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I. Main duties of the research unit in 2017

The main duty of the institute in fundamental research focusing on atomic, nuclear and particle physics, as well on nuclear astrophysics was carrying out aligned, cutting edge research work with large-scale international collaborations, making balanced use of the local research infrastructure and that of the leading international research centres. Compared to the previous years, launching the GINOP projects (operative program for economic development and innovation, funded by the government from EU sources) won in 2016 represented a new administrative and technical task. In relation with these, beginning the reconstruction of the building housing the Laboratory of Climatology and Environmental Physics (ICER) played a central role. Further tasks in 2017 were participating in university education, training of PhD students and international specialists, as well as organizing outreach activities to promote sciences.

II. Outstanding research and other results in 2017

II. a) Outstanding research results

Theoretical Physics

(D×D)-dimensional positive partial transpose (PPT) states have been constructed, which violate, for any D>2, a bipartite Bell inequality. It is known that separable states are PPT, and such states cannot give rise to Bell violation. Nonseparable PPT states are called bound entangled states. It is conjectured that the proposed class of Bell inequalities acts as a dimension witness for bound entangled states: For any D>2 there exists a Bell inequality from this class that can be violated with bound entangled states only if their Hilbert space dimension is at least D×D. Numerics supports this conjecture up to D=8.

For Coulombic systems the eigenfunctions exhibit peculiar properties at those points, where the spatial coordinates of two or more charged particles coincide. The behaviour of the wave function is described by the so-called Kato cusp (KC) equations. Two-electron atoms have been described in terms of Hylleraas- and Kinoshita-type basis functions, and the fulfilment of the KC equation has been studied. It was shown how the Kato's cusp conditions restrict the range of the employable basis functions. The coefficients defining the superposition of the correctly chosen basis functions are also restricted. The corresponding equations were refined, and test functions satisfying the KC equations have been given. It was found that the fulfilment of the KC equations leads to a more efficient description of photo-ionization processes.

Thin layers of materials attached to a substrate get cracked during solidification, which leads to breakdown. However, the control of the emerging crack pattern opens up novel applications. A discrete element study was performed to understand how shrinkage induced crack patterns can be controlled by varying the amount of materials' disorder. It was shown that for low disorder, a cellular crack pattern emerges with a log-normal distribution of fragment sizes. Increasing the amount of disorder, a transition occurs to a percolation phase, dominated by the random nucleation and merging of cracks, which gives rise to a power-law

size distribution. It was shown that crack formation can be controlled by the microscale materials' disorder, which has a high potential for applications in microelectronics.

Foreign experiments have verified the prediction of the multichannel dynamical symmetry (MUSY), developed previously in Atomki. This symmetry connects the energy spectra of different configurations of the atomic nucleus, e.g. those of quartet (shell) model, core+alpha, or exotic cluster states. In an inelastic alpha-scattering experiment the high-lying alpha-cluster states of the ^{28}Si nucleus were found with 0^+ spin-parity. MUSY is able to give a detailed prediction of this spectrum, based on the quartet-model description of the low-energy spectrum. The experimental result was found to be in good agreement with the theoretical prediction. Further support for the predictive power of this symmetry comes from the fact that it was able to predict the high-lying ^{12}C+^{16}O spectrum as well, in good agreement with the experimental data.

The mechanism of level crossing was studied in exactly solvable complex quantum mechanical potentials, by tuning the coupling coefficient of their imaginary component. In contrast with real potentials, level crossing is possible for PT-symmetric potentials (i.e. those invariant with respect to the simultaneous space and time inversion). In particular, energy levels carrying different n (node number) and q (quasi-parity) quantum numbers can cross. The first example for this in the literature was the Scarf II potential, for which it was demonstrated that the two energy eigenfunctions become linearly dependent at the crossing point. The present study, illustrated also with three concrete examples, proves that this phenomenon is a general feature of Natanzon-class potentials

Particle Physics

In heavy-ion collisions, rapidly moving heavy ions produce strong magnetic fields that can influence the transition from the hadronic to the quark-gluon plasma (QGP) state. Most often the influence of this magnetic field on the QGP is studied within the framework of low-energy effective models, as approximations of the QCD. The quark states are usually approximated with the lowest Landau level of free charges moving in a background magnetic field. The accuracy of this approximation has been studied using lattice simulations. It was found that for strongly interacting quarks, only the lowest Landau level can be identified unambiguously. Its contribution to various physical quantities has also been determined.

The localization transition has been studied in the SU(3) gauge theory. It is well-known that the transition of strongly interacting matter from the hadronic to the QGP state is accompanied by an Anderson-like transition of the lowest quark eigenstates. While the localization transition occurs at a well-defined temperature, the cross-over to the QGP would become such a sharp transition only if the quark masses were substantially higher. Using such a model with heavy quarks, the critical temperature of the localization transition has been determined, and it was found that it exactly coincides with that of the thermodynamic transition to the QGP. This result contributes to a better understanding of the transition to the QGP state.

There is a mapping between the O(2) and the sine-Gordon scalar field theory and also between the XY spin model and the 2D Coulomb gas. This also means that these theories belong to the same universality class. The mapping between the O(2) and the sine-Gordon model is only approximate, but it can be made exact by taking into account amplitude fluctuations. However, the resulting sine-Gordon model will differ from the usually considered one. A recent study of the O(2) model showed that contrary to experimental

results, amplitude fluctuations can modify its phase structure. Using the functional renormalization group method, the phase structure of the sine-Gordon representation of the O(2) model has been studied, and the role of the amplitude fluctuations has been clarified.

In addition to the basic activities related to the position monitoring system (M&O) for the CMS, work was carried out on the position measuring system for the GE1/1 muon trigger detector and on the positioning measurement of the newly developed strip detectors in the coordinate system of each component. Additionally, the development of fiber optic sensors based on LPG technology was continued under the research agreement with the EP-DT group of CERN. Based on the experience gained during the previous years, the aim of the experimental work was to understand the physical background of repair mechanisms that occur in the LPG sensors after each irradiation.

Components were developed and delivered for foreign large equipment: In collaboration with the Brookhaven National Laboratory (Phenix), the calibration method for the planned SiPM based sensors (third derivative method) has been developed to renew the ECAL readout system. Furthermore, the multichannel electronic system for calibration has been developed and manufactured. The SIM unit of the RF-LPS Interlock system has been developed and delivered in the framework of the ESS-ERIC project. The SCB prototype has been built for transforming the signals of the technical units of the RF system. Parametric and system integration tests of the SCB prototype were carried out.

Nuclear Physics

In order to check and clarify earlier experimental results connected to the dark matter, which created a great interest in the field, the electron-positron spectrometer was moved to Atomki's new Tandetron Accelerator Laboratory. Modern DSSD (Double Sided Silicon strip Detector) detectors have been used to replace the gas-filled detectors used for angular measurement. The data collection system has also been significantly upgraded. The previous measurements were repeated and the anomaly observed in the ^{8}Be 18.15 MeV transition was successfully reproduced, allowing to put a more precise constraint on the mass of the new particle.

A novel method for measuring nuclear reactions in inverse kinematics with stored ion beams was successfully used to extract the nuclear-matter radius of ^{58}Ni. The experiment was performed at the experimental heavy-ion storage ring at the GSI facility. Elastic angular distributions were measured on internal helium gas-jet target. The angular distributions were fitted using density-dependent optical model potentials within the eikonal approximation. This pioneering experiment demonstrates a major breakthrough towards future investigations with far-from-stability stored beams using the present technique.

According to the classical liquid drop model, depleted central densities are unexpected in atomic nuclei. However, in the nuclear shell model bubble-like structure will arise if the $s_{1/2}$ single particle orbitals, which can be found in the inner part of the nucleus, are almost empty, while the higher angular momentum orbitals, which are located in the outer part of the nucleus, are fully occupied. The neutron-rich ^{34}Si nucleus was studied in an international collaboration using radioactive ion beams. It was found that the proton distribution of this nucleus exhibits a bubble-like structure, while its neutron density is constant.

According to the nuclear shell model, protons and neutrons move in orbitals, which are grouped into shells separated by energy gaps. The so-called magic nuclei, in which the shells

are completely filled, are extremely stable. Studying the structure of the nucleus ^{79}Cu in an international collaboration, Atomki researchers showed that the structure of this nucleus can be described as a valence proton outside a ^{78}Ni core, in which both the proton and the neutron shells are closed. Thus, ^{78}Ni is one of the most neutron-rich doubly magic nucleus.

Atomki participated in the installation of the AGATA (Advanced GAmma Tracking Array) γ-spectrometer at the GANIL facility, Caen, France. It exploited the stable and radioactive heavy-ion beams delivered by the cyclotron accelerator complex of GANIL to address in-beam γ-ray spectroscopy of exotic nuclei. Development works on the firmware of the NUMEXO2 digital signal processor, used for most of the ancillaries, made DIAMANT, the charged-particle detector system of Atomki, an integral part of the AGATA+DIAMANT +NEDA set-up to be used in the 2018 experimental campaign.

Atomki researchers studying the island of deformation at N=60 in an international collaboration using the AGATA γ-detector array at GANIL identified the second 4^+ excited state in the neutron-rich ^{96}Kr nucleus. The deduced energy ratio of the second 4^+ to the first 2^+ states in ^{96}Kr confirms that Kr is the low-Z edge of the island of deformation at N=60. However, its unexpectedly low value is in contradiction with the smooth development of collectivity observed before in krypton nuclei, and shows a rapid onset of deformation.

The ^{17}O(p,γ)^{18}F reaction plays an important role in hydrogen burning processes in several different stages of stellar evolution. As the first completed scientific project at the new Tandetron accelerator of Atomki, the cross section of this reaction has been measured in a wide energy range. The astrophysically important total cross section has been determined with the activation method, which has never been applied in the studied energy range before. The measured data aided by R-matrix analysis confirmed the literature cross section around the low energy resonances, while lower direct capture cross section was recommended at higher energies.

The nuclear physics input of astrophysical γ-process model calculations has been tested by measuring the α-capture cross section of Ir isotopes. The experiments have been carried out by a novel technique: the combination of thick-target yield determination and X-ray detection. The high sensitivity of this method allowed the study of these reactions for the first time. The measured data have been compared with statistical model calculations and it was found that the recently suggested modification of the α + nucleus optical potential gives a good description of the results.

The LUNA collaboration has proved that the rate of the ^{17}O(p,α)^{14}N astrophysical reaction is about a factor of two higher than estimated so far. Based on this result, the long-standing puzzle of the origin of heavy oxygen isotopes has been solved. The result provides direct evidence that 4-8 solar mass stars produced some of the pre-solar grains found in the Solar System, and thus these stars contributed to the dust inventory from which the Solar System formed.

Applied Nuclear Physics

There are various liquid materials whose elemental composition is of interest in various fields of science and technology (e.g. biological samples, mineral oil, etc.). However, the sample preparation can be complicated, or would destroy the original environment before the

analysis. Standard solutions of several metal salts and human blood samples were analysed by external PIXE-PIGE method, elemental concentrations were determined for various major and trace elements (e.g. Na, P, S, Cl, K, Ca, Fe, Cu, Zn, Br).

Polydimethylsiloxane (PDMS) has been used so far in micro and nano-lithography as a mold. In this work Atomki scientists have shown that PDMS can also be used as a positive or negative resist for direct writing, depending on the applied developer chemical. It was concluded that KOH or NaOH was suitable to develop the material as a positive resist, as the irradiated areas were removed with an etching speed depending on the ion fluence. On the other hand, H_2SO_4 was used to remove the unirradated material, i.e. negative resist behaviour. Resistance tests showed that the final micro-structures became stronger against organic solvents than the original material.

Within the IPERION CH H2020 project, among other activities, the geochemical characterization of chert sources in the Pyrenees was performed with the aim of comparing the results with archaeological finds from the Magdalenian culture. In cooperation with the Hungarian National Museum, the elemental composition of gold objects from the Bronze Age was determined. On the request of the Hajdúsági Museum, the elemental composition of locally found situlae was given. These are large vessels, probably used for mixing and storing liquid. The results contributed to the clarification of the origin of the so-called second situla of Hajdúböszörmény, seized by the police on suspicion of illegal trading.

The Positron Emission Tomograph (PET) was used for investigation of micro-element uptake by field crops. The uptake and the bio-distribution of manganese in plants and nitrogen-fixing bacteria, living together in symbiotic connection were studied with miniPET camera. Another application of PET method was the dynamic imaging of separation and transport processes. The separation efficiency was followed by imaging of radio-labeled compounds during gradual separation. This method was also used for imaging and analyzing of ^{11}C-labeled methanol-olefin reaction on a new and high efficiency catalyst column.

During the investigation of the wear of machine parts, it became necessary to determine and prove the homogeneity of the produced activity. To measure and certify the homogeneity, a new method was developed by using the newest version of miniPET device constructed by Atomki. The activity distribution was determined by measuring the positron emitter isotopes.

Cross sections of nuclear reactions for production of medically related radio-isotopes were determined. New experimental reaction cross sections were gained, which support establishment of reference data bases, assist by the development of theoretical models, as well as involve the practical application of the data. Al, Ti, Cu, Mo, Cd, Tm, Y, Zn, Zr and Ir target materials were investigated. The new on-line version of the IAEA monitor reaction data base was prepared, and the experimental data were compiled for the EXFOR data base of IAEA.

New high efficiency isolation methods of radio-terbium from massive (>500 mg) Gd target have been developed. Four radioisotopes of terbium can be used in radio-biological research and nuclear medicine (cancer therapy: ^{149}Tb and ^{161}Tb; SPECT diagnostics: ^{155}Tb; PET diagnostics: ^{152}Tb). The radio-terbiums combined with bio-targeting agents have great potential to accelerate the ‘theranostic’ (combining the diagnostic and therapeutic isotopes into a single agent) research and clinical progress.

Atomic and Molecular Physics

In connection with a recent experimental study, the process of single ionization in 75 keV p + H_2 collision system has been investigated theoretically. The calculations were performed in the continuum distorted wave model within the framework of the two-effective centre approximation. Theoretical results for the multi-differential cross sections, as compared to earlier ones, showed much better agreement with the measurements, especially for large values of the momentum transfer. The measured projectile angular distributions were also reproduced reasonably well for both coherent and incoherent proton beams.

Water molecules were bombarded by 1 MeV H^+, 1 MeV He^+ and 650 keV N^+ projectiles. Fragmentation cross sections have been determined from the energy and angular distribution of the fragment ions originating from the Coulomb-explosion of the molecules. From the individual fragmentation channels, multiple ionization cross sections have been deduced, and compared with the results of classical and quantum mechanical calculations, performed within the framework of the independent particle model (IPM). The experimentally obtained distributions of the multiple ionized states were interpreted on the basis of the theoretical results. The limitations of the IPM approximation with the increasing perturbation strength were pointed out.

Magnetically trapped and microwave generated plasma was investigated by a home-developed device designed for plasma diagnostics. The instrument is able to record the detailed temperature and density map of a plasma by taking voltage-current characteristics by four automatically moving Langmuir probes. A batch process computer code was developed to analyse the recorded data. The research group is participating in the H2020 ENSAR2/MIDAS collaboration, within the framework of which a successful scientific hands-on training was organized for four foreign visiting researchers.

Photo-absorption properties of negative endohedral fullerene ions ($Sc_3N@C_{80}$) were investigated in the region of the L-shell ionization threshold of scandium at the PETRA-III synchrotron in Hamburg. Measurements were carried out within the collaboration of Atomki, Justus Liebig Universität (Giessen) and the DESY synchrotron laboratory. By analysing the final charge-state distribution of the ions, the resonant excitation process for the Sc L shell and the subsequent cascade Auger-electron emission was successfully demonstrated.

The photo-ionization of astrophsically relevant iron ions has been studied by detecting the Fe ions in different final states (Fe^{q+-ne}, n=1,2,…7) originating from different initial states (Fe^{q+}, q=1,2,3). The measurements were carried out at the Petra III synchrotron in Hamburg. Single- and multi-photoionization of Si^+ ion has also been investigated in the energy range of the resonant excitation of the K shell. Cross sections excited by 1800-2000 eV photons were also measured for mapping the resonance structure.

The time dependence of the deflection of ions transmitted through a conical glass capillary has been applied - as a kind of an ideal electrometer - for the determination of the potential at the insulator surface. It was demonstrated that the potential can reach the value of 500 V, even in the case of single charged ion impact. This may open a way to increase the ion transmission of conical capillaries, which is important for potential applications. The arrangement is also applicable for the determination of leak currents. It was proved that the

secondary electron emission may significantly influence the growth of the capillary potential, as the result of which, Coulomb blocking effects can be avoided.

Surface Physics

The electron spectrum of a nano-crystalline type transition metal oxide cathode of double layered electric capacitors (supercapacitors) was studied by two methods. While chemical states of nano-powders containing Co, Ni, Mn, Zn, O, N and C elements were determined by photo-electron and Auger electron spectra, the forbidden band gap was determined by another method. The nano-powders were prepared by the cooperating partner, the Materials Research Center, Tehran. Based on these nano-powders, supercapacitors were prepared and their charge storage capacity was checked experimentally. It was experienced that even after 1000-2000 charge-discharge cycles the capacitance, energy and current densities stayed unchanged.

Optical parameters of transition metals were derived by Monte Carlo simulation from electron spectra measured experimentally. Energy loss spectra of Ni and Fe were measured at primary energies of 1-3 keV. Using the experimental results, the Chinese cooperating partner (University of Science and Technology, Hefei, Anhui, China) determined both the optical parameters and inelastic scattering free paths of Ni and Fe by derivation of energy loss function from 0-100 eV (Fe) and 0-200 eV (Ni) energy loss spectra. The measurements resulted in more accurate optical parameters than those obtained previously from optical measurements.

The absolute determination of optical functions of materials was shown by the help of a newly developed inverse Monte Carlo technique and of backscattered electron energy loss spectra. The method applied a precise modelling of electron transport processes by global optimization of energy loss function. After checking the calculations by the f and ps summation rules, optical constants of materials and electron inelastic free paths were given.

Iron and carbon steel surfaces coated against corrosion by hot-dip galvanization using Zn-Ti and Zn-Mn alloys were studied. It was shown by photo-electron and mass spectrometry measurements that in the coating of Zn-Ti alloy the Ti-oxides (TiOx) have different oxidation states as a function of depth, and form a layered structure. The formation of the layered structure is determined by the chemical composition of the liquid alloy and the cooling speed of the coating layer. It was shown that at nanometer scale the activation energy of layer creation equals with the activation energy of surface roughness creation. Revealing the layered structure of TiOx is a novelty from the point of view of technical and materials sciences.

The crystal growth characteristics of semiconductor tellurium nano-wires synthesized by wet chemistry have been investigated in crowded solutions of inert macromolecules. The kinematic behaviour of the synthesis was studied by systematic measurements of the time-resolved concentration and the geometrical parameters of the nano-wires. This field of research is relevant both to materials science and to biology. In biological systems, macromolecular crowding plays a crucial role in biochemical processes as a non-specific catalyst, and its deeper understanding is important for engineering the stability and functionality of inorganic nano-particles, which were entered or transferred into living organisms.

Environmental Science

Based on systematic K-Ar geochronological survey of the Main Ethiopian Rift (MER), two distinct magmatic periods have been recognized. The pre-rift volcanic sequence comprises basaltic lavas and rhyolitic ignimbrites and can be dated between approximately 38.5 Ma and 22.3 Ma. The late syn-rift volcanic sequences (mainly basaltic lava flows and minor rhyolitic breccia) originate from ages between 1.2 Ma and 0.5 Ma. In the formation of the Bale Volcanic Complex (BVC) belonging to the studied territory, the magmatic activity reflect long-lasting evolution taking place for about 20 million years.

Noble gas analytical measurements (He, Ne, Ar, Kr, Xe) were performed on the Kaba meteorite that landed near Debrecen in 1857. The noble gases were extracted from the samples by stepwise heating (at 600; 800; 1000 and 1800 °C). A cosmogenic exposure age for the meteorite was calculated from the Ne isotopic concentrations. Its more precise, newly determined age (12.1 Ma) is slightly higher than the 11.8 Ma obtained previously. The estimated radius of the meteorite is ~ 15 cm, thus, it is somewhat larger than it was previously thought (i.e., ~9-10 cm). It might have experienced a rather small ablation loss of roughly 70%. Based on the Xe isotopic ratios, its inferred abundance of pre-solar nano-diamonds in Kaba is ~500 ppm. This value is much higher than that of the reference Allende meteorite, attesting to Kaba's more primitive nature.

New evidences have been discovered to demonstrate that North Atlantic climatic events had significant impact on the climate and palaeo-environment of Europe and the Carpathian Basin. Accelerator mass spectrometry based high-precision radiocarbon dating has been performed on small shell and charcoal samples from the Dunaszekcső loess deposit sequence profile. Using the more precise calibration data set and Monte Carlo simulation, it was possible to reconstruct the age-depth model of the loess deposit. The elaborated loess sedimentation rate, dust flux, and the stable isotope results of the shell remains, as well as the size distribution of the deposit matrix and quartz crystals gave essential information about the palaeo-environmental changes in the study area.

Ten marine reservoir effect (R) values were obtained from archaeological shell-middens along the San Matías Gulf, North Patagonian Atlantic coast, Argentina. They were determined by ^{14}C dating on marine shell and charcoal samples derived from a common stratigraphic unit. The R values fluctuate between 205±48 and 358±56 ^{14}C years from ca. 5300 to ca. 700 ^{14}C years, with no obvious temporal trend. The mean R value obtained (266 ± 51 years) constitutes a useful value for correcting ages in shells found in other deposits.

Detailed study of the distribution of S and O stable isotopes has been carried out on the gypsum deposits formed in the Provalata Cave (Macedonia). Only few studies apply combined use of S and O stable isotopes in cave sulfates to further understand the processes operating in sulfuric acid speleogenesis. Positive correlation has been found between the $\delta^{18}O$ and $\delta^{34}S$ values, which can be attributed to environmental control or isotope effects during multi-step microbial oxidation. Additionally, a shift in $\delta^{34}S$ values prior to the H_2S oxidation indicates a changing composition of the sulphur isotopes.

The ^{190}Pt and ^{186}Os isotopes are frequently used in the field of geochronology and cosmochemistry. The currently used half-life of ^{190}Pt is $6.5(3)\times10^{11}$ years had to be refined due to the wide range of published values (2×10^{11} - 12×10^{11} years). For this study, a low background double grid Frisch-type ionisation chamber was built within an international

cooperation. The isotopic composition of Platinum used for the measurements was determined by laser ablation inductively coupled mass spectrometry. According to the results of the measurement, the abundance of the ^{190}Pt isotope in the used sample differed slightly from the natural value, which had to be taken into consideration in the determination of the half-life. The suggested half-life of ^{190}Pt was $T_{1/2} = (4.97 \pm 0,16) \times 10^{11}$ years.

Intensive spread and use of MRI applications lead to increased release of gadolinium based contrasting agents (GBCAs) to waste waters. Uptake of frequently used contrasting agents (Dotarem and Omniscan) by four aquatic plant species was investigated under laboratory conditions. Concentration dependent uptake was determined, and significant accumulation of gadolinium could not detected. Gadolinium leached out completely; in the case of duckweed the half-life of Omniscan and Dotarem was 1.9 and 2.9 days, respectively. Significant biofiltration of GBCAs by common macrophytes could not be detected, therefore constructed wetlands are not expected to reduce the concentration of GBCAs in waste water.

Daily aerosol samples were collected in a synchronized way in five Hungarian cities (Budapest, Debrecen, Miskolc, Nyíregyháza, Pécs). Based on the concentration and elemental composition of the samples, as well as on their organic, inorganic, fossil and modern Carbon content, the source of the aerosols and their contribution to air pollution were determined. The role of aerosols originating from long-range transport were also studied. The following pollution sources were identified based on receptor model calculations: soil, secondary aerosols from regional transport, biomass burning, oil combustion, traffic, seas salt and biogenic emission. The geographical origin of episodes occurring in the five cities were determined using dispersion model calculations.

An intensive two-week aerosol measurement and sample collection campaign was conducted in central Budapest during a mild winter. Besides online analyses, elemental carbon, organic carbon, levoglucosan and other components were determined, and radiocarbon analysis was performed on the aerosol samples. A novel, straightforward coupled radiocarbon–levoglucosan marker method was introduced for the source apportionment of the major carbonaceous chemical species. Elemental and organic fractions were associated with different fossil fuel combustion sources. Most elemental components were emitted by vehicular traffic, while the source of organic components was mainly domestic and industrial heating.

Tritum, radiocarbon and radiocaesium measurement were performed from depth water columns collected in 2011 and 2012 at the coast of Fukushima and in the western parts of the North Pacific Ocean. The highest ^{134}Cs and ^{137}Cs values, which were 3 orders of magnitude higher than the level before the accident, were measured at the coast of Fukushima. The tritium level increased to a lesser degree; it was only six times higher than the natural level, while the growth of the radiocarbon was only 9%. The direct emission of the strongly contaminated water body, furthermore the fall and wash out from the damaged Fukushima power plant significantly changed the concentration of these isotopes in the seawater of the North Pacific Ocean.

Separation technique for the determination of the ^{107}Pd content of liquid radioactive wastes has been developed. For the improvement of the radiochemical separation procedure in regard of the complete decontamination of fission and activation products, liquid form ^{103}Pd tracer has been produced using acidic leaching on cyclotron irradiated $RhCl_3$ targets. The gamma-emitting tracer allowed for the improvement and optimization of the separation

procedure applied to actual waste samples, with special attention to silver isotopes, which are responsible for considerable interferences during ICP-MS measurements.

II. b) Science and society

Activities of Atomki reaching the public in 2017 were *the European Science on Stage Festival, Researchers' Night, Physicists' Days* and hosting visiting groups.

Atomki was the co-organizer of the 10th jubilee event of the *European Science on Stage Festival* (2017.06.29-07.02) taking place in Debrecen. About 400 elementary and secondary school science teachers from 30, mainly European countries met to exchange their experience and innovative teaching methods. They presented their best experiments and teaching practices in a fair, workshop events and stage performances. Atomki researchers played active role in the international jury, and Atomki offered one of the special prizes, the one awarded to the technically most demanding experiment.

The central event of *Researchers' Night* (2017.09.29) was the lecture *`What tales do archaeological findings tell – to physicists?*. Scientific methods play an increasingly important role in analysing works of art and archaeological findings. The audience of about 80 learned how physics helps to determine the age and the elemental composition of various objects, and to unveil previously unknown details.

Physicists' Days (2017.11.20-24.) were organized for the 38'th time in Atomki . This year's guiding theme was *Humankind in the Focus of Science*. Therefore, the four lectures discussed what kind of challenges humankind is facing, and also the response it gives to them with the help of science. They discussed physical models of climate change, the developing of the atomic bomb, artifical intelligence, as well as the anthropic principle. The total attendance was 339, ranging from primary school pupils to pensioners. In the morning hours Atomki received visitor groups from 24 schools based in Debrecen and even in some distant cities, to attend 28 different unconventional lectures. Altogether 70 lectures were given and 1975 visitor hours were spent. The last day's program was presented by the Debrecen unit of the Disaster Recovery Authority, and included a lecture on fire protection followed by a test fire alarm, during which the audience moved to the sports field to observe how the specialists put out a fire engulfing a car wreck. With this one-week program, the institute joined to campaign *Research Institutes with Open Doors* under the nationwide event entitled *Celebration of Hungarian Science*.

Besides the above programs, Atomki hosted 20 groups with 504 visitors this year (primary, secondary school pupils, university students and interested adults), who spent there 1282 visitor hours in total. The program was adjusted to the knowledge level and interest of the groups, and it contained lectures accompanied by experiments and laboratory visits. In the visitor centre the main features of radioactivity and its measuring methods were introduced, while cryophysical demonstration taught visitors about phenomena taking place at very low temperature.

Atomki researchers contributed to the training of secondary school teachers at CERN, took part in developing the National Radon Action Plan, and also in working out new radiation protection standards.

The five popular publications written by the researchers of Atomki in 2017 are available on the webpage of Atomki.

Videos recorded during the lectures of *Researchers' Night* and *Physicists' Days* are available at the most popular file sharing portal. According to the feedbacks, the videos most popular with teachers are those four made within the program called *Traveling Physics* a few years ago: *Water*, *Natural protection systems of the Earth*, *Cold – warm* and *Energy*.

In 2017, 119 appearances of Atomki researchers were recorded in the Hungarian media.

III. Presentation of national and international R&D relations in 2017

The collaborative research activities of the institute are traditionally carried out in terms of large international collaborations (e.g. CERN-CMS, LUNA, RIKEN, etc.) and bilateral cooperations of various level. In 2017, the range of collaborations has been extended by the AGATA (Advanced Gamma Tracking Array) collaboration. Atomki is the Hungarian coordinator of the H2020 E-RIHS PP (European Research Infrastructure for Heritage Science Preparatory Phase) project. Atomki researchers joined two new projects of the International Atomic Energy Agency (IAEA). New bilateral cooperations were signed with partner institutes located mainly in the neighbouring countries (University of Warsaw; Institute of Nuclear Physics, Cracow; Charles University, Prague; University of Oradea, Romania; Slovakian Geological Institute), but new agreements were initiated with institutions of more distant countries too (University of Eindhoven; CIMAP, Caen, France; NECSA, South Africa).

Among the new domestic cooperations, those signed with other institutes of the Hungarian Academy of Sciences can be mentioned: one with the *Lendület* (*Momentum*) group of the Institute of Archaeology at the Research Centre for The Humanities, and one with the Centre for Ecological Research. In the commercial sector, MVM Paks Nuclear Power Plant Private Llc. is still the most significant industrial collaborator of Atomki.

In 2017, Atomki researchers organized the *2nd Radiocarbon in the Environment* conference in Debrecen (July 3-7), where 108 participants from 27 countries delivered more than 110 lectures.

The International Advisory Committee held its yearly session in Atomki on November 20, when it was informed, among others, about the projects planned by Atomki researchers at the Szeged and Bucharest plants of the ELI (Extreme Light Infrastructure).

Participation in higher education continued to play an important role in the activity of Atomki researchers in 2017 too. This concentrated mainly at the Faculty of Science and Technology of the University of Debrecen. Altogether 32 theoretical and 20 practical courses were held. Atomki hosted 21 PhD, 12 MSc and 29 BSc students in 2015. The student researcher fellowship program continued in Atomki with the participation of 7 students in the spring and 8 in the autumn semesters. Altogether 48 Atomki researchers were involved in PhD education, seven of them as ``core members'' of doctoral schools. Five of them belonged to the physics, and two to the informatics doctoral school of the University of Debrecen.

IV. Brief summary of national and international research proposals, winning in 2017

- *GEOCORE Establishment of a Drillcore, Geological Sample Library and Geological Laboratory*, GINOP-2.3.3-15-2017-00043, 36 months, 166175 kHUF
- *Precision study of exotic nuclear decays*, OTKA K124810, 48 months, 47840 kHUF
- *Collective and single-particle motions in nuclei,* OTKA PD124717, 36 months, 15219 kHUF
- *Investigation of sources of atmospheric aerosol at urban environment*, OTKA PD125086, 36 months, 15219 kHUF
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