CENTRE FOR ENERGY RESEARCH, HUNGARIAN ACADEMY OF SCIENCES

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The Centre for Energy Research, Hungarian Academy of Sciences (MTA EK) was formed from the KFKI Atomic Energy Research Institute and the Institute of Isotopes from January 1, 2012. According to the mission statement of MTA EK the main aims of the centre are as follows:

- Research and development in the field of nuclear science and technology for facilitating the adoption and the safe use of nuclear technology in Hungary.
- To participate in international research efforts aiming at the establishing a new generation of nuclear power plants and closing the fuel cycle.
- Research and development in the field of low carbon energy technologies and of energy saving in industrial technologies.
- Maintaining and improving competence in nuclear science and technology, especially in the field of nuclear safety and security.
- To assist in peaceful uses of nuclear energy in areas other than energy production (e.g. comparative analysis of environmental effects of energy production, investigation of effects of low doses, space dosimetry).

MTA EK operates the 10 MW Budapest Research Reactor and is hosting the Budapest Neutron Centre, accessible also for studies within several international projects.

The Centre is proud of the achieved scientific and technological results recognized worldwide. The experience gained during the past decades in the safety of nuclear power plants, especially of Russian designed PWR (VVER) is an important asset of MTA EK. Physicists, chemists, mechanical, power and electrical engineers, mathematicians, computer analysts and programmers form more than half of the 250 strong staff; the total number includes the operational staff of the Budapest Research Reactor (around 45).

The first part of this summary is devoted to the activities of the KFKI Atomic Energy Research Institute (AEKI) included the Budapest Research Reactor, the subsequent sections describe the activities of the Institute of Isotopes (IKI).

BRIEF HISTORY

The site of the research centre was selected as a major site for research in physics in 1950 and the so called Central Research Institute for Physics (abbreviated in Hungarian to KFKI) was formed. Mots of the time KFKI belonged to the Hungarian Academy of Sciences, with an interrupt when it belonged to the Hungarian Atomic Energy Commission. KFKI was transformed into a research centre in 1974 consisting several institutes, including AEKI. After the political changes, from January 1, 1992, AEKI and its sister KFKI-institutes all became independent legal bodies and the KFKI centre ceised to exist. AEKI played a major role in the

Hungarian nuclear program, especially because of experiments acknowledged worldwide and the development of simulation codes. Reactor physics, thermohydraulics, fuel behaviour, ageing of reactor materials, health physics are the traditional research areas. AEKI was continuously involved in the safety enhancement of the Paks NPP starting with the replacement of man-machine connection tools. AEKI became the main consultant of the plant in safety related issues and, at the same time, it serves as a Technical Support Organisation of HAEA.

The Institute of Isotopes was founded in 1959 to foster and promote the production and application of radioisotopes. The institute fulfilled these expectations, it became the national principal organisation on these fields. The research fellows developed and propagated methods for several industrial and medical applications. These achievements provided sound basis for establishing limited companies for production radioisotopes primarily for medical applications (Izotóp Intézet Kft) and for their commerce (Izinta Kft) in 1992. The parent academic institute maintained its activities in the fields of radiation chemistry, radiation safety and security, nuclear reactions and analytic application of radioisotopes and surface chemistry and catalysis. The Institute of Isotopes became also one of the Technical Support Organisations (TSOs) of the HAEA primarily with respect to nuclear security issues. The number of scientific publications prepared by the researchers of the Institute since its foundation is about 3600.

ATOMIC ENERGY RESEARCH INSTITUTE

NUCLEAR SAFETY RESEARCH

Nuclear safety research is supported by the Hungarian Atomic Energy Authority (HAEA) and is performed mainly in international and domestic projects. Paks NPP contributes to find the corresponding matching funds and also requires safety research in certain areas. MTA EK is the Technical Support Organisation (TSO) of the HAEA.

In reactor physics the analytical work is based mostly on experiments done in AEKI in the past: a subcritical and six critical assemblies were set up. ZR-6 was the model of the VVER-type 1000 MW power reactors. The ZR-6 measurements were done by an international team and the results are included in the OECD NEA Criticality Safety Benchmark Book.

For the reactor physics calculations of the rather unique hexagonal core of VVER-type reactors the institute developed two program systems: KARATE serves for core design calculations while KIKO-3D solves three-dimensional space-time dynamic problems.

The basis of thermohydraulical investigations is the PMK-2 facility, an integral-type scaled-down model of the primary and partly the secondary circuit of Paks NPP. Several laboratories and firms have been interested in the results of measurements and use the data for benchmarking VVER specific calculations. Recently a significant modernization of instrumentation was performed which enabled the experiments on water hammer conditions and on flow mixing in VVER-440 fuel assemblies.

Due to the lack of available database concerning VVER fuel behaviour in accident conditions, a research project was launched in the early 1990´s. The activity concentrated on the determination of the E110 cladding material behaviour in transients and the core degradation during the in-vessel phase of severe accidents. Our results are widely used by the nuclear community e.g. in establishing new LOCA (Loss-Of-Coolant Accident) criteria. Various complex measurements were performed at the CODEX (Core Degradation Experiment) facility for the integral test of non-irradiated small fuel bundles. The results attracted worldwide attention.

Experience and knowledge concerning fuel behaviour has been extensively applied in assisting to understand the reasons and to eliminate the consequences of the Paks Unit 2 incident in 2003.

The embrittlement and ageing of reactor vessels and their projected lifetime are estimated by determining the influence of radiation damage on the fracture material properties corresponding to the thick-wall material and the actual temperature. AEKI performed large series of measurements on samples irradiated at the Budapest Research Reactor. AEKI has been participating in all relevant EU Framework program projects and also in IAEA coordinated projects aiming better understanding of radiation embrittlement or use of Master Curve. AEKI developed the methodology for the evaluation of RPV (Reactor Pressure Vessel) integrity during PTS (Pressurized Thermal Shock) transients and other accidental cases, which forms the basis of the corresponding Hungarian Regulatory Guide.

As the accident management of mitigating severe accidents at Paks NPP is based on in-vessel retention, the efficiency of external cooling plays a decisive role. The CERES facility of AEKI has been serving for the experimental test of cooling efficiency in the most conservative circumstances.

NEW REACTOR SYSTEMS

Hungary started the preparations for constructing new nuclear units at the Paks site. AEKI contributed in several fields of the preparations (updating the safety regulation, preparing the tender document, preparing environmental and site licences).

As to Generation-4 reactors, AEKI first decided to concentrate its efforts to the Supercritical Water Reactor. The investigations (core physics, themohydraulics, materials and safety) are carried out in the framework of a Hungarian financed project that supplements the EU HPLWR project where the institute also participates. Recently the research has been extended to fast reactor systems, especially to the gas cooled fast reactor (GFR). Hungary, together with the Czech Republic and Slovakia applies for hosting the GFR demonstration reactor ALLEGRO.

SAFETY ANALYSIS

AEKI is mainly specialised in DBA (Design Basis Accident) analysis, safety analyses are performed basically in the framework of contracts with Paks NPP Co. These activities are strictly separated from TSO activities by appropriate measures formulated in the quality management system.

Extended design basis accident analysis was performed for the safety reassessment of the Paks NPP in the framework of AGNES project (1991-1994) and recently in connection with the preparation of the Final Safety Analysis Report of Paks NPP, covering thermal hydraulic transients, reactivity and power distribution anomalies, loss of coolant accidents, anticipated transients without scram, pressurized thermal shock. Based on AGNES results a safety enhancement programme has been carried out at Paks NPP. AEKI participated in the design of various technical modifications by providing corresponding safety analyses. When safety enhancement programme was completed AEKI performed a complete DBA analysis of the modified plant (2002-2004).

AEKI and its partner VEIKI completed a level 2 PSA study for the assessment of vulnerability of the Paks NPP against large radioactive releases and for the determination of the strategy of accident management measures.

AEKI devotes a lot of attention to the modernisation of the fuel of Paks NPP. In the last years a new Russian fuel was introduced with enrichment profile, higher burn-up limits and other modifications. AEKI was responsible for the neutron calculations and safety analyses. AEKI was strongly involved in the preparations of increasing the primary power level of the Paks NNP units which was successfully introduced first at Unit 4 in 2006. Now all the four units have a nominal power of 500 $MW_{e.}$

Paks NNP submitted the application for lifetime extension. AEKI contributed to this effort especially by the reactor physical, thermohydraulical and fracture mechanical calculations of the pressurized thermal shock of the pressure vessel.

Based on the accumulated experience in safety matters, AEKI strongly contributed to afterFukushima stress-test of Paks NPP.

MAN-MACHINE RESEARCH AND APPLICATIONS

Man-machine research and applications are of extreme importance for the nuclear industry operating a Russian designed NPP. Originally, the main drawback of these NPPs was the shortcomings of operator aiding systems.

The development of an advanced core monitoring system was started in line with the construction phase of Paks NPP. The achievements of our institute in this field made possible to overcome the original problems in a way which was unique in Eastern Europe. Since 1982 the on-line core monitoring system VERONA has been developed in different versions to continuously monitor the detailed 3D power distribution within the core by combining measurements and theoretical modelling.

AEKI has developed the system CERTA-VITA for HAEA making possible the observation of actual safety parameter displays of every Paks unit at the Budapest headquarters. A Plant Safety Monitoring and Assessment system was developed in the framework of an international R&D project supported by OECD NEA for facilitating the introduction of symptom/oriented EOPs (Emergency Operating Procedures).

The lack of training simulators was also an important drawback of Soviet designed NPPs. This is why a full-scope simulator was constructed in a joint project with NOKIA (Finland). The simulator is in use from 1987 for training and retraining. Since the installation AEKI modified the simulator several times to follow the changes in plant technology. The new reactor protection system (RPS) was tested in the simulator as well.

DOSIMETRY, HEALTH PHYSICS, ENVIRONMENT ANALYSIS

Dosimetry and health physics have more than 40 years tradition in AEKI. The assessment of environmental consequences of potential radioactive releases in the framework of safety analyses is the main goal of this field. After the Chernobyl accident various measurements were performed helping the country in assessing the situation and recovering from the problems.

AEKI developed the environmental monitoring system at the Budapest Research Reactor and at Paks NPP. AEKI was the main contractor of the reconstruction and modernisation project for the environmental radiation monitoring system, including release control, at Paks NPP. Mobile laboratories were developed to record dose rates for Civil Defence and for the Budapest Research Reactor.

A simulator was developed to follow radioactive substances in the environment. In accident conditions the simulator gives fast visual information on the radiological status of the environment and on the expected consequences. The simulator is installed at the National Civil Defence Centre and at the CERTA centre of HAEA.

The specific knowledge in nuclear measurement techniques led AEKI to develop and manufacture on-board space dosimetric and other space electronic devices.

THE BUDAPEST RESEARCH REACTOR

The reactor serves as a research device for solid-state physics, material tests, radiography, activation analysis and biological research, ensuring also the production of radioactive isotopes for diagnostic and other medical purposes. The reconstruction and upgrading was completed in 1992. The Budapest Neutron Centre (BNC) has been established for reactor utilization in basic and applied research. BNC has an international advisory board, the host institute is AEKI. Some of the applications are

- neutron radiography to investigate objects in closed volumes or in moving (turbine blades, compressors, heat-exchangers, valves, pipelines, etc.);

- neutron activation analysis enables the extremely sensitive detection of 70 chemical elements (up to 10^{-10} g/g concentrations)

- surveillance of NPP pressure vessel and fusion confinement samples to study neutron induced embrittlement of 20-40 years (by the high flux irradiation of the materials for a few months).

The installation of the Cold Neutron Source (financed basically by EU and IAEA) was completed in 2001. The CNS has increased significantly the scientific capabilities of the reactor, for small angle scattering, reflectometry, prompt-gamma activation analysis and triple-axis spectrometry.

Traditionally, the reactor was fuelled with Russian HEU (36 % enriched) fuel. In the framework of a conversion program a great amount of spent HEU fuel was transported back to Russia and LEU (20 % enriched) fuel has been introduced. The conversion will be completed in 2013 by the transportation of the remaining spent HEU fuel to Russia.

INSTITUTE for Energy Security and Environmental Safety (EKBI)

NUCLEAR SECURITY RESEARCH

To the enforcement of the Non-proliferation Agreement IAEA introduced a Nuclear Safeguards Agreement, which specifies the method development of analytical techniques for safeguards verifications. To assure these aims method developments and updating for national and international control of nuclear (fissile) materials have been carried out at MTA EK. Non-destructive (gamma spectrometry, neutron coincidence counting system) and destructive (ICP-MS) techniques are used for this purpose in EKBI.

At the same time MTA EK has got tasks in the field of Nuclear Forensics. Method developments are carried out for analysis of confiscated and smuggled nuclear materials. Also a governmental decree (IKI, 17/1996) designates our Centre for the identification and characterization of unknown-composition (seized) nuclear materials. In this field an agreement with IAEA is in progress. IAEA finds MTA EK suitable as a regional nuclear forensics laboratory.

Another task for safeguards verification is the development of new techniques and methods for analysis and control of fresh, burnt, damaged and re-encapsulated fuel pellets at the Paks NPP. Novel methods have been developed, used successfully and continuously at Paks NPP during e.g. safeguards verifications performed by the IAEA inspectors.

RADIATION CHEMISTRY AND ITS APPLICATIONS

Radiation chemistry studies were initiated also at the start, in the 1960's. These studies got a great impetus in 1983 when a linear electron accelerator was obtained with the help of the IAEA. The Laboratory maintained its leading role in the field, e.g. it hosts the quadrennial topical Tihany conference series since then. The expertise is often used for expert missions by both the authority (HAEA) and by the user (Paks NPP).

The Laboratory recently contributes with its radiation chemical possibilities to the development of Advanced Oxidation Technologies for purification of wastewaters. In these technologies short lived aggressive chemical intermediates induce the degradation of harmful non-biodegradable organic pollutants, like pesticides, hormones, pharmaceuticals. Major benefits with respect to conventional treatments are: no usage of chemical additives, room temperature operation, penetration in the bulk of water even in case of turbidity, production of high concentrations of oxidizing radicals in microseconds, and simultaneous disinfection. In order to show the advantages of wastewater treatment with ionizing radiation a demonstration equipment was built in the frame of an IAEA Technical Cooperation project.

The Institute often helps the industrial irradiation facilities in Hungary and through IAEA worldwide by lending service for high-dose dosimetry mainly determining dose-maps.

RADIATION SAFETY AND SECURITY

The research and development within these fields focus mainly on non-destructive analysis of nuclear materials with applications in nuclear safeguards, combating illicit trafficking of nuclear materials and nuclear forensics.

Probably Hungary is the only country in the world where the fate of all radioactive materials can be followed in the Hungarian national registry of radioactive materials. The database contains all radioactive materials produced in or imported to Hungary since the beginning (1954) of the domestic use of artificial radioactive products. IKI is responsible for this registration (now under an agreement with HAEA) including the continuous development for the registry software.

The nuclear materials confiscated by police or customs have to be handled by IKI. The Institute developed several methods for characterisation nuclear material, including chemical composition, isotopic composition (enrichment), impurities (trace elements), surface properties, crystal structure, history (time of production) (Nuclear forensics).

A great achievement of the Laboratory was the experimental determination of lost nuclear and fissile materials following the irregular operation occurred at the block II in the Paks Nuclear Power Plant on April, 2003. Several fuel rods were damaged; their content was removed and encapsulated afterwards. The contents of fissile materials in each capsule were determined providing a mean to calculate the exact balance of the amount of the total nuclear material lost due to the irregular operation.

Basic studies have been performed in the field of solid state dosimetry. Various materials have been developed, and the principal activation-deactivation processes of the thermal luminescence have been analysed. The study of radiation stimulated emission processes commenced and usage of retrospective dosimetry started recently with respect to perspective nuclear security applications.

In 2004-2005 an ICP-MS laboratory was established in IKI, using this unique technique e.g. long-lived radio nuclides in environmental samples in ultra-trace amount are analysed. There is a possibility for direct analysis of solid samples (e.g. adsorbed nuclear material on metal surfaces) and micrometer size particles by Laser Ablation ICP-MS technique.

As containing nuclear (fissile) material, PuBe sources represent a nuclear safety and safeguards issue. A large number of such sources - mostly out of use - are stored in Hungary (and this is the case in several neighbouring countries, as well). Only estimated Pu-contents of these sources were known. IKI developed high-resolution gamma-spectrometric and neutron coincidence methods for the precise determination of Pu contents and applied these methods for over 100 PuBe sources.

NUCLEAR REACTIONS, -ANALYSIS, APPLICATION OF RADIOISOTOPES

Studies related to basic nuclear physics have been carried out since 1980. From 1993 the research was gradually shifted to the (n, γ) reactions based on the reconstructed Budapest Research Reactor (BRR). By 1995 a prompt-gamma activation analysis (PGAA) facility was constructed at the BRR. The methodology had continuously been developed, and later became quantitative for most of the elements. A new library which contains analytical data for all of the elements was systematically measured and now it is known worldwide as Budapest PGAA library. The library was published in two books; one of them was supported by the IAEA (Database of Prompt Gamma Rays from slow Neutron Capture for Elemental Analysis) and is available on line. A great improvement in the sensitivity was attained by installing a so-called cold neutron source for the activation in the year 2000 and the follow up OMFB NAP VENEUS project have been supporting many upgrades of the instrumentation. The

Laboratory became one of the most attractive facilities of the Budapest Neutron Centre. The scientists of the PGAA facility participate in several broad international co-operations in archaeometry, geology, material and nuclear sciences. Furthermore a part of the operation time of the PGAA facility is reserved for direct international access supported by direct EU funds (NMI3, CHARISMA and ERINDA). Beside the scientific work many training activities have been conducted in the organization of IAEA.

The most recent development at the PGAA-NIPS facility was started within the EU supported ANCIENT CHARM project for measurements of 3D elemental composition in which the first of this experimental setup was constructed in 2007. The setup was constructed from a neutron tomography (NT) and a double (neutron, gamma) collimated PGAI(maging) detector. Following this temporary setup, they succeed to build up a permanent PGAI/NT station supported by the Hungarian NORMA10 and the NAP VENEUS projects. Based on the operation experiences the most successful project of the PGAA-NIPS experimental station is the in-beam catalysis service, which is based on the collaboration between IKI and the Fritz-Haber Institute. This topic is further detailed under the Catalysis section.

The PGAA facility has also been used for measuring nuclear-structure and -data using the (n,□) reactions. Recently a lot of interest was coming from the nuclear data community to improve the thermal capture cross section data and to measure spectra for identification of nuclear waste. These works have been supported by EU Access programs of EU FP6 EFNUDAT and currently EU FP7 ERINDA. The most recent development is the foundation of the TANDEM project which is an International effort on Transuranium Actinide Nuclear Data Evalutaion and Measurements. A part of the effort is devoted on the development of the Evaluated Gamma-ray Activation File (EGAF) which is based on the PGAA library and will serve as an input for Monte Carlo calculations such as MCNP.

Beside the development of the PGAA a great deal of efforts were paid to set up a world recognised database for nuclear model calculations. This project has been co-ordinated by the IAEA since 1997 and lasted for a decade. The results were summarized at 3 stages and called Reference Input Parameter Library (RIPL I-III) and now it serves as starting or reference point for many nuclear model calculation for GEN-IV reactors, Accelerator Driven Systems (ADS) and Nuclear Astrophysics.

SURFACE CHEMISTRY AND CATALYSIS

The activity of Laboratory of Surface Chemistry and Catalysis has developed from the application of radioactive tracers in catalysis. The main research topic for decades was the investigation of catalytic conversion of hydrocarbons on various catalyst samples primarily unsupported metal catalysts, later supported bimetallic species and finally using transition metal cluster samples.

The Laboratory acquired state of the art equipments in the 1980's (mass, infra-red, and X-ray photoelectron spectrometers). Utilizing the possibilities it became a leading laboratory in the field of heterogeneous catalysis in Hungary. Due to its international reputation the principal scientists organised the XIXth. International Conference of Catalysis with over 1000 attendants in Budapest, in 1992. The determining part of the scientific output (scientific publications) of the Institute has been published by the members of this Department.

Environmental catalysis started in 1990 by studying DENOX reaction as well as the elimination of volatile organic compounds. As a continuation presently green chemistry is planned to develop along with environmental catalysis. One of the most important research topics is Au catalysis, which means the preparation, characterization and application in selective reactions of the nanostructured gold catalysts.

A novel, common research topic with the Radiation Chemistry Laboratory is the combination of catalytic and high energy radiation induced reactions for the purification of process wastewaters, supported by Swiss-Hungarian cooperation. They continue the study of catalytic processes which belong the alternative energy area, such as biodiesel production with catalytic hydrogenation, CO removal by PROX, methane dry reforming which are parts of the European research program. The application of tracer compounds in catalytic investigation further is our unique technique in Hungary.

The Laboratory has several international co-operations in the field of catalysis. For example together with the researchers of Fritz-Haber Institute, it could be pointed out with in situ PGAA measurements combined with a catalytic reactor that during hydrogenation reaction the amount of dissolved hydrogen in Pd and together the selectivity changed also (published in Science). Consortium on methane dry reforming has been established with Austrian and German scientific institutions.

Updated in February 2013