

INSTITUTE FOR ENERGY SECURITY AND ENVIRONMENTAL SAFETY  
CENTRE FOR ENERGY RESEARCH  
HUNGARIAN ACADEMY OF SCIENCES

Address: Konkoly Thege Miklós 29-33, 1121 Budapest, Hungary  
postal address: P.O.B. 49, 1525 Budapest, Hungary, phone/fax: +36-1-392-2531 / 392-2533  
e-mail (director): [belgya.tamas@energia.mta.hu](mailto:belgya.tamas@energia.mta.hu) web-page: <http://energia.mta.hu>

### **I. Main duties of the research unit in 2013**

The Institute for Energy Security and Environmental Safety (EKBI) was formed by reorganisation the Institute of Isotopes (IKI) and the KFKI Atomic Energy Research Institute (AEKI) on January 1<sup>st</sup>, 2013. To harmonize with the major topics of the two institutes of the centre, three departments from IKI (Nuclear Analysis Dept., Radiation Chemistry Dept., Surface Chemistry and Catalysis Dept.), and the Department for Environmental Physics from AEKI were assigned to the new EKBI, while the fourth Department of the IKI (Radiation Security Dept.) was assigned to the Institute for Atomic Energy Research.

The new research profile of the EKBI shifted the emphasis of the research activities to direction of its name. The following research activities have been performed:

- improvement of nuclear analytical and imaging methods and their applications for energy and materials science, as well as on interdisciplinary fields.
- performing studies in the field of environmental physics related to energy generation and its impact on the public health (*e.g.* effects of small doses) and on environmental safety,
- study of environmentally benign and economic radiochemical processes,
- study of environmentally benign and economic (“green”) catalytic and surface processes,
- initiating novel research topics related to reactor safety, storage of energy and in the field of renewable energies.

### **II. Outstanding research and other results in 2013**

#### ***II/a Outstanding research and other results***

##### *Nuclear analysis and radiography*

*Application of nuclear analytical methods for energy science, chemistry and industry:* Results of in-beam PGAA studies carried out on catalytic processes in 2012 have been published in a few communications. It was found that three-valent additive elements may promote the performance of CeO<sub>2</sub> catalyst in oxidation of HCl. In particular, addition of Hf or Zr doubled the activity. The conditioning of catalysts was also improved; they are now suitable for industrial application as well.

The local compositions of Zr based fuel mantles and reactor materials have been analysed in cooperation with colleagues of the Fuel and Reactor Materials Department. They proved that the splitting of the fuel mantle and the content of the absorbed hydrogen in it are strongly correlated under accident conditions. The effects of boron addition to the Co-Re-Cr alloys applied in turbine blades under extreme operating conditions were studied in cooperation with the researchers of the TU Braunschweig. It was found that grain boundaries are enriched in boron, decreasing thereby the brittleness and preventing the rupture. Thus, better thermal efficiency can be achieved allowing a 200 °C lift in the operating temperature. Compositions, primarily boron contents of the raw silicon materials applied for preparation of solar cells were determined.

*Applications of nuclear methods in cultural heritage studies:* The provenance studies of the raw materials used for manufacturing stone objects in the Carpathian Basin have been continued in connection with K100385 OTKA and partly in EU FP7 CHARISMA projects. Chipped obsidian tools, radiolarite, flint and silex tools originated from Central and Eastern Europe and farther provenances had been analysed by PGAA. Polished stone tools (axes, chisels) made of metabasite, pebble, greenschist and originated in part from museum collections and in part from field collections in Italy, Romania, Czech Republic and Poland. The concentration data were included into databases to be used for provenance identifications.

Metal pieces originated from recent palestinian/israelian territories and dated BC 1750-1550 were provided for PGAA and neutron radiography studies from the Egyptian Collection of Museum of Fine Arts. One part of the brass assembly was made of iron, the question was whether this iron part is of meteoritic origin. The analysis results did not confirm this hypothesis.

Various measurements had been performed on stone tools, ceramics, glasses and on metal objects (silver coins, brass and iron tools) by the users of CHARISMA project. Corrosion of archaeological iron objects was followed with elemental mapping technique (PGAI) by quantitative determination of the local chlorine content. Results of a comprehensive study related to one of the most ancient man-made iron object have been published. The report received the highest ranking in the Altmetrics index of the Elsevier Publishers, and attracted significant attention in the Hungarian electronic media.

*Measurement and evaluation of nuclear data for developing Generation IV (GEN IV) reactors:* There is a continuous cooperation with researchers of the Berkeley National Laboratory (California) and of Charles University (Prague) in the fields of determination of cross sections,  $(n,\gamma)$  spectra and nuclear decay schemes. In the framework of this cooperation a report was published on the evaluation of measurements on potassium in Phys. Rev. C. They demonstrated that the statistical decay model provides an acceptable description for the decay of potassium nucleus excited by neutron capture. The gamma-strength-function (GSF) of  $^{196}\text{Pt}$  was determined in cooperation with the researchers of Helmholtz-Zentrum Dresden-Rossendorf and of Charles University Prague. The authors confirmed that the same GSF can be used for description of  $^{196}\text{Pt}$  nuclei de-excitation, either they were excited by neutron capture or by resonance fluorescence. Determination of  $(n,\gamma)$  spectra of actinides was carried out together with the researchers of Jülich GmbH Institute of Energy and Climate Research in the framework of EU FP7 ERINDA and TANDEM international projects. The aim of these experiments was the accurate determination of nuclear data necessary for nuclear waste characterisation. They have measured accurately the prompt fission gamma spectra of  $^{235}\text{U}$  in cooperation with IRMM, a good correlation was found with the data of the most complete earlier measurement except of the low-energy region. The uncertainty of measurements is significantly smaller than 7.5 %, a requirement for adequate calculations of GEN IV reactors. Prompt gamma spectra of  $^{206}\text{Pb}$  were published in cooperation with IRMM, whereas the capture cross section data and prompt gamma spectra of iron isotopes were accurately described in LBNL and CERN cooperations.

*Studies related to energy generation:* The development of the ANCARA measuring loop has been completed at the Dynamic Neutron Radiography station at BNC. This facility provides a tool to study the properties of supercritical water related to application in GEN IV reactors.

*Methodological developments:* The response function and efficiency of the Compton-suppressed detector at the NIPS experimental station have been successfully described up to 11 MeV by MCNP-CP calculations. The first experiences and primary results related to 3D elemental analyses achieved with the PGAI technique have been published. The technique has

also been proven successfully for nuclear security investigations, in case of encapsulated and shielded objects. They participated in an international intercomparison of analytical laboratories (IAEA - TC project RER 4/032/RER/007, 2011-2013) WEPAL (WAGENINGEN Evaluating Programs for Analytical Laboratories) to determine inorganic constituents in plant and soil samples. The laboratory achieved the best possible rating in the intercomparison. The NAA laboratory was also validated by a series of measurements carried out on geological standard samples. The same standards were measured with PGAA as well. The comparison of the NAA and PGAA was accomplished, the potential complementary applications of the two methods were elaborated.

Reverse Monte Carlo simulation was applied for description of phosphate containing electrolytes based on neutron- and X-ray diffraction studies carried out in cooperation with the Wigner RC for Physics.

*Studies in geology and in environmental sciences:* NAA measurements were carried out on lapis lazuli and blue pigment samples. These results complement well the data previously obtained from PGAA measurements, as these latter were of limited use for provenance determination of semi-precious stones. Determination of concentrations of further trace elements (mainly rare-earths) is expected to improve the provenance identification in the future. Compositions of xenoliths collected from the Earths' crust were determined by NAA, the data are in good agreement with those obtained from previous XRF measurements.

A low-background iron chamber for gamma spectrometry and a radon-tight sample holder were applied to determine the activity concentrations in materials used in construction of buildings. A technique providing a mean for quick analyses was also tested. 40 samples were analysed, the activity concentrations in most of them were below the regulatory limits, except the slag containing samples in which the values exceeded these limits.

*Mössbauer-spectroscopy:* A summary report has been prepared on the application of the method for catalysts characterisation. Changes in the coordination and valency states of iron in promoted porous ferrisilicates have been monitored in catalytic processes. The effects of difference of the structures of SBA-15 and SBA-16 mesoporous supports on the properties of doubly promoted copper-iron oxide catalysts were compared in catalytic oxidation of toluene. The oxide particles were incorporated in the channels of SBA-15, whereas larger particles formed on SBA-16, partly blocking the entrances of channels. Ca/Fe and Mg/Fe layered double hydroxides (LDHs) were also analysed, the effect of the change in the Ca:Fe and Mg:Fe ratios on the stability was investigated. The Mössbauer studies were completed with positron life-time measurements. Life-time spectra of various micro- and mesoporous ferrisilicates were decomposed to four components, the differences in their intensities have been correlated with the different pore structures of them.

Main directions of magnetisation were determined in nanocrystalline FINEMET alloys of different permeabilities. Structural effects of repetition of charge-discharge processes and heavy ion irradiation were investigated by combination of  $^{119}\text{Sn}$  and  $^{57}\text{Fe}$  Mössbauer spectroscopies in electrodeposited ternary Sn-Ni-Fe alloys. The technique was also applied for the confirmation of the structure of Fe(II)citrate coordination polymer.

*Studies related environmental physics and renewable energy*

*Storage of carbon dioxide in deep geological formations:* The Hungarian Geological and Geophysical Institute provided samples from potential cap rock. Samples were evaluated in cooperation with the University of Oslo. Namely, they were exposed to supercritical  $\text{CO}_2$  dissolved in water in order to model the expected processes taking place during injection of  $\text{CO}_2$ . Samples were characterised before and after the treatment, the comparison of the

corresponding phases may contribute to evaluation of the safety of long-term geological disposal of CO<sub>2</sub>. In parallel, they participated in studies of samples provided by the Spanish Geological Survey. It was found that the clayey components are washed away from the pore filling of rocks in the vicinity of the injection well.

*Geological disposal of nuclear waste:* Radionuclide retention properties of rocks originated from Swiss and Hungarian potential deep level disposal sites were investigated in the framework of a joint Swiss-Hungarian project in relation to disposal of high level nuclear waste. Micro-EXAFS measurements provided explanation to the differences between the observed and calculated sorption capacities for Ni and Zn. In the case of uranium, if present in high concentration, they proved that sorption takes place by formation of a new phase.

*Biological effects of small doses:* The influence of the ionizing radiation induced cell lesion in the development of tumour has been studied. Effects of the inhomogeneous irradiation on the cell composition of tissues are in the focus of studies performed in cooperation with the research team of the Leiden University Medical Center. Model calculations have been carried out for determination of the necessary change in the number of cells enabled to mitosis in order to maintain the equilibrium in the tissue. The calculations demonstrate that the number of mutations due to the increased frequency of mitosis is larger than the number of mutations initiated by direct irradiation.

*Radiation chemistry studies related to energy saving and environmental safety*

*Application of novel, energetically economic processes for waste water treatment:* Hydroxyl radical induced decomposition of 20 various toxic compounds (including maleic- and fumaric acids as well as several compounds containing aromatic ring) has been studied in dilute air saturated aqueous solutions. Hydroxyl radical was generated by the radiolysis of water. Maleic- and fumaric acids as well as phenols were efficiently decomposed. Smaller efficiency was detected in case of compounds containing amine-, acetamide- or hydrazo groups attached to the phenolic ring. The latter case can be explained by the lower reactivity of the intermediate compounds with the dissolved oxygen. Furthermore, the participation of the reductive intermediates of radiolysis of water (atomic hydrogen and solvated electrons) was also demonstrated in the process.

A mechanism was proposed for the hydroxyl radical induced decomposition of a frequently used non-steroid inflammatory drug, Ibuprofen. The intermediates and final products formed have been identified. In pulse radiolysis experiments hydroxycyclohexadienyl type radicals as intermediates were identified which are converted to hydroxylated derivatives of Ibuprofen as final products. The final products were analysed by HPLC-MS/MS equipment. Under reducing conditions hydrated electron attacks the molecule at the carbonyl group of Ibuprofen. An important conclusion of the studies is that Ibuprofen can be more efficiently decomposed under oxidative conditions than under reducing ones.

The metabolites of drugs are usually more toxic than the original molecules themselves. This is the case with Ibuprofen as demonstrated by *Daphnia magna* standard microbiotests and *Vibrio fischeri* bacterial luminescent tests. The toxicity first increased, and then decreased with the increase of the absorbed dose in air saturated solutions. For the interpretation of this phenomenon it was suggested that the toxicity of the primary decomposition products (hydroxylated derivatives of Ibuprofen) is high, and the secondary products are less harmful. The toxicity of the solution can significantly be decreased by selecting an appropriate dose.

*Theoretical study of radiolysis:* Twin-recombination of H<sub>2</sub>O<sup>+</sup> ion ⇌ hydrated electron pairs generated in photochemical or irradiation processes may result either in formation of H<sub>3</sub>O or OH<sup>-</sup>. The thermodynamic analyses of processes reveal that the first process is endothermic,

whereas the second one is exothermic. The enthalpy differences are smaller under supercritical conditions than under ambient ones.

*Polymer modification by radiation induced grafting:* Precipitated ZnO nanostructures exhibited inhomogeneous ordering on grafted cellulose samples in previous experiments. The grafting process has been modified recently; the homogeneity of nanorods has been improved, thereby providing a mean for the preparation of fabric usable for energy production.

Hydrogels with appropriate strength and high swelling capacity were prepared from water-soluble derivatives of cellulose (carboxymethyl cellulose, CMC, hydroxyethyl cellulose, HEC, and hydroxypropyl cellulose, HPC) by applying high energy radiation. The number of cross-links was varied by dose. The increase of dose increased the number of cross-links and decreased the swelling capacity simultaneously, increased the portion and the strength of gelled molecules. The order of the swelling capacity in distilled water is: CMC > HEC > HPC. There are possible applications where hydrogels are contacted with electrolytes. The swelling capacity of CMC decreased one order of magnitude in electrolytes as compared to distilled water; the decrease was ca. 50 % with HEC, whereas the capacity of HPC remained unaltered. The order of swelling capacity in isotonic saline solution is HEC > CMC > HPC. The swelling capacities of the cellulose based hydrogels are comparable with those of the commercially available acrylate based ones. The cellulose based hydrogels can be applied as textile coatings, or in health care (*e.g.* as diaper insert) or for soil remediation.

The experiments to develop a domestic fruit ripening equipment have been successfully finished. The polymer with the appropriate permeability for ripening gases has been selected. The prototype of the apparatus has been manufactured in the cooperating organisation.

*Catalytic and surface chemistry studies for promotion of energy saving, protection of environment and economy*

*Dry reforming of methane, utilisation of natural gas of low caloric value and biogases:* These studies are carried out in order to provide methods for production of hydrogen or synthesis gas from the domestic natural gases of low caloric values. First mixture of pure methane and carbon dioxide is used, from which synthesis gas can be obtained in the  $\text{CH}_4 + \text{CO}_2 \leftrightarrow 2 \text{CO} + 2 \text{H}_2$  process by applying appropriate catalysts. Unfortunately, the applied catalysts are deactivated by coking. In the related studies they have finished the investigation of the Au-Ni/MgAl<sub>2</sub>O<sub>4</sub> catalysts. The formation of the AuNi alloy phase results in deposition of carbonaceous patches which can hardly be removed and the catalytic activity drops. In a further stage they commenced studies with Ni and Pt containing catalysts, supported on ZrO<sub>2</sub>. In addition, the mechanism of the formation of the carbonaceous deposit was also investigated with <sup>13</sup>C isotope labelled CO<sub>2</sub> and CH<sub>4</sub> in the framework of the EraChemistry – NN107170 international cooperation. Formation of carbonaceous deposits was not observed on Pt catalysts, however their catalytic activity in the temperature programmed reaction was inferior in comparison to that of Ni samples. Dominance of the reverse water-gas reaction was also observed on the catalysts of small metal content at 600 °C (CO/H<sub>2</sub> >> 1). CO forms from the activation of CO<sub>2</sub> in the first stages at low temperatures as studies performed with <sup>13</sup>C isotope at 50 mbar pressure in a circulation reactor revealed. The thermal desorption study carried out on the spent catalysts after the reaction resulted in characteristic CO<sub>2</sub>-H<sub>2</sub>-CO triplet signal probably due to the decomposition of surface intermediates (carbonates or formiates). CO desorption can be detected on Ni and NiPt catalysts, on which carbon deposition proceeds whereas CO does not evolve from spent Pt samples.

*Preferential oxidation of carbon monoxide in hydrogen (PROX):* This process is important for generation of pure hydrogen for application in PEM fuel cells. The earlier studies have been continued on the manganese-cobalt mixed oxide catalysts, which have good performance

( $\text{MnCoO}_x$ , with Mn/Co atomic ratios 5/95 and 12/88). The improved activity was attributed to the presence of Mn substituted  $\text{Co}_3\text{O}_4$  spinel phase. The XRD diffractogram of  $\text{MnCoO}_x$  (Mn/Co = 12/88) catalyst displayed the presence of ca. 30 % amorphous component beside the crystalline spinel oxide. The crystallinity of the sample was increased by a thermal treatment at 700 °C that resulted in a tremendous decrease in the catalytic activity. Surprisingly, the good catalytic activity of the original sample could be restored by a reduction treatment (in PROX reaction) followed by temperature programmed oxidation, both up to 360°C. The superior catalytic activity of  $\text{MnCoO}_x$  in comparison to the  $\text{Co}_3\text{O}_4$  is attributed to the enhanced presence and role of lattice defects in the Mn substituted  $\text{Co}_3\text{O}_4$  spinel phase and amorphous phase in the former samples.

*Selective partial oxidation processes* performed with oxygen/air have importance from both the aspects of energy saving and protection of environment. The excellent properties of gold catalysts in these processes have already been proven earlier. Further improvement of their performance in oxidation of various functional groups was aimed with combination of a second metal. In particular AuAg catalysts supported on silica and AuCu catalysts supported on alumina were studied in oxidation of glucose to gluconic acid in aqueous solution. Bimetallic nanoparticles with controlled structure were synthesized with liquid phase reduction and were stabilised in aqueous sols, then adsorbed on the support and were calcined at 400 °C.

The effects of the subsequent 350 °C reduction were studied on the AuAg/SiO<sub>2</sub> samples. Both the calcined and the reduced catalysts consisted of bimetallic particles – the calcined sample contained Ag-oxide islands scarcely. The reduction subsequent to calcination resulted only in minor changes. Namely, the previous mean AuAg particle diameter of 3-5 nm, the wavelength of surface plasmon resonance, the Au/Ag ratio on the surface of bimetallic particles have not changed noticeably. In correspondence, the catalytic activities were similar in the both instances as well, synergetic activity increase was observed for bimetallic samples of Ag/Au ≤ 0.5 atomic ratio.

In the case of alumina supported AuCu catalysts samples were prepared with 1:1 Au/Cu atomic ratio in three variations. First, bimetallic particles were formed in co-reduction of gold and copper (Au&Cu samples). In the second instance copper was reduced onto gold particles (Cu→Au), and in the third case gold was deposited onto copper (Au→Cu). These three types of catalysts were compared after calcination and after subsequent reduction in the process of the oxidation of glucose. Among these catalysts only Au&Cu/Al<sub>2</sub>O<sub>3</sub> showed some synergetic activity increase, however its extent was much lower, than in the case of AuAg/SiO<sub>2</sub> (Ag/Au ≤ 0.5). There were no significant differences between the activity of calcined and calcined+reduced samples on the contrary that in calcined state lower Cu concentration in the AuCu alloyed phase and higher Cu-oxide content around the metallic phase was detected.

*Study of the mechanism of catalysis in selective hydrogenation:* The studies directed to the investigation of molecular conditions eligible for asymmetric induction have been completed. In the course of these investigations enantioselective reductive alkylation of cyclic, prochiral-, and chiral ketones were performed. The studies provided additional support for the presumption that the enantioselectivity develops not only in the liquid phase, the role of the surface of the heterogeneous catalyst is also important in the process. A corresponding communication has also been published.

*Wet oxidation:* Limits of working conditions for various catalysts and model compounds were determined by applying comparative methods of selection of optimal set of experiments. The combination of the irradiation and wet oxidation was advantageous for decomposition of phenol model compound.

*Desulfurisation of fuels:* The effects of addition of gallium to the uptake and exchange of sulfur on NiMo, NiW catalysts in thiophene desulphurisation were studied in cooperation with researchers of Departamento de Ingenieria de Procesos e Hidráulica, Metropolitan Autonomous University. Based on the experiments a novel mechanism is proposed for the thiophene desulphurisation, in which essential role is attributed to the interaction of adsorbed thiophene with adjacent –SH groups. A related PhD thesis was prepared based on these and earlier results (entitled: Influence of the mobility of sulphur in the sulphide catalysts on the thiophene desulphurisation process) and was submitted to the Pannon University.

*Production of biodiesel:* Decarboxylation of oleic acid was studied in hydrogenation treatments on presulphided NiMo(P)/Al<sub>2</sub>O<sub>3</sub> and on NiW/Al<sub>2</sub>O<sub>3</sub> catalysts in connection to production of biodiesel from vegetable oils containing triglycerides and fatty acids. Formation of CO was also detected beside CO<sub>2</sub> and CH<sub>4</sub> during the decarboxylation, thus the mechanism of the process could be described more accurately.

### ***II/b Dialog between science and society***

A lecture, entitled to “High performance oxidation processes for water treatment: irradiation techniques”, was presented on the Multidisciplinary Water Conference organised by the Presidential Committee for the Environmental Science of the Hungarian Academy of Science (HAS) in order to formulate scientific messages for the Budapest Water Summit.

A scientific session was organised at the House of HAS by the Committee for the Radiation Protection and Environmental Physics of HAS on the occasion of the opening of the Bábaapáti Nuclear Waste Disposal Site. The event was opened by the General Secretary of HAS and the management of PURAM participated the meeting. The researchers of the Laboratory of the Environmental Physics gave accounts on the results of their studies related to the safety of deep geological disposal of nuclear waste.

An interview was given on the activity of the Department of Environmental Physics, it was published in the 2013 May issue of the Innoteka magazine. Articles, clear to all, on the disposal of high-level nuclear waste and on the deposition of aerosols in the respiratory system were published in the October 22 issue of the local monthly “Hegyvidék”.

Short features, introducing the experimental facilities at BNC and presenting the work performed at the PGAA-NIPS experimental station in the framework of EU FP7 NMI3 and NMI3 Imaging JRA was prepared with cooperation of the colleagues from the Department of Nuclear Analysis and Radiography. The features are available at the web page of the project and on the YouTube as well (<https://www.youtube.com/watch?v=s-pmuGPJEG8> and <https://www.youtube.com/watch?v=CRoJi1JUzkg> ).

Lectures and visits of Laboratories were organised on the occasion of the Festival of Hungarian Science.

Visit was organised for 36 students of the Illyés Gyula Secondary School to the laboratories of the EK and the accelerator of the Wigner RC.

They took part in the organisation of the 7<sup>th</sup> Central European Training School on Neutron Techniques, CETS2013, 27-31 May, Budapest, Hungary with presenting lectures and guiding laboratory practices.

### **III. A presentation of national and international relations**

The quota of beam time allocated to users of the EU FP7 CHARISMA project at the PGAA and NIPS facilities was overexhausted due to the large number of applications. 37 foreign researchers were hosted within the CHARISMA and ERINDA projects. An important international conference for the neutron activation analysis, the 6<sup>th</sup> International  $k_0$ -users' Workshop was successfully organised. Their contributions to the interdisciplinary NINMACH2013 conference on archaeometry were significant. They applied five times with success for access to beam time at the prompt-gamma station of the Forschungs-Neutronquelle Heinz Maier-Leibnitz (FRM II), altogether 15 days beam time was allocated for these proposals. The higher flux of FRM II (compared to domestic BNC) was utilised in nuclear-physical, geological, biological and chemical (catalysis) studies. Cooperations were accomplished in the frames of Moroccan-Hungarian and Slovenian-Hungarian bilateral projects, 2 Moroccan and one Slovenian guests were hosted in topics related to PGAA and Mössbauer spectroscopies, each for 2 weeks, respectively.

Support was provided for the organisation of the international "Energy Conference – E2C 2013" held at the Flamenco Hotel Budapest, 27 – 30 October, 2013. The conference gave account on the broad spectrum of studies related to energy science; several lectures were presented by authors from EK.

Laboratory practices were held for seven groups of M.Sc. students from ELTE, BME and DE. Presentations and laboratory practices were held for participants of the Central European Neutron School (CETS2013). They participate in the education performed directly at universities as well, *e.g.* on the fields of radiation chemistry, materials science, environmental protection and water purification. University courses are also held for students of University of Óbuda, of Pannon University and of BME.

Novel partner institutes (China Tsinghua University, Beijing, and Departamento de Ingenieria de Procesos e Hidráulica, Mexico) are involved in studies related to waste water treatment, the Wrocław Medical University in studies related to catalytic processes.

Optimisation of future renewable energy mix was carried out based on multi-criteria decision analysis on the request of Ministry of National Development. The study supports the country's commitment undertaken in the 2009/28 EU directive.

A survey was accomplished for a perspective brown-field development of the Tisza II Power Plant for a renewable energy investment.

An agreement for cooperation on the coordination of activities on the fields of research, development and innovation carried out on in relation with decentralised electricity networks was established with the Bükk-region LEADER Association (details: <http://www.youtube.com/watch?v=-Z4y9XoUKo8>).

#### **IV. Brief summary of national and international research proposals, winning in 2013**

The CHANDA EU project (Solving Challenges in Nuclear Data for the Safety of European Nuclear Facilities – coordinated by CIEMAT and lasting for 48 months) devoted to provide a background for studies on nuclear data started in December, 2013.

They successfully participated in the Research Infrastructure Improvement Programme of HAS. 57 million HUF has been awarded for upgrading four facilities of the Budapest Neutron Centre.

Support was obtained for theoretical and experimental study of sedimentation from aerosols in correlation with frequent diseases of the respiratory system (asthma, COPD) from the

Research and Development Innovation Fund (KTIA\_AIK\_12-1-2012-0019) with duration of 30 months.

## V. List of important publications in 2013

1. Rehren T, Belgya T, Jambon A, Káli G, Kasztovszky Z, Kis Z, I. Kovács, Maróti B, Szentmiklósi L et al. (15): 5000 years old Egyptian iron beads made from hammered meteoritic iron. *J. Archaeol. Sci.*, 40: 4785-4792 (2013)  
<http://dx.doi.org/10.1016/j.jas.2013.06.002>
2. Schulze R, Szentmiklósi L, Kudejova P, Canella L, Kis Z, Belgya T et al. (11): The ANCIENT CHARM project at FRM II: Three-dimensional elemental mapping by prompt gamma activation imaging and neutron tomography. *J. Anal. At. Spectrom.*, 28:1508-1512 (2013) <http://dx.doi.org/10.1039/c3ja50162k>
3. Firestone RB, Krtička M, Révay Z, Szentmiklósi L, Belgya T: Thermal neutron capture cross sections of the potassium isotopes. *Phys. Rev. C*, 87: Paper 024605 16 p. (2013)  
<http://dx.doi.org/10.1103/PhysRevC.87.024605>
4. Lázár K: Mössbauer spectroscopy in catalysis, *Hyperfine Interactions* 217: 57-65 (2013)  
<http://dx.doi.org/10.1007/s10751-012-0720-6>
5. Berrezueta E, González-Menéndez L, Breitner D, Luquot L: Pore system changes during experimental CO<sub>2</sub> injection into detritic rocks: Studies of potential storage rocks from some sedimentary basins of Spain. *Int. J. Greenh. Gas Control*, 17:411-422 (2013)  
<http://dx.doi.org/10.1016/j.ijggc.2013.05.023>
6. Homlok R, Takács E, Wojnárovits L: Degradation of organic molecules in advanced oxidation processes: Relation between chemical structure and degradability. *Chemosphere*, 91: 383-389 (2013) <http://dx.doi.org/10.1016/j.chemosphere.2012.11.073>
7. Illés E, Takács E, Dombi A, Gajda-Schranz K, Rácz G, Gonter K et al. (7): Hydroxyl radical induced degradation of ibuprofen. *Sci. Total Environ*, 447: 286-292 (2013)  
<http://dx.doi.org/10.1016/j.scitotenv.2013.01.007>
8. Horváth A, Guczi L, Kocsonya A, Sáfrán G, La Parola V, Liotta LF et al. (8): Sol-derived AuNi/MgAl<sub>2</sub>O<sub>4</sub> catalysts: Formation, structure and activity in dry reforming of methane. *Appl. Catal. A-Gen*, 468: 250-259 (2013)  
<http://dx.doi.org/10.1016/j.apcata.2013.08.053>