Centre for Energy Research Hungarian Academy of Sciences
Atomic Energy Research Institute
Main Results in 2013

I. MAIN DUTIES OF THE RESEARCH UNIT IN 2013

The major research tasks of the institute can be derived from the strategic research agenda of the research centre, described in part I of the 2012 year report of the centre. This concept is still actual, it serves three goals: research related to nuclear safety according to the demands of the present time, preparation of the new NPP units to be built in Hungary, support of the energy production of the future: Generation IV nuclear reactors and nuclear fusion.

The safe operation of the Budapest Research Reactor, the continuous development of the research possibilities and thus keeping the world standard, remained an important task of the institute.

II. OUTSTANDING RESEACH AND OTHER RESULTS IN 2013

a) Outstanding Research and Other Results

Research in Reactor Physics and Multi-physics

The competitiveness of the present and future (e.g. the new units in Paks) nuclear reactors with other energy producing technologies depends on the well based but not too conservative definition of the safety margins for normal operation and incidental conditions. Beside this it is also the condition for safe operation. To the margins belong confidence levels and probabilities. The development of the methods giving these data (safety margins with confidence) continued for normal operation as well as for incident conditions. The institute takes part in the OECD NEA WPRS UAM („Uncertainty Analysis in Modeling") cooperation. In 2013 the burn-up dependent cell calculations were performed. The resulted uncertainty of the multiplication factors is about 0.5% without burn-up, but significantly higher, i.e. about 0.8-0.9% with burn-up. The major reason of the increase is the build up of Plutonium isotopes as their cross sections have a relative big uncertainty.

In the field of Generation IV reactor research the development of the code KIKO3DMG continued. This code will be capable for the core design calculations of the fast spectra of the liquid metal and gas cooled reactors, as well as for their reactivity type incident analyses. These reactors are important for the closure of the nuclear fuel cycle. An on-line coupling was established in 2013 between the reactor physics code KIKO3DMG and the thermal hydraulics code ATHLET3.0.

For the estimate of the Uranium and Plutonium demand of different reactor parks (different generation reactors may belong to them) the operation of the units and the material transport between them has to be modeled. The development of the alogrithm of

the fuel cycle analyzer code SITONG4 was continued in 2013 by including more realistic and more versatile physics models. By means of this code the possibility of closing the fuel cycle with Generation IV gas cooled fast reactors of the Hungarian reactor park was investigated.

The final goal of the Euratom Supercritical Water Reactor - Fuel Qualification Test (SCWR-FQT) Project is the design and the analyses necessary for licensing of an irradiation channel containing fuel elements operated in the super critical phase. The channel is foreseen for the Czech LVR-15 research reactor. The task of the research centre is to perform burn-up calculations for the fuel and the determine the power profile, as well as performing the transient analyses for reactivity input, by means of the coupled KIKO3D-ATHLET codes. The 3D coupled KIKO3D-ATHLET model was developed in 2013. The parameters calculated earlier enabled performing conservative dynamic calculations using the special options of KIKO3D-ATHLET.

Research in Thermal Hydraulics

The operability of the external reactor vessel cooling system was investigated in the years 2010 – 2012 by means of CERES measurements, for different cooling channel geometries. As it can be assumed, that during such an accident the boron concentration in the sump water might be high, and the cooling can be needed for longer period of time – as the Fukushima accident indicates too – the question arose, whether or not the boron sedimentation jeopardizes the cooling. As the CERES equipment can be operated separately from other systems, the cooling experiment can be performed using boric acid. The experimental results showed, that steam is periodically produced during the cooling process in the critical waists of the cooling channel. This may lead to boron precipitation and potentially to the blockage of the tight channel. Using these results in 2013 the experimental analysis of the effect of borated cooling water was performed. The boron concentration was permanently monitored in the range of 14 – 40 g/kg. The results showed, that the presence of boric acid influences only slightly the effectiveness of external cooling. The temperature of the outer surface of the vessel was below 300 C^o during the entire long term cooling process.

The PMK facility was prepared for the first experiments in 2013 in the OECD NEA PKL-3 Project. To examine the pressure waves induced by the primary circuit break high frequency pressure transmitters were purchased and the break model including a splitting disk was prepared. Two measurement series were realized with two different break sizes, varying the temperature and the initial system pressure. Due to the delay in the procurement of the fast acting valve the measurements of the acting time are postponed for 2014.

The 2013 task of the joint Korean-Hungarian laboratory was to extend the limited number of the pressure wave experiments performed in the frameworks of the PKL-3 Project, thus enabling to analyze the entire spectrum of the parameters influencing the process. During the preparatory phase of the experiments pre-calculations were performed by means of three codes (WAHA, MARS and ATHLET). As it was indicated

in the PKL-3 project report, the entire series of experiment for the validation of the mentioned codes could not have been finished in 2013. The results proved, that both the MARS and ATHLET codes reproduce the measured values, however to the deeper explanation of the differences the comparison to the entire experimental matrix is necessary. Three Korean colleagues took part in the experiments and three other in the calculations. Each of them spent three months in the institute.

The cooling process in case of the natural circulation has been investigated in the Paks NPP. If the evaporation of the hot water in the upper head of the reactor pressure vessel starts while the cooled primary circuit water can cool down the water below the steam bubbles, than a remarkable steam - water temperature difference can be resulted in the border layer. In such a case a very quick condensation can start producing a pressure wave, which may endanger the mechanical integrity of the structures in the upper head; consequently the bubble production in the upper head has to be prevented. A measurement of the OECD-PKL Project simulates the bubble production in the upper head due to aggressive cooling. The experiment is good for validation of the process modeling. The calculations were performed; the consequences are included in the input to the power plant. The ability for cooling the upper head during natural circulation could be demonstrated by a refined upper head model.

Research of Fuel and Reactor Materials

In the field of fuel research the investigation of secondary hydride production processes of the zirconium cladding was continued by means of mechanical and structural studies. In the frameworks of the above systematic comparisons were carried out for the old (E110) and new (E110G) alloys, at high temperatures. The results for loss of coolant accidents indicated, that the flatulent section of the cladding is the most vulnerable part of the fuel. The new cladding material – after oxidation under identical conditions -could survive a much higher mechanical stress than the older one.

The numerical model of the sipping equipment used for identification of leaking NPP fuel was improved using the results of special measurements performed in the power plant. According to the calibration measurements the numerical model gives a more reliable estimate for the activities to be expected during the investigations.

In a working group of the OECD a survey was performed, how the leaking fuel elements are treated in different power plants. The survey was lead by the experts of the research centre.

The methodological unification of the experiments performed for determining the safety criteria for loss of coolant accidents continued in international cooperation. Participants were from Korea, France and the USA besides the experts from the institute.

In an emphasized project in the field of reactor materials research the development of a new evaluation method, finer than required by the present regulation, started. The main idea is to base the evaluation on a finite element method instead of the widely used

analytical procedures. The finite element method includes basic physical assumptions. The new method will be used for the medium and long term renewal of the safety analyses of Paks NPP.

The plating technology of the VVER-440 type reactor pressure vessels was investigated by on-line measurements after a welding performed according to the original technological instructions, on an industrial size probe. Based on this experiment a calculation method using finite element method was developed, which could be used for the simulation of the welding technique. The aim of the validated model is to follow the influence of the remaining stress field after manufacturing in a more realistic and more precise way, than required by the present regulation and recommendations

Analyses were carried out for the planned fuel utilization strategy of Paks NPP to revise the conditions for the lifetime extension and to prove the fulfillment of the requirements. During this project up to now the calculations of neutron fluence, system thermal hydraulics and structural material aging have been revised. On the basis of the results the pressurized thermal shock (PTS) calculations will be performed. These calculations are essential from the point of view of the safety of reactor pressure vessels.

The EU FP7 projects LONGLIFE and STYLE continued in 2013. Both projects answer questions of long time relevance for nuclear power plant operation

Development of Reactor Monitoring and Simulation Systems

The coupled neutron physics - thermal hydraulics code system VERETINA was extended in 2013 by the module SURET. The VERETINA system was developed for the Paks NPP, it describes the hydro-dynamical and thermo physical phenomena processing in the active core of the reactor more precisely and in more detail, than the models used previously. The role of the module SURET is to bring the details of the thermal hydraulic modeling to the level of sub-channels. This means, that all the fuel rods and the space between them are included to the model, in 50 axial positions. The development of the module as well as the preliminary testing were done in 2013.

Regular reactor diagnostic measurements at all the units of Paks NPP were performed in 2013 and the linked evaluations were done as well. The results of the monthly performed noise diagnostic measurements were used to systematically monitor the condition of the units, the evaluations were performed for monitoring the flow of the coolant through the active core and to detect the vibrations of the in core structures. None of the evaluations showed any abnormality or any other technical problem. The investigations were continued with the aim of estimating the temperature reactivity coefficients.

The full scale simulator of Paks NPP was developed about twenty years ago and consequently it is out of date regardless of the continuous maintenance. The operational system (VMS) of the computer, on which the simulator is running, is not supported by the manufacturer any more, the communication interface (VME) between the control room and the simulator is out of date, the always growing demand for maintenance

requires a full scale reconstruction soon. The power plant wants to ask a big foreign simulator company to do the reconstruction. As the simulator was developed by the research centre the power plant asked the Center for Energy Research to help in communicating with potential foreign partners and to collect information about the necessary activities for the development of a new simulator and about the software tools of the potential suppliers. The research centre contacted four big international suppliers and asked for technical information, organized meetings with them and evaluated the information. The evaluation was formulated in a report. As the research center still has the knowledge necessary for the development of a full scale simulator, but its tools are out of date, a developing work started. As a result of this work the SIMTONIA (SIMulation TOols for Nuclear Industrial Applications) frame system was developed, which has similar capabilities to those of the foreign partners. The simulator reconstruction tender may be releases next year, the Center for Energy Research can take part in the tender with Hungarian partners with the real chance for winning.

The Hungarian Atomic Energy Authority (HAEA) formulated in 2012 the demand, that certain measured data of the Budapest Research Reactor have to be available in CERTA, where the HAEA experts work in case of nuclear or radiological danger. CERTA stands for Centre for Emergency Response, Training & Analysis. HAEA asked the Centre for Energy Research to elaborate a feasibility study, how the data should be transferred, evaluated and used. The feasibility study was prepared in 2012, the system was developed on its basis in 2013, tests will be performed during 2014.

Paks NPP decided to change gradually the 12 month fuel cycles for 15 month cycles (C15). The C15 cycles can only be realized economically using a new fuel type Gd-2, differing significantly from the present fuel. According to the preliminary analyses the new fuel requires a greater amount of on-line calculations. The resources of the present core monitoring system VERONA do not allow to perform the required amount of calculations. The basic requirement for the introduction of C15 cycles from the point of view of core monitoring is to enhance the reactor physics calculation system, further the enlarge the capacity of the used computation system. Paks NPP asked the Centre for Energy Research to elaborate a feasibility study. The study was completed in 2013 and it gave answers to the following questions:

- what reactor physics development is necessary due to the increase of the cycle length,
- what software and hardware development is necessary,
- how can the computing development of the last ten years be included to the new system,
- how can other development works in the NPP (e.g. technological computing system) harmonized with VERONA development.

The so called ex-core neutron detectors of Paks NPP are close to the end of their life-time. The power plant intends to use new detector types. A reactor physics measuring

system was designed and built; preliminary measurements were performed in the training reactor of the Budapest University for Technology and Economics.

The EU project NURESAFE started in 2013. NURESAFE can be considered as the continuation of NURESIM and NURISPE. The Centre for Energy Research performs bubble dynamic investigations in the project, using the models developed in the former projects. The modeling of the bubble growth and stripping started using numeric simulation. The forces between the stripped bubbles and the liquid are investigated too.

Research in Health Physics

The dosimeter system *Pille-MKS,* developed in the research centre (former in AEKI), serves on the Russian module of the International Space Station (ISS) as part of the service system since 2003. Main service of the system is to determine the doses of the staff during extravehicular activities and during enhanced solar activities; mapping of dose distribution, taking part in onboard experiments. The results of the few thousand measurements were evaluated and discussed on panels, in 2013 as well, similarly to previous years.

Measurements were performed on board the ISS until 10th of May 2013 by the dosimeter system comprising a three-dimensional silicon detector telescope (TRITEL) and several thermo-luminescent and solid state nuclear track detectors delivered to the European Columbus module of the space station in autumn 2012. An advanced version of the experiment provided with touch-screen display arrived at the Russian Service module of the International Space Station in March 2013, where it was switched on on the 5th of April.

It will be the first time in history when a spacecraft, the ESA's comet-chasing Rosetta probe, will be inserted into orbit around comet 67P/Churyumov-Gerasimenko and its Lander will be delivered to the surface of the comet in 2014. Two instruments on board the Lander (the ROMAP/SPM plasma- and the SESAME/DIM dust detector) were developed with the contribution of EK. In 2013 EK's specialists were involved in the scientific program planning for the descent phase and for the operation on the surface of the comet, as well as in the on-ground calibrations of the instruments.

The thermo-luminescent and solid state track detectors of the Centre for Energy Research were put on board the Russian BION-M1 returnable satellite. The goal of the satellite is to investigate the behavior and reproduction of biological samples in the harsh cosmic environment. The participation in the program was motivated by the interest in determination of cosmic ray exposure.

The SINAC program system was developed to follow the consequences of radioactive releases to the atmosphere, including dispersion, plume depletion by dry-out and wash-out, cloud-shine and ground-shine doses, dose consequences of inhalation and ingestion, early and late health effects and the introduction of countermeasures. Several changes were implemented on the software considering the new end-user comments and demands.

Several calculations and analyses were performed supplying the operation safety of the Hungarian nuclear facilities, primarily by estimating the environmental consequences. The used software was partly own development, partly commercial.

Measurements were performed in the field of interaction of radiation with matter. Radiation shielding properties of a new type of building material were investigated.

Research and Development in Nuclear Security

In the frameworks of gamma spectrometric analyses

- the verification of enrichment of the fresh fuel assemblies in Paks NPP was continued. The enrichment of the outer and inner fuel rods of the newly purchased fuel assemblies was determined by gamma spectrometry and by Monte Carlo simulation.
- the determination and verification of enrichment was extended for new assemblies using gamma spectrometry. For the Monte Carlo modeling the addition of fuel rods in different positions was determined.
- In the framework of the EU project BOOSTER the results of the development of methods and instruments as well as their applicability for real accidental and terror attack conditions was demonstrated in an on-site exercise.
- In the framework of the EU project SCINTILLA a test laboratory was set up for research and development. The laboratory was introduced in an international workshop, where the members of international companies and of the IAEA participated. The laboratory has two main goals; the first is to provide the scientists of the research center with ideal conditions for non destructive analyses; the second is to serve for base of international cooperation in the field of detector development.
- Surface layers of Uranium oxide samples were investigated by X-ray photo electron and Auger electron methods. It was concluded, that the Uranium, Oxygen and Carbon peak can be well detected and further the chemical shifts can be seen on the peaks too. The primary measured results were refined, taken into account the electric loads of the samples. Preliminary results prove, that the presence of Ca, Cl and Pb can be verified too. For nuclear forensic analyses the variety of the samples to be investigated has to be extended.

In the frameworks of neutron coincidence investigations

The PTR-32 neutron coincidence data collection system was improved in the framework of the IAEA Hungarian Support Program. According to the IAEA demand the software was updated to promote the use of the system for international non proliferation control use. The same PTR-32 device was used to test the Passive Scrap Multiplicity Counter (PSMC) neutron detector in the Nuclear Safeguards and Forensics department of ITU. During these tests authentic measurements of fissile material samples and highly enriched metal Plutonium samples were successfully carried out.

The determination of Plutonium content in Pu-Be neutron sources was performed by precise calculation and measurement of the neutron flux, and by radiography.

In the frameworks of the development of materials and methods for dose measurements:

- The applicability of some material from the environment (dolomite, rock-salt and limestone) for nuclear forensic and retrospective dose determination was investigated. The rock-salt samples were investigated below 10 Gy, the limestone in the range of 1 – 8 kGy, the dolomite in the range 1 -10 Gy. The result is, that altough the dolomite is less sensitive for thermo-luminescence than NaCl, but it can be used for dose estimate after irradiation. In case of limestone samples the curves ar complex, consequently further investigations are necessary. The investigation of the environmental material showed, that their sensitivity is less, than the sensitivity of SMD, however after a nuclear accident they could be used for the determination of the environmental doses after the accident.
- The systematic investigation of the recently synthetized potential thermo-luminescent (TL) detector material Lithium – tetraborat (LTB) continued. The detailed analysis of LTB was performed. The TL sensitive of the material is about sixty times less than that of TLD-100, the linear dose response range is between 3 mGy and 60 Gy; based on this LTB is a promising material in high dose measurements, especially for radio therapy.
- The spectroscopy investigation of the double doped LTB samples started. Optical absorption investigation showed, that in the LTB:Ag,Eu the Ag^{+} ions are reduced to Ag0 and the aggregation of the silver atoms start, silver nano particles are produced.

Technological dose meter development was performed for Li halogen (LiF) so called Sunna dose meters. The sensitivity range of these devices is in the range of 1 to 200 kGy. The lower end of the range was extended by measuring the emitted radiation in the infra red range. The response signal of the LiF dose meter in the range of 50 to 1000 Gy was determined and found almost linear.

In connection to mass spectrometry the investigation of biological samples was continued. The fast and precise determination of the radioactive material content of small samples might be significant for the identification of internal exposure of persons involved in terror actions or nuclear accidents. The related methods laser ablation ICP-MS, destructive chemical separation and methods using liquids were improved and extended for further radio/isotopes (e.g. Th).

The development of a Hungarian nuclear forensic data base started, using the data of the confiscated material, stored in the research centre. The analyses were carried out by different methods (optical microscope, electron microscope, mass spectrometer, gamma spectrometer) and were repeated a few times to get a statistically well established data base. New methods are being developed, e.g. the determination of the Pb and Nd isotope ratio in the samples. The development of the entire data base takes years.

Main Results of the Operation of the Budapest Research Reactor

A significant event of the year 2013 was the repatriation of the highly enriched Uranium (HEU) spent nuclear fuel in the frameworks of the Russian Research Reactor Fuel Return program with the active help of the United States. Since November 2013 there is no HEU material in Hungary.

The research activities at the facilities of the Budapest Research Reactor are still coordinated by the Budapest Neutron Centre (BNC). BNC is member in EU supported programs (NMI3, CHARISMA, ERINDA) consequently European scientist can apply for travel support if they have an accepted proposal for reactor experiment. Due to the extreme big demand only excellent and very good proposal can be accepted.

The new web site of BNC started in 2013. It contains the description of the equipment and a list of possible research proposals. The progress report of BNC, containing the research results of three years can be downloaded from the web site.

In May 2013 the Central European Training School on Neutron Scattering was organized. The school had 30 participants, most of them from Central and Easter European countries. This was already the sixth school of this type.

In November 2013 a user meeting was organized by the International Scientific Advisory Council and by the User Selection Panel of BNC. Scientist reported on their results on the panel.

b) Dialog Between Science and Society

The institute reports on its activity and results occasionally in web sites, in newspapers and in different radio and television programs.

In the frameworks of the Feast of Science, organized by the Hungarian Academy of Sciences, a few presentations were offered to the public. The main purpose of the presentations was partly to explain the most interesting research results, partly to make publicity for the strategy of the research centre.

The Budapest Research Reactor accepted plenty of guests in 2013, as well as usually. The majority of visitors were students, but one has to mention the group of diplomats from the Embassy of the United States, which expressed special interest for the reactor and for the research performed on it. The American interest seems to be continuous.

III. A PRESENTATION OF NATIONAL AND INTERNATIONAL RELATIONS

The Hungarian Sustainable Nuclear Energy Technology Platform continued its activities in 2013. Financing of the platform activities is unfortunately not yet solved, consequently still only preparatory work could be carried out. There is a well based hope, that in 2014

an appropriate call will be published, and in case the proposal of the platform will be accepted the real work might start.

The institute singed a cooperation agreement in 2010 with two research institutes from the Czech Republic and Slovakia to make preparation for the design and construction of the ALLEGRO facility which will be a demonstrator of the Gas Cooled Fast Reactor. The preparation continued in 2013.

Scientists of the institute take part in the undergraduate and in the post graduate training both at the Eötvös Loránd University (ELTE) and at the Budapest University of Technology and Economics (BME). In ELTE they are mainly active in chemistry, closer physical chemistry, in BME in nuclear technology, closer reactor physics.

An essential part of the international relations is realized in taking part in EU projects; there are extensive relations to a number of research institutes and universities, mainly in Europe, but even overseas.

A good relation was established with the US State Department in 2013; their experts took part in forming forensic data basis for different countries. An expert of the research centre was elected to the management of International Technical Working Group on Nuclear Forensic (ITWG).

An expert of the Research Centre for Energy is member of the directorate of the European Safeguards Research and Development Association (ESARDA). In two EU FP7 projects a cooperation was established with the French Nuclear Authority (CEA). A few common projects are expected in this field..

IV. BRIEF SUMMARY OF NATIONAL AND INTERNATIONAL RESEARCH PROPOSALS, WINNING IN 2013

The major part of the winning proposals is from EU framework programs. The significance of these proposals is, that they give links to international efforts towards up to date nuclear energy research, allowing the study of future versions of nuclear reactors as well as taking part in fusion research. These two seemingly far away fields are related by the common problems of future structural material, applicable at high temperatures.

The national possibilities for research grants have been rather limited in recent years. In 2013 the hope revived, that significant proposals may be accepted. The biggest hope is, that the Sustainable Nuclear Energy Technology Platform will get the necessary support. If so, the possibility for dealing with problems of long perspective as well as with the preparation for the new NPP units will be possible.

V. LIST OF IMPORTANT PUBLICATIONS IN 2013

A. Keresztúri, I. Panka, A. Molnár, Á. Tóta: Multi-physics development for the hot-channel calculation of fast reactivity transients, Progress in Nuclear Energy, 67 (pp 74 – 81) 2013

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