new crystal is built per atomic layer, with precise control of the composition and relative rotation (structure) of the successive layers. Production of new topological insulation materials and investigation of their topologically protected conditions. Optimization of chemically selective optical vapor detection with bioinspired photonic nanoarchitectures and research on the biological formation of such nanostructures. Integrating new materials into demonstration tools.

Thin Film Physics Laboratory

The research directions of the Thin Film Physics Laboratory are the development of various thin films and coatings, the research of modern 2D semiconductor layers and hetero transitions; development of technical and bioceramics, development and investigation of a new type of layered Si_3N_4 / graphene composite and nanostructured calcium phosphate. Furthermore, transmission electron microscopy to develop such tests and microscopy (TEM) sample preparation, test methods and methodical purpose.

Their medium-term strategy: They will continue the research tasks of the "Strategic workshop on the technological challenges of the renewable energy system" VEKOP project, in which new Fe_2S_2 and $FeSiS_4$ layers will be developed and studied. Resumed ceramic composites development FLAG ERA) and the multi-layer Si_3N_4 - Si_3N_4 / graphene - graphene coatings ceramic coatings improve Composites (ERA-FLAG), and the development of nano-structured ceramics is transparent AlON. Their nanostructured bioceramics research reveals the production possibilities of calcium phosphate from eggshells using powder technology and an alkaline method. 2D semiconductor layers and devices (FLAG-ERA) with new physical properties are fabricated and studied. Thanks to the new-generation THEMIS microscope, they are expected to be able to participate in several domestic and international projects, and the Laboratory will receive more requests for industrial cooperation. It is planned to implement *in situ* studies *in a* corrected microscope of the only spherical fault in the country (heated as a first step with a sample holder with MEMS chip heating, to follow phase transitions). Educating potential users of modern transmission electron microscopy will be of paramount importance as it is a new method of characterizing materials and material structures. Their traditional research area is the structure of GaN and wide band gap semiconductors, methodological developments based on electron diffraction and TEM sample production. With the help of these basic research, they show the effect of structure on the properties of newly developed materials, which is essential for the controlled creation of the optimal structure.

Nanosensors Laboratory

The goal of the NanoSensors Laboratory is to apply the latest basic research results in the field of nanotechnology and materials science in new types of physical sensors, especially micro- and nano-sized electromechanical sensors. In connection with this, the Laboratory deals with the research of piezoelectric materials, semiconductor-based nano-sensors, as well as low-consumption and by developing a self-supplying sensor system. The staff operates a unique nanopreparation laboratory in Hungary, which is one of the key experimental infrastructures of the National Quantum Technology Program (HunQuTech). In addition, nano-devices showing memristic coupling on an atomic scale are being developed in another domestic collaboration.

Their medium-term strategy is to develop nanosensor-based prototypes to solve practical problems using the experience gained in systems integration; initiating new topics towards submicron-sized actuators and nanorobots based on knowledge gained in the field of nanomaterials and sensors. In line with previous practice, in addition to domestic collaborations, they also try to research all of these in the framework of international projects.

There are also plans to develop a nano-vibration laboratory that can be used in several modern research topics, e.g. the large figure of merit factor resonators, the szubnanométer field definition actuators and the vibration energy collectors (vibrational energy harvesters). All this would be a significant step towards the independent operation of some detectors without power supply and the development of "narrow band IoT" systems.

Microsystems Laboratory

The staff of the Microsystems Laboratory is working on the development, design, and integration of micro and nanosystems and sensor structures, the application of which may open new perspectives in medical diagnostics, Minimally Invasive Surgical Procedures, and also in the application of energy-efficient autonomous systems (sensor networks, self-driving cars). In addition, their research covers the field of optical applications (spectroscopy) and environmental analysis and safety (gas detection) sensors.

Their medium-term strategy:

Research and utilization of sensing principles applicable in MEMS and NEMS systems in integrated, portable / wearable / implantable, autonomous devices. Development of sensing systems with design and integration of novel and complex micro- and nanostructures for environmental analytical / chemical (gas and pollutant detection), physical (mechanical, optical, thermal), medical (microfluidic, biochemical, physiological and electrophysiological) applications and validation of their operation in real conditions between. Development of special microfluidic systems for sample transport, sample preparation and analysis in Lab-on-a-Chip / Organ-on-Chip devices. Research and development of machining technology for solid-state nanofluidic structures for molecular detection. Infrared light emitting diodes with broadband and multiple characteristic emitted wavelengths (NIR LED) for spectroscopic applications: for environmental analytical, food safety and medical diagnostic purposes, which meets well-founded needs in the direction of the evolving market of today's miniaturized, integrable and portable analytical equipment. Development of functional semiconductor, micro- and nanoelectromechanical structures and their production technology, creation and application of new materials and technological transfer based on industrial needs, for industrial partners at the appropriate level of technological development (TRL1-TRL6, from basic research to prototype).

Photonics Laboratory

The Photonics Laboratory develops unique methods and tools for non-destructive optical and magnetic measurement of surface nanostructures and materials (spectroscopy; magnetic material testing; biosensors; surface curvature; surface purity; water contamination).

Their medium-term strategy: Development and further development of non-destructive material testing and characterization methods: for magnetic testing of industrial materials, single-particle spectroscopic studies and preparation of nanostructures, as well as for optical detection and qualification of surfaces. Exploring new measurement principles, increasing accuracy and reliability, utilizing results in patents, industry and research collaborations, and education. Production and optoelectronic application of self-assembled nanoparticle clusters, plasmonics. Targeted applications include the qualification of structural materials for nuclear power plants and mechanical engineering.

The Photonics Laboratory is successful in both domestic and international applications. In the last two years, they have won 5 new OTKA applications and one M-ERA.NET application. The laboratory is a key partner in a H2020 project developing non-destructive measurement technology at a nuclear power plant and was a participant in a recently completed project with a budget of HUF 1,500 million for zirconium materials science research. The Laboratory performs consistently well in both applied and basic research areas. The base of its domestic and international partners is constantly expanding, as is the repository of developed methods. The self-developed unique capillary probe method should be highlighted, with which the hydrophobic or hydrophilic nature of the surface can be examined more accurately, more reliably and in a wider-angle range than the traditional contact angle measurement. Significant results are also achieved in ellipsometry research dating back 40 years, where the laboratory is a respected member of the international research community (the head of the laboratory is the first winner of the most prestigious Drude Award in ellipsometry , founded in 2007). Most of their methods have been expanded in recent years with significant new innovative solutions: e.g. combinatorial materials science, *in situ* mid-infrared ellipsometry, *in situ* bioellipsometry, new magnetic and Makyoh topographic methods, microfluidics for single-particle spectrometry, further development of photoluminescence.

Nanobiosensors Research Group

The Nanobiosensorics Research Group focuses on the development and application of unlabeled optical biosensors and combines these instruments for unique cell manipulation techniques. Their research topics are broad; they range from cell adhesion kinetics, migration, signalling to mathematical modelling of measured biological signals.

Their medium-term strategy: Their main goal is to develop a highly sensitive and reliable, unlabeled optical method (s) that will be able to monitor a single cell from a heterogeneous cell population. To this end, the developed optical sensors are combined with single-cell manipulation techniques (micropipette, FluidFM) to pick up and place the individual cells examined. A further aim is to produce functional surfaces with well-controlled chemical, mechanical and geometric properties. Various compounds (anticancer agents, exosomes, other cells) are added to the cells and tissues and their reaction is monitored. Optical and biophysical theoretical models are being developed to interpret the kinetics of the measured signals and changes.

Complex Systems Laboratory

The traditional field of research of the Complex Systems Laboratory is statistical physical analysis of equilibrium and non-equilibrium systems, which has begun to expand in recent years with the application and development of learning algorithms.

Medium-term strategies: a systematic exploration of phenomena and mechanisms to support the continuation of cooperation in the biological and social systems, including epidemics spread similar evolutionary processes and the four basic game strategy analysis of the interplay of media effects. Using the concepts and tools of statistical physics, the effect of heterogeneities is studied in dynamic models close to the critical state, which e.g. they can also be electrical or neural networks. An explanation for the stability and scale-free behaviour of such systems is sought in line with real measurements. By developing different self-learning algorithms, the relationships and historical connections between folk songs and features hidden in genetics data are examined.

3. Atomic Energy Research Institute

Institute director: Dr. Ákos Horváth

According to the outlook of the National Energy Strategy, the share of nuclear energy use will not decrease in the coming decades. All this also means that maintaining the competence that underpins the domestic nuclear safety culture is a long-term goal. The main custodian of nuclear competence is an independent research institute, which can act as a technical scientific background for both the operator and the licensor. An important part of the mission of the Institute is to cooperate with universities and doctoral schools to maintain competence.

The main chapters of the Strategic Program for Nuclear Energy Research are:

1. Maintaining and expanding the existing competence in the scientific issues of nuclear energy for the long-term operation of the Paks nuclear power plant units and intensive professional participation in the construction of the new Paks units,
2. Participate in the development of future technologies, contribute to the development of nuclear fusion-based energy production and fourth-generation nuclear power plants, and solve the nuclear fuel cycle closure.
3. Strengthening competence in radiation protection and nuclear safety issues related to the use of nuclear energy.

The nuclear safety related research and development tasks in nuclear power plants of different generations around groups: the existing Paks blocks belong to the second generation, the new blocks to the 3^{rd} generation, while the 4^{th} generation will be realized in the long run. Some of the research and development tasks concern the fate of spent fuel and radioactive waste. These tasks are partly related to existing and new Paks units and storage facilities, but in the longer term, Generation 4 reactors offer a radically new opportunity: closing the fuel cycle, ie exploiting the full potential of spent fuel fission through recycling, and thus decisive reduction of radioactive waste generated.

Among the international relations of the institute, the relationship with the International Atomic Energy Agency in the field of nuclear safety and security research should be highlighted. As a milestone in recent decades, the EK concluded a cooperation agreement with the IAEA in 2016 in the field of nuclear forensic analytics.

We cooperate in the field of research on the safety of nuclear reactors in the OECD Nuclear Energy Agency (NEA) and the EURATOM. In addition to research collaborations, EK staff participate in several expert organizations in the fields of fusion energy, major accidents, radiation protection and structural integrity, among others. The EK organizes scientific cooperation since 1990 VVER reactors operating in the country (AER), which helped develop several innovative ideas. AER cooperation has been operating for thirty years without external funding.

The EK is a founding member of the V4G4 Center of Excellence, which organizes nuclear cooperation between the V4 countries and aims to build a demonstrator of an innovative, high-temperature gas-cooled reactor. The achievement of the objectives has also been / is being supported by EURATOM by funding several successive research programs.

The annotated chapters of the Strategic Research Plan of the Atomic Energy Research Institute are the following:

1. Multi-scale integrated thermal-hydraulics and reactor physic models and simulation tools development:
   More accurate modelling of the physical and chemical processes taking place in nuclear equipment is possible with integrated developments (multi-physics*)* linking the individual disciplines, which at the same time reduce the unnecessary conservatism of previous calculations. Multiscale modelling will be required for deterministic safety calculations that combine reactor physics, fuel behaviour, and thermohydraulic analyses.
2. Research of reactor structural materials:
   The safe operation of reactors also depends to a large extent on the integrity of the structural materials. The built-in materials are exposed to neutron radiation, high temperatures, high mechanical stress, and erosion. Research focuses on the aging of structural materials, with reference to the effects of neutron radiation and extreme conditions, such as reactor accident conditions.
3. The fourth-generation reactors, nuclear fusion-based energy production, the modernization of radioactive waste and fuel cycle treatment:
   The nuclear energy generation to another, radically different way of controlled be applying nuclear fusion, which is like the processes taking place in the Sun produces energy by combining hydrogen isotopes to heavier atomic nuclei. Research requires the development of high-reliability, fault-tolerant, custom tools, which can only be achieved through the close collaboration of engineers and physicists working in the field and the procedures common to fission power plants. The nuclear energy sustainability depends also on how the fresh fuel replenishment and management of spent fuel can be solved in the long term. The solution to the two issues, i.e. the closure of the fuel cycle, is facilitated by the use of fourth-generation fast reactors.
4. Research related to the safe operation of nuclear power plants:
   Scientific support for the power plant will also be needed during the extended operation of the operating Paks units. In addition, a need to prepare for the new technology to support

licensing of blocks. The tasks formulated for the effective management of aging and the maintenance of competence are covered in this chapter.

5. Radiation protection, research on the biological effects of radiation, nuclear chemistry: Research on radiation protection, activity propagation calculations, and the biological effects of low doses are covered in this chapter. Space dosimetry activities focus on the development of active and passive dosimeters and space weather monitoring to effectively protect space assets.
6. Nuclear security research related to the peaceful uses of nuclear energy: Development of the experimental background necessary for the analysis of nuclear materials, as well as the operation of qualified operating staff and a nuclear forensic laboratory equipped with modern equipment. One of the important applications of the activity is the provision of modern training programs and related technical background (test laboratory suitable for the examination of radiation detection systems, a team of experienced specialists).

4. Cooperation with domestic institutes and organizations

Energy, environment, and non-destructive analytics

BNC is collaborating with Atomki researchers on the E-RISH PP project, which aims to create an archaeometric ERIC. In 2018, the Ecological Research Center signed a new cooperation agreement with radiochemical research on drug residues connection. A relationship will be established with the University of Pannonia for the development of a biofuel reactor system. With TTK AKI, we carry out largely complementary research in the field of renewable energies. Fuel cell electrocatalysts are being developed at AKI, where it is possible to diagnose electrodes containing catalysts (membrane electrode assemblies - MEAs). The latter two connections will take us one step closer to building a link between Energy Research Infrastructures in the National Infrastructure Roadmap.

We cooperate with the University of Pécs in the sub-theme Biomedical Engineering, which is also related to the capacities of the Research Reactor.

Physical materials science

There are no parallels, complementary activities with other ELKH institutes and universities. Such as e.g. the National Quantum Technology Program (HunQuTech) program, the preparatory background for which is largely provided by MFA.

The semiconductor technology equipment of MFA is used in the clean laboratory by the Institute of Physics of BUTE for teaching and research purposes.

Most of their senior staff teach in various courses of ELTE, BME, ÓE, PPKE, SE, PE, DE, ME, SZTE, PTE, mainly in PhD training. Their doctoral are members of doctoral schools, doctoral and habilitation councils of the above universities, several are founders of doctoral schools or core members. Our staff regularly holds internships in the preparatory and analytical laboratories of the institute for undergraduate and postgraduate courses at universities (without any external financial compensation).

In one of the topics in Nanobiosensory (out of five), they are collaborating with the University of Pannonia, in which PE provides flagellin proteins and the antibacterial layers are made from them in the MFA.

Nuclear safety and security

The EK is a founding member of the Sustainable Atomic Energy Technology Platform and the Hungarian Nuclear Fusion Technology Platform, which coordinate domestic nuclear research directions with relevant research, industry, and government actors. The Bay Zoltán Alk. Kut. Institute of Structural Integrity Department is old partner of EK within the framework of the Platform and other EURATOM organized projects. Additional complementary cooperation exits with the Atomki and the BME NTI-TV. In joint domestic and international projects we cooperate with the experts of NUBIKI, TÜV Rheinland Kft, ELTE, the University of Debrecen and the University of Pannonia, which is mostly based on the rational sharing of professional competencies and research infrastructures.

We cooperate with the Emergency Police and the Counterterrorism Centre in the field of nuclear forensics. Several staff members teach at Hungarian universities (e.g. BME, ÓE) and participate in the councils of doctoral schools.