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I. MAIN DUTIES OF THE RESEARCH UNIT IN 2012

The research concept of the institute corresponded to the strategic research agenda of the research centre, described in part I of the report of the centre. This concept served 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 2012

a) Outstanding Research and Other Results

Research in Reactor Physics and Multi-physics

The research related to the Generation IV reactors was performed in the framework of the NUKENERG Project, financed by the national funding institution NFÜ. One of the goals of the investigations was to elaborate a steady coupled Reactor Physics - Thermal Hydraulics program system for the European version of the Supercritical Water-Cooled Reactor, (SCWR), the HPLWR reactor (High Performance Light Water Reactor). The NUKENERG Project was finished in 2012. The last action of the project was the integration of the rectangular fine mesh diffusion model. This completed the development of the HPLWR core design code system. The reactor core was analyzed by means of the new, more precise code system. It was investigated what steps are necessary in fuel assembly design and in fuel optimization for significant decrease in cladding temperature. The safety sizing of the HPLWR safety systems was performed by the safety analyses. In 2012 calculations were performed by means of the code system extended by safety systems for a series of cases. The results allowed to evaluate the acceptability of the safety systems. Based on all these a proposal was elaborated for the appropriate variants, and for parameters, for which the accaptance criteria of the safety analyses are fulfilled.

Another goal of the activities performed in the NUKENEG Project was the reactor physics and safety analysis of the Generation IV fast reactors with liquid metal cooling. The reactor physics and safety features as well as isotope inventory of the following liquid metal cooled fast reactors were investigated and compared in steady states.

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- Sodium cooled fast breeder reactor with oxide fuel for burning of fission products of long half-lives
- Lead cooled fast reactor with oxide fuel
- Sodium cooled fast reactor of high power with carbide fuel
- Sodium cooled fast reactor of high power with oxide fuel
- Sodium cooled fast reactor of medium power with metal fuel
- Sodium cooled fast reactor of medium power with oxide/carbide fuel

Investigations proved, that from among the sodium cooled variants the large core with carbide fuel is the most promising. The Doppler coefficient's large positive value compensates for the positive void coefficient in this variant, further the efficiency of the absorbers is sufficiently low, this is good in case of incidents with unplanned movement of absorbers, however the core can always be shut-down. The high efficiency absorbers in the medium size cores may cause serious problems from the safety point of view. The variants with metal fuel are less attractive because of the small Doppler coefficient. The conversion rate is also optimal for the high power core with carbide fuel, its is much over unity. The operational temperature is relatively high, it is near to 1000 °C, it is somewhat lower than in case of oxide fuel, but the melting point of fuel (~2500 °C), and the heat conduction coefficient are high as well. Another advantage is that this fuel hardly interacts with sodium.

The final goal of the *Supercritical Water Reactor - Fuel Qualification Test (SCWR-FQT)* FP7 project is the design of the supercritical irradiation channel to be built in the LVR-15 reactor in the Czech Republic, as well as performing the analyses required for the authority licensing - in international cooperation. In 2012 the quasi steady coupled neutron physics - thermal hydraulics model of the LVR-15 reactor and of the irradiation channel (KARATE-LVR) was developed in the institute. The power shape in the fuel rods during irradiation was analyzed based on the burn-up calculations of the research reactor. The power production in the thick pressure tube of the irradiation channel was calculated, and it was shown, that it has a non negligible effect on the heat distribution in the cooling water of the channel. The decay heat distribution was determined using conservative assumptions, the results will be utilized in safety analyses. The development of the dynamic model, based on the code KIKO3D-ATHLET has been started.

The reactors of present time as well as those of the near future (e.g. the new units foreseen for Paks) are and will be only competitive with other modes of energy production if the limits for normal operation and incidents will be determined on a well established but not too conservative manner. To determine these limits confidence levels and probabilities are needed. The development of methods for calculating these data (safety margins with confidence levels) continued for normal operation and for incidents as well. To achieve these goals the institute takes part in the cooperation WPRS UAM („Uncertainty Analysis in Modeling"), organized by OECD NEA. In 2012 the uncertainty analysis for the sub-channel code COBRA was performed for steady and transient states, the results will be used in the planned multi-physics investigations.

Research in Thermal Hydraulics

Paks NPP Co requested the experimental works on CERES equipment. The operability of the outer cooling system of the reactor pressure vessel varying the geometrical properties of the system was investigated earlier using the measurements on CERES. Experts of the NPP and NUBIKI and HAEA raised the question, that in these accidental conditions the boric acid concentration might be high in sump water. This involves the question - partly based on the experience from Fukushima - whether the sedimentation of boric acid does or does not block the outer cooling of the vessel if the cooling is necessary for a longer period of time. As CERES can be operated separately from other systems, it is capable for cooling experiments with boric acid or with some salt, which models the boric acid sedimentation. The results show, that during the cooling there is a periodic steam production in the critically tight parts, which may lead to boric acid sedimentation and consequently to the blockage of the tight parts. To ensure the long-term (about 24 hours) operation a special cooler was built into the return line of the system, by means of which the temperature of the sump water could be stabilized. The effect of the boric acid could be detected by decreasing the cooling and by visual inspection (eventual photographs) of the system after dismantling the critical parts. The boric acid concentration can be continuously controlled by sampling. The boric acid concentration was between 10 and 40 g/kg.

Paks NPP Co also asked for the experimental verification of the statements concerning the water hammer on ECC lines, as the theoretical investigation contained a few uncertainties, which could only be clarified by means of experiments. Therefore it was proven by building a 1 : 1 scale model and performing a few series of experiments on it, that under the given conditions no water hammer can be developed in the lines of the NPP. In 2012 a method was developed for qualifying the lines of the NPP, based on the great number of experimental data. This method enables to decide on the basis of parameters, without WAHA calculations, whether or not condensation may lead to water hammer.

Preparations started for the revision of the stand by Probabilistic Safety Assessment of Paks NPP, the lack of the analyses of leak type incidents with Nitrogen atmosphere became obvious. The consequences had to be analyzed as well, for the actualization of the event trees. Earlier only large break LOCA events were analyzed for Paks NPP, consequently in 2012 a few small break LOCA events were analyzed – specified by Paks NPP Co.

The suitability of CFD tools has been analyzed on the basis of experiments with air cooling, performed on the German L-STAR equipment, performed in cooperation with French, Czech, Slovak and Polish scientist in the framework of the GoFastR project of EU FP7. The incident analyses, necessary for safety analysis for the experimental fast reactor ALLEGRO were continued by means of the CATHARE computer code.

According to the program of PKL-3 Project, in 2012 experiments were only performed on the PKL equipment, as on the PMK equipment of the research centre only the preparation for the first experiment was done.

Research of Fuel and Reactor Materials

High temperature oxidizing tests were performed in 2012 at 1000 °C and 1200 °C temperatures, at 300 and 600 ppm Hydrogen content, for the E110G clad, fabricated by means of new technology from metal sponge. No basic difference could be observed in the oxidizing kinetics of cladding materials with different Hydrogen contents. According to the mechanical investigations the original clad showed a more ductile behavior, than the samples with Hydrogen content. The higher Hydrogen content resulted in a more rigid behavior. Based on these experiments one can assume, that the Hydrogen intake of the clad during normal operation would have a negative effect on the mechanical properties of the cladding in case of LOCA events.

A source term estimate was done for the placement of leaking fuel elements to the Temporary Storage Facility for Spent Fuel Assemblies. Experts of the research centre calculated the leak rates from the fuel elements. The calculated models were based partly on following the physical processes, partly on engineering estimates. In the model of calculating the wet solution the results of measurements, made in Paks were used. The source terms for incidents were given in a conservative way, i.e. it was assumed, that the source term is equal to the entire solved activity in the fuel. The results of the calculations help in the decision about permitting the storage of leaking fuel in the Temporary Storage Facility for Spent Fuel Assemblies.

The RIA (reactivity initiated accident) experiments, performed in the Japanese NSRR and the French CABRI research reactors have been modeled in the frameworks of an OECD project, by means of the fuel behavior code FRAPTRAN. The few years long irradiation before the transients has been simulated by the FUROM code. The results of our research centre did never show big differences to the results of other participants, i.e. our results were always in the middle range, close to the measured values. Summarizing, we can state, that reasonable modeling experience was gained during the calculations performed in the OECD CABRA and NSSR RIA benchmark exercise. The experience will be used in future works at Paks NPP.

In the frameworks of the STYLE Project a small scale model of the main line stump of a VVER-440 type reactor vessel was built. The residual stress produced by welding has been determined on this model by many methods. The knowledge of the residual stress is essential for the judgment of the safety of the real structure. There are only very few empirical data and even less calculated results for residual stress, according to the literature. Consequently the measurements on the model terminate the lack. Our research resulted in a finite element 3D simulation, within the MARC code system, which simulates the welding. The experimental works and the calculations performed are on high level, the results are comparable to world standard, the experience will be used in future works at Paks NPP.

The new irradiation device BAGIRA II, foreseen for the Budapest Research Reactor has been completed during the year. It is capable for performing mechanical and material tests during irradiation. There are only very few such experimental equipment in the world, consequently our device terminates an important lack. The test operation was successfully finished; the HAEA provided the operational license. The real experimental work starts in the first quarter of 2013.

Development of Reactor Monitoring and Simulation Systems

The elaboration of the coupled neutron physics - thermal hydraulics code system VERETINA was continued in 2012. The system, requested by Paks NPP Co, 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 development of the system is done in more phases. In 2011 the conceptual design and the design plans were elaborated, as well as the project for the validation and verification (V&V) of the computer codes. The development works of Phase I were performed, preliminary calculations were carried out by means of the new models. In 2012 development works of the Phase II were completed: the description of the core on the fuel assembly - node level was done, later the prescribed V&V calculations were performed using the operational data of Paks NPP. The user and developer documentation of the system was elaborated too.

The activities linked to the preparation for the establishment of the new NPP units at Paks continued in 2012. The most important work was to take part in the tender document preparation, performed in the frameworks of the Lévai Project of the Hungarian Electricity Board. Besides preparing background documents and finalizing some sub-chapters of the tender document, the research centre had to coordinate the works too.

Regular reactor diagnostic measurements at all the units of Paks NPP were performed in 2012 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.

The hardware and the operational system of the computers at the units of Paks NPP and at the full scale simulator became out of date in 15 years, consequently the updating became acute. To guarantee the long term availability and reliability of these computers the NPP decided to support the updating by a conceptual design. The conceptual design was contracted by Scadanet Co. the research center was a subcontractor in this work. The following items were treated in detail in the conceptual design:

- evaluation of the current computer from user's, operator's and maintenance point of view;
- assessment of the functions to be realized in the update;
- formulation of proposals for technical investments;
- determination of the task to be realized and scheduling;

- well founded estimate of costs.

The update concept was elaborated by the end of 2012 the decision will be made early 2013. The conceptual design, when accepted by the NPP will serve as basic document for the update, based on it the detailed design works may start in 2013.

Paks NPP Co decided in 2012 to evaluate a device, based on the upgrading of the full scope simulator, which could be used for training the personal in connection with severe accident phenomena. The upgrading was justified partly by the Safety Review performed after the Fukushima accident, partly by the efforts to make the simulation model more accurate to fulfill the new training demands. Paks NPP Co asked the research center and the NUBIKI Co. to perform an evaluation, summarizing the international experience on use of simulators, on technical solutions, and takes into account the development options and the potential developer partners (including international ones) of the Paks simulator. A conceptual design was elaborated by the end of 2012, which analysis the feasibility of the above tasks, taking modeling, calculating and other (e.g. development and construction questions) points of view into account. The conceptual design, when accepted by the NPP will serve as basic document for the upgrade of the simulators, based on it the detailed design works of the severe accident model may start.

The Hungarian Atomic Energy Authority (HAEA) formulated in 2012 the demand for reaching specified measured data of the Budapest Research Reactor in the Centre for Emergency Response, Training & Analysis (CERTA), where the experts of HAEA work under nuclear or radiological accident conditions. Per procurement of HAEA a feasibility study was elaborated, which gives a well founded proposal for the data transfer to the CERTA, and further specifies the data indication and use. The study was finished by the end of 2012, it describes the data acquisition procedures, to be used in the information system of the Budapest Research Reactor, and the concept of the data transfer. The study specifies the amount of data, the technical realization of the on-line connection, the development tasks and other necessary activities. The realization is foreseen for 2013, based on the concept accepted by HAEA.

Research in Health Physics

The dosimetry system *Pille-MKSz,* 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. Main service of the system is to determine the doses of the staff during space walks and during enhanced sun activities; mapping of dose distribution, taking part in onboard experiments. The results of the few thousand measurements were evaluated and discussed on panels, in 2012 as well, similarly to previous years. The upgrading of system *Pille-MKSz* started.

The experience from *Pille* was utilized in the development of the *PorTL* system to use on earth. These systems are produced by the daughter company AEMI. In 2012 the *PorTL* system took part in the EURADOS IC2012 personal dosimetry system inter-comparison., where it proved to be applicable for personal dose measurements too.

A specimen of the triple axis space telescope TriTel, with silicon detector having nearly equivalent sensitivity in 4π space angel, was developed in recent years, was delivered to the European module Columbus of the International Space Station (ISS), where it has been continuously measuring since November 2012. This equipment is not only capable of determining the absorbed dose, but also the linear energy transfer factor (LET) and the quality coefficient of radiation as well, consequently the equivalent dose can be calculated.

In the frameworks of the REXUS/BEXUS program of the European Space Agency (ESA) a successful experiment was carried out – in cooperation with students – by means of active (TriTel telescope, GM counters) and passive (Pille dose meter, neuron track detectors, high sensitivity TL pellets) dose meters in northern Sweden, on board of the BEXUS-14 stratosphere balloon.

The comet research space device *Rosetta* of ESA will reach the 67P/Churiumov – Gerasimenko comet in 2014. Two devices (*ROMAP/SPM* plasma and *SESAME/DIM* powder detector) were built with the cooperation of the research centre for the landing unit of the space device. Experts of the institute continued the preparations of the measurements to be performed on the surface of the comet as well, as the calibration of devices on earth.

To map the cosmic ray radiation conditions on two Russian segments of ISS in cooperation with the Biological Problems Institute of the Russian Academy of Sciences (RAS IBMP) started in 2010; in 2011 further detector were sent to the station and so the investigations continued in three segments. The name of the program is Dose Map (SPD). The evaluation and analysis of the detectors form the first phase was finished in 2012; the evaluation of the detectors from the second phase started. The results will be published soon together with international participants. The dose mapping continues by means of upgraded devices.

The in depth distribution analysis of cosmic ray in biological systems (BioTrack program) started in 2010 in cooperation with IBMP as well. The devices fulfilling the task come back to earth for evaluation in four steps.

The results of the evaluation of the SPD and Bio Track detectors reflected the changes of the sun activity in the investigated three years period, and showed the effect of a few big solar flares on the space station. The dose load of the Russian astronauts from cosmic rays has been continuously monitored from 2011 by the request of IBMP.

Researchers of the centre take part together with a few European institutes in the study related to dose mapping program DOSIS-3D of the Columbus module, organized by ESA. The program started in 2012 and is foreseen for six cycles.

The measuring equipment manufactured in the research centre belongs to the series of instruments, which realize the in-kind contribution of Hungary to the ISS, by helping in the measurement of the spectrum of cosmic rays and the integral dose produced by them. This promotes the scientific and technical reputation of the country.

The propagation and sedimentation of the radioactive material released to the environment, the dose related to the release as well as, the health consequences, including the effect of the early measures of precaution can be modeled by means of the SINAC environmental simulator code system. The first development phase of the new version of SINAC was finished in 2012. An exhausting test was performed and the training material for SINAC users was prepared too.

Research in Environmental Physics

The research strategy for the environment friendly energy production and storage was elaborated in the newly established Environmental Physics Department, according to the new strategic research agenda of the research centre. A middle term research plan was elaborated, based on the human and instrumental resources of the department, taking into account the diversified links to universities and industrial companies. In November 2012 this research plan was sent to the Hungarian Academy of Sciences as well. The research strategy for renewable energies is based on the special knowledge of the research centre in the field of energy production and on the existing research infrastructure; the strategy fits to a broader frame of fossil – nuclear - renewable energy research frame. The main research directions include investigations for carbon dioxide storage, optimization of bio mass fuelling, modeling of the shovel form of wind turbines, thermal hydraulic analysis of salt melts, investigation of new energy storage systems, research of hydrogen storage and modeling of smart grids.

The sorption capacity of the ground rocks in Hungary and in Switzerland were investigated in Swiss Hungarian cooperation, in the framework of investigations for the safe storage of high activity radioactive wastes in deep geological repositories. It was determined in facets made from the clay rocks of the Aleurolit Formation of Boda, which minerals have an essential role in binding the radioactive nuclides. It was observed, based on the measurements by means if fluorescent and adsorption X-ray spectroscopy, that beside the Nickel the Cesium is also bound to the clay, but the Uranium behaves differently. In binding the Uranium the Fe-Mg-carbon (ancerit) content of the rock play a significant role too. About 25% of the bound Uranium is joined to the FeOOH phase, produced by weathering of ancerit.

From among the results of low dose research in 2012 exceeds the comparison of the dose loads from primary radioactive subsidence in the respiratory system and from the released radioactivity; leading to the conclusion, that these two fractions are of the same order of magnitude. Further it was shown on the example of the Radon daughter elements, that the unevenness of the dose load can not, but also should not be taken into account in the current radiation protection regulation, because the nominal risk, the effective dose and the dose equivalent are all linear function of the absorbed dose. It was shown, that the significance of the non linear dose dependent phenomena, characteristic for the low dose range, is presumably less in case of the influence of the inspiration of Radon daughter elements on the lung, than in case of a radiation source producing even dose load distribution in space.

Main Results of the Operation of the Budapest Research Reactor

The main task of the Budapest Neutron Center (BNC) is to ensure the effective use of the Budapest Research Reactor and its facilities in the field of basic and applied research. To do this BNC operates an international user program, giving the frame for research proposals of Hungarian and foreign scientists. The proposals are evaluated and short-listed by an international board. The demand is very high, consequently only excellent and very good proposals can be accepted.

The Neutron Scattering School for Central Europe was organized late May 2012. There were 30 participants, most of them from the Central European region. This was the eleventh such event. Due to the extreme large interest the organizers decided, that form 2013 on the school will be organized annually, not bi-annually as before. The Eastern European Reactor Coalition was formed in 2008, initiated by the Budapest Research Reactor. The cooperation in recent year has been realized in the field of education and training, isotope production, utilization of reactor equipment and in material science.

b) Dialog Between Science and Society

The institute describes 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 2012, as well as usually. The majority of visitors were students, but one has to mention the large group of diplomats from the Embassy of the United States, which expressed special interest for the reactor and for the research performed on it.

III. A PRESENTATION OF NATIONAL AND INTERNATIONAL RELATIONS

The Hungarian Sustainable Nuclear Energy Technology Platform continued its activities in 2012. In this year the nuclear research program for the next few years was further refined, taking into account the needs and necessities of the Hungarian nuclear community, and of international tends too. The main goals of the platform correspond to the research plans of the institute and answer the requirements of the present nuclear industry and serve as basis for the future developments too. A new source to finance the platform's activities was formed according to the new governmental proposal, this allows to be more optimistic about the future of the platform, than it was last year.

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 2012.

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.

IV. BRIEF SUMMARY OF NATIONAL AND INTERNATIONAL RESEARCH PROPOSALS, WINNING IN 2012

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.

From among the EU FP7 the NMI3 II grant was the most important in 2012; this gives reasonable financial support to the experimental research performed on the Budapest Research Reactor.

The national possibilities for research grants have been rather limited in recent years. In 2012 the hope was recovered, that significant proposals may be accepted. The most important proposal is towards the development of a prototype gas cooled fast reactor, the ALLEGRO. This proposal has good chances to win; if accepted enables the research centre to deal with long term problems more intensively.

V. LIST OF IMPORTANT PUBLICATIONS IN 2012

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J. Szabo, J. K. Palfalvi: Calibration of solid state nuclear track detectors at high energy ion beams for cosmic radiation measurements: HAMLET results. Nuclear Inst. and Methods in Physics Research, A, V. 694, pp. 193-198., 2012

Szőke I, Farkas Á, Balásházy I., Hofmann W: 3D-modeling of radon-induced cellular radiobiological effects in bronchial airway bifurcations: direct versus bystander effects. INTERNATIONAL JOURNAL OF RADIATION BIOLOGY 88:(6) pp. 477-492 (2012)

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Frey K, Iablokov V, Sáfrán G, Osán J, Sajó I, Szukiewicz R, Chenakin S, Kruse: N Nanostructured MnOx as highly active catalyst for CO oxidation Journal of Catalysis 287: pp. 30-36. (2012)