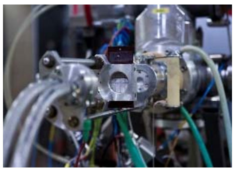    

3rd French-Czech «Barrande» Nuclear Research Workshop

- Advancing Science through Bilateral Collaborations -

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Liblice, Czech Republic

Book of Abstracts

Influence of isomers on s-process nucleosynthesis and the case of ^{180}Ta

P. Alexa, A. Prášek

Majority of stable neutron-rich nuclei heavier than iron are synthetized in stellar nucleosynthesis in the s-process, only a small fraction of them in the r- and p-processes. The importance of long-lived isomeric states for the s-process has been noticed very early [1]. There are about 2500 isomeric states known in the nuclear chart with a lower limit of half-life of 10 ns (about 400 in even-even nuclei, 800 in odd-odd nuclei and the rest in odd-A nuclei) [2]. Among them the longest living and the only naturally occuring isomer known so far is ^{180m}Ta having a spin of 9-, half-life > 10^17 yr and the excitation energy of 77 keV above the 1+ ground state [3]. One can distinguish five types of nuclear isomerism: spin isomers, K-isomers, shape isomers, fission isomers and seniority isomers. On few examples we illustrate how isomeric states can influence the stellar nucleosynthesis depending on their lifetimes and the characteristic time scale of the nucleosynthesis process and its temperature. There exist criteria delimiting a thermalization temperature above which a nucleus may be considered a single species and below which it must be treated as two separate species: a ground-state one and an isomeric one [4]. In more details, we discuss 180mTa production in both s- and p-processes.

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Laboratory Of Fast Neutron Generators at NPI-CAS in Řež

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Accelerator-driven Fast Neutron Generators (FNG) based on the reactions of the accelerated protons with the Li and Be targets present the experimental base for the research activities of the fast neutron research group at the Nuclear Physics Institute of the Czech Academy of Sciences. Our FNG group is mainly focused on the experimental validation of the neutron cross-section libraries for the materials used as neutron monitors (Au, Bi, Co, Nb, Tm, etc.) and construction material (Fe, Cr, W, Ta, etc.) in the future thermonuclear technologies (IFMIF-DONES, ITER). The validation is based on the comparison of the evaluated cross-sections (libraries) with the experimental results, which are obtained by the irradiation of the studied material with well-defined quasi-monoenergetic or continuous spectrum neutron beams and subsequent analysis of the induced activities using gamma-spectrometry. A brief overview of the available experimental methods used on FNGs at NPI will be given.

Isotopic separation for radionuclide production: one health example

Charles-Olivier Bacri

IJCLab-Orsay, CNRS, Université Paris-Saclay, Université Paris-Cité

In the development of new radionuclides for vectorized internal radiotherapy, isotopic purity is one of the challenges to be solved. Indeed, it is necessary to reduce as much as possible any additional radioactivity to that required for the targeted treatment or imaging. Production of radioisotopes is performed by different nuclear reactions, eventually followed by a radioactive decrease. A radiochemical purification step is generally necessary, but not always sufficient when many isotopes of the radioelement of interest have been produced into the irradiated target. Different strategies to overcome this difficulty can be used (online or offline electromagnetic separation, use of a laser ion source, …). Nevertheless, some of the final products are not pure enough to be used for medical purpose. In addition, they increase the production time and consequently are not always efficient for short-live time isotope production. The high performances of the SIDONIE electromagnetic separator at IJCLab gave us the opportunity to develop a "proof of concept experiment" in order to enlarge existing techniques to produce very pure isotopes for medicine. Instead of using natural stable target (often composed by a large number of isotopes) for radioisotope production, the main idea is to use isotopically pure target. It reduces drastically the number of other reaction channels and then, the contaminant production. Therefore, a pure final product could be synthetized with a simplified radiochemical separation. After a presentation of the SIDONIE separator, some results about its performances will be presented and the ongoing TTRIP project * (Tools for Tb RadioIsotope Production for nuclear medicine) will be briefly described.

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Experimental studies for the *p* process nucleosynthesis: alpha optical potential and alpha-induced reactions

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Abstract: The 35 neutron-deficient stable isotopes from ^{74}Se to ^{196}Hg, known as *p* nuclei, cannot be explained by the nucleosynthetic neutron-capture processes, such as the *s* and the *r* process. For their explanation, a process which consists of series of photodisintegration reactions (γ,n), (γ,p), (γ,α) together with β+ decays and electron-captures, which commence on nuclei already created by the *s* process, has been proposed. This process is called the *p* process (the term γ process is also used interchangeably) [1]. The astrophysical sites that the *p* process is considered to be taking place is under constant investigation, with Supernova type II [2] and type Ia [3] proposed to be the most probable sites. The modeling of the *p* process consists of a large reaction network consisting of around 20,000 reactions and is solved by using Hauser-Feshbach calculations [4]. Reaction cross sections inside the astrophysical Gamow window is essential information for the accurate determination of the relevant reaction rates. Inside the astrophysically relevant energy range, one of the key ingredients to determine these cross sections is the Optical Model Potential (OMP). The relatively large discrepancies between different α-OMPs [5] makes the need of elastic-scattering measurements imperative, especially near the regions of the *p* nuclei. Upcoming experimental campaigns for α- scattering measurements using the Split-Pole magnetic spectrometer at the ALTO facility [6] will be discussed in this presentation. Future measurements of alpha radiative captures will also be envisaged.

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Innovative Medical Radioisotopes production: a focus on Pa project

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The PRISMA (Physics of Radiation Interaction with Matter and Applications), team of Subatech (UMR CNRS/IN2P2, IMT Atlantique and Nantes Université), conducts both fundamental and applied research on the interaction of radiation and particles with matter. One of its fields of expertise concerns the production of innovative radionuclides for diagnosis and therapy (RaMI for Innovative Medical Radioisotopes). For this purpose, it combines its skills in nuclear physics and radiochemistry in the acquisition of fundamental data in order to respond to the health challenges of the future.

Uranium-230 (U-230) is considered as a promising alpha emitter. The decay of a U-230 nucleus results in a chain of rapid decays accompanied by the emission of 5 alpha particles with a total energy of about 33.5 MeV. The half-life period of U-230 (20.8 d) is suitable for the production and transport of the radionuclide and subsequent radiopharmaceutical. In addition, the use of U-230 as the parent radionuclide for a short-lived period (31 min) Th-226 generator is of great interest. However, one of the major issues in the development of this technique is their availability.

The protactinium project takes its meaning. Indeed, U-230 can be produced by the decay of protactinium-230 (Pa-230), itself generated under irradiation of natural thorium by protons. In this context, the objectives is our Pa project are to optimize the production of Pa-230 with the C70XP cyclotron of GIP ARRONAX. Based on the acquired fundamental data, a production procedure for the recovery of Pa-230 and U-230 could be set up. These data will be used to meet the isotopic and chemical purity requirements for the production of U-230 for medical applications.

Nuclear Astrophysics at GANIL

Francois de Oliveira Santos

GANIL, Caen, France

I will start with a general and succinct presentation of the field of nuclear astrophysics and the issues involved. I will then present, in more detail, the results of a recent experiment carried out at GANIL, not yet published, on the production of ^{22}Na in stellar explosions called Novae. I will then give a very quick overview of some experiments carried out at GANIL in recent years.

Review of CEA R&D on instrumentation for irradiation experiments in the JHR Material Testing Reactor

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Constant improvements of numeric modelling tools and physic theoretical models in nuclear reactor applications imply as counterpart the development of new high-resolution measurements to validate them. A typical 5% measurement uncertainty value (1 sigma) is now the minimum level required. On line measurements are also now needed to compare to results provided by new kinetic modelling calculation codes. As analysis of interface effects is getting importance, the associated geometry meshes description become also more and more detailed; In response, precise spatial distribution measurements of the parameters of interest are developed in reactor experiments to compare to. At last, study of the accidental situations implies to extend the range of the existing instrumentation toward extreme conditions (high temperatures, high flux pulse). In addition, in-pile experimental sensors and measurement systems developed for this goal have to satisfy several severe criteria due to the harsh environment encountered, such as high gamma and neutron radiation flux levels (up to $1E14 n/cm^2 s$) and doses (up to $1E21 n/cm^2$, several GGy), high level and gradient of temperature (up to 1600°C). Strong operational criteria, such as miniaturization, high reliability (as no repairing is possible on irradiated sensors), long distance between sensors and electronics, etc.

After a reminder of the conditions encountered in the future JHR (MTR) Material Irradiation Reactor under construction at the CEA Cadarache center and in the associated irradiation devices, a review of developed measurement techniques is presented for in core neutron and gamma flux, temperature, pressure and dimensions: Self-powered Neutron Detectors, Sub-Miniature Ionization/Fission chambers, Calorimeters, Optical fiber based sensors (Bragg gratings, pyrometry techniques, Fabry-Perot extensometers…), solid state dosimeters, magnetic based sensors for dimensional measurements, etc . The key role of the sensor qualification under irradiation, of the modeling codes and of nuclear and physical data are eventually discussed.

Interaction of ionizing radiation with DNA nanostructures

Jaroslav Kočišek

J. Heyrovský Institute of Physical Chemistry, Prague, Czech Republic

The talk will provide a short overview of our recent experiments concerning radiation damage to DNA and its components. We will focus on fundamental mechanisms of the radiation damage such as interaction with low-energy electrons, studied in gas phase experiments with microhydrated molecules. Then surface and bulk experiments with high energy radiation will be described using DNA origami for nanodosimetry and as a substrate for in singulo experiments with short DNA segments.

First results of the Neutron For Science Facility

X. Ledoux on behalf of the NFS collaboration[1]

[1]*GANIL, Caen, France*

The neutrons for science (NFS) is the running facility of SPIRAL-2 located at GANIL (France). It provides intense neutron beams in the 1-40 MeV range, produced by the interaction of proton or deuteron beams, delivered by the LINEAR accelerator of SPIRAL-2, with lithium or beryllium converters. The intense neutrons flux available and the large time-of-flight area make NFS a perfect facility for fast neutron induced reaction studies. Large number of physics cases will be studied at NFS, from fundamental research to industrial applications. NFS received its first beam in December 2019 and the commissioning started in the fall of 2020 with proton beams. The first experiments are being carried out between October and December 2021. After a description of the facility, physics cases studied at NFS and some of the already performed experiments will be presented.

Activities of IEAP CTU in Prague within SuperNEMO collaboration.

Miroslav Macko

Institute of Experimental and Applied Physics, Czech Technical University in Prague

The neutrino physics was gradually gaining its importance during the last decades. In last years it became one of the fastest growing fields of particle physics. Nevertheless, the most fundamental property of the neutrino – its mass – still remains unknown. One of the possibilities to measure the mass of the neutrinos is to study a process called Double Beta Decay.

The talk will be dedicated to the search for neutrino-less Double Beta Decay with SuperNEMO experiment. The SuperNEMO detector is unique in the field because it is using so-called tracko-calo method capable of reconstruction of event topology and particle identification. Its first phase – the demonstrator – is in the late phase of commissioning. Young team from IEAP CTU in Prague played and still plays an important role in the detector construction, simulations and data analysis.

High energy PIXE & analysis of cultural heritage objects

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An ion beam analysis platform using protons and alpha particles up to 70 MeV, including PIXE (Particle Induced X-ray Emission) and PIGE (Particle Induced Gamma-ray Emission) techniques, is being developed at the Arronax cyclotron in Nantes (France). The use of high energy beams allows a non- destructive multi-elemental analysis in the air of thick samples, beyond the surface. These methods are well suited for the quantification of heavy trace elements in light matrices [1] and for the analysis of multilayered materials [2]. The fields of application are varied: archaeometry, geology, mineralogy, environmental measurements, pollutants, art objects, etc.

The knowledge of the interaction cross-section with the atoms is essential to perform quantitative PIXE analysis. As data in the range of tens of MeV are scarce, K-X-ray production cross-sections for some selected elements first have been measured and compared to the RECPSSR model. [3].

Various studies of cultural heritage objects have then been conducted. The first one concerns the search for traces of indium in silver coins from the 16th century, to enrich historical knowledge about the origin of the metal of the coins, their periods and techniques of manufacture and the main trade routes of the time. Studies of other heritage objects (seal matrices, crucifix,...) will also be presented [4,5].

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[4] Q. Mouchard et al., *8e Rencontre "Ion Beam Applications Francophone" - IBAF 2021*, Jul 2021, ⟨hal-03283860⟩

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Nuclear physics opportunities at the ILL high flux reactor

Caterina Michelagnoli

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Among the different approaches to study the structure of nuclei, thermal neutron induced reactions can be used to probe different phenomena. Capture reactions on (rare) stable or radioactive targets populate low-spin states below the neutron separation energy. With thermal neutron induced fission on actinides, neutron-rich nuclei are populated at moderately high spin. Those reactions are used at the Institut Laue-Langevin (ILL, Grenoble), at a new high-resolution gamma-ray spectroscopy setup. FIPPS (*Fission Product Prompt gamma-ray Spectrometer*) has been used to study the structure of nuclei in different region of the nuclear chart, addressing phenomena as shape isomerism in light nuclei and shape coexistence in neutron rich Kr and Br isotopes.
After a general introduction about the nuclear physics activities at the Institut Laue-Langevin, recent results obtained in different experiments at FIPPS will be reported. Particular focus will be dedicated to the first fission campaigns, showing the innovative technique of *fission tagging* and first results.

Indirect methods in nuclear astrophysics

Jaromír Mrázek

Nuclear Physics Institute of the Czech Academy of Sciences

Indirect methods in nuclear astrophysics like ANC and THM may provide an access to cross sections at low energies, where the direct measuremets are extremely difficult or impossible. Examples of application of the method of Asymptotic Normalization Coefficients (ANC) for the determination of the cross-sections and astrophysical S-factors will be presented.

Ion and electron beam induced molecular dissociation

Pamir Nag, Miloš Ranković, Leo Sala, Jaroslav Kočišek and Juraj Fedor

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In this conference I will briefly speak about our joint experiments performed in GANIL, France and in Synchrotron SOLEIL France. Also, I will be discussing about a new experimental setup developed in Prague and the possibility to extent new collaborations.

Focused Electron Beam Induced Deposition (FEBID) and Focused Ion Beam Induced Deposition (FIBID) are important processes for nano fabrication. At the ARIBE low-energy ion facility in GANIL we studied the fragmentation of iron pentacorbonyl ($Fe(CO)_5$), a precursor molecule for nanofabrication, upon interaction with different projectiles ions. Out of the different projectile ions Ne^+ ions induced the highest fragmentation resulting mainly in pure Fe^+ ions fragment, which may be advantageous for FIBID [1].

On the other hand, to understand the effect of radiation induced damage to biologically important molecules or living cells, it is important to perform the experiments in an environment similar to human body – i.e., in bulk water. We performed x-ray photoelectron spectroscopic study with aqueous solvated nimorazole molecule, an important radiosensitizer [2] clinically used for treatment of head and neck cancer, at synchrotron SOLEIL, France.

As a part of collaboration between the Prague research group and PLÉIADES beamline at Synchrotron SOLEIL, France, we are also currently developing a new experimental facility to study electron energy loss spectroscopy (EELS) from liquid phase and solvated molecules and recently we obtained the first ever EELS spectra of liquid phase molecules.

Similar high-vacuum compatible recirculating liquid microjet setup was recently commissioned also in our Prague laboratory. The setup is equipped with an electron gun (energy range between 200-800 eV) and its compact dimensions allow us to transport it for missions at large facilities.

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Introduction to Neutrino Physics

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The most recent results on neutrino physics (neutrino oscillations parameters, mass measurements,...) and main future projects will be presented with a focus on neutrinoless double beta decay search to determine the nature of the neutrino.

Ex-core neutron measurements with a SiC-based p+n junction diode in a TRIGA Mark II-type research reactor

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In order to meet the growing needs in the field of nuclear instrumentation and the increasingly extreme conditions of future major nuclear fusion or fission facilities, new sensors based on new technologies have renewed interest. Moreover, with the low carbon strategy, new reactors such as Small Modular Reactors (SMR) are emerging and also need new instrumentation. These different installations share common characteristics that induce the requirements of these new sensors such as restricted spaces, high power densities, high absorbed dose rates also called nuclear heating rate, high neutron and photon fluxes. Thus, from now on, these sensors must target the following properties: a small size, a fast response, a high sensitivity, a stability versus radiations, a strong neutron and photon discrimination, and a high energy resolution. That is why wide-bandgap semiconductors such as Diamond, Gallium Nitride (GaN) and especially Silicon Carbide (SiC) stimulate a strong interest. The latter are especially widespread and well-known for their high-power, high-frequency, high-temperature and harsh environment applications due to their intrinsic properties (high breakdown-field, energy threshold of defect formation and thermal conductivity).

In the field of nuclear instrumentation, previous works were achieved for these detectors all around the world and especially within the framework of the LIMMEX joint laboratory between Aix-Marseille University and the CEA. For nearly a decade, p^+n junction diodes based on Silicon Carbide (4H-SiC) are developed for the detection of thermal and fast neutrons in research reactors and other nuclear facilities such as Deuterium-Tritium fast neutron generators. Neutron measurements were achieved in the Zero-Power Reactor MINERVE at CEA Cadarache center (France) with a total and maximum neutron flux of around 9.4×10^{8} n·cm^{-2}·s^{-1}. Thermal neutron fluence performance of the detectors was studied in BR1 nuclear research reactor at SCK-CEN (Mol, Belgium) with a maximum cumulated fluence of around 2×10^{13} n·cm^{-2}.

However, in order to further develop these detectors, a new objective is being targeted: the optimization of SiC-based diodes from the detector to the acquisition chain to perform online measurements under higher neutron fluxes from 10^{7} to 10^{10} n·cm^{-2}·s^{-1}. The presentation will show the results obtained during an ex-core irradiation campaign at the Jožef Stefan Institute TRIGA Mark II-type research reactor. Thermal neutron measurements were realized in the Tangential Channel by means of a SiC-based diode and a sCVD Diamond detector with both a Neutron Converter Layer (Boron-10 and Lithium-6 respectively).

The different results obtained for the SiC-based diode and thanks to a parametrical study of the sensor response and a pulse shape analysis will be shown. The influence of various parameters such as the applied bias-voltage, the reactor power/neutron flux and the fluence will be detailed. An in-depth analysis of detector pulse-shape will be discussed in terms of amplitude, rise and decay times at 90%, and full-width at half-maximum. A comparison of the response of the SiC-based diode and the one of the sCVD Diamond detector will be done for some selected parameters.

Materials for radon adsorption

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Investigation of rare processes in particle and astroparticle physics, e. g. neutrinoless double beta decay or direct dark matter detection, requires ultra-low radioactive background. One of the ultimate sources of the radioactive background is radon. To reduce its contribution, a common solution consists of the use of radon suppression facility, which is based on radon adsorption by activated charcoal at low temperature [1, 2].

Activated charcoal is relatively cheap, commercially available and well investigated material for radon adsorption [3, 4]. However, the discovery and use of materials with higher radon adsorption capacity can improve the existing radon suppression systems. Among the materials gaining attention in this context are zeolites, class of porous materials composed of aluminosilicate networks. The silver-containing zeolites stand out among other materials of this class. They have been reported to show high adsorption capacity for noble gases in general [5, 6] and radon in particular [7, 8].

Here, we present the first systematic study of radon adsorption properties of silver-containing zeolites. The results obtained for the zeolites Ag-ZSM-5 and of Ag-13X are comparable to the cheaper activated charcoals. However, Ag-ETS-10 shows a record high radon adsorption at room temperature (Figure 1).

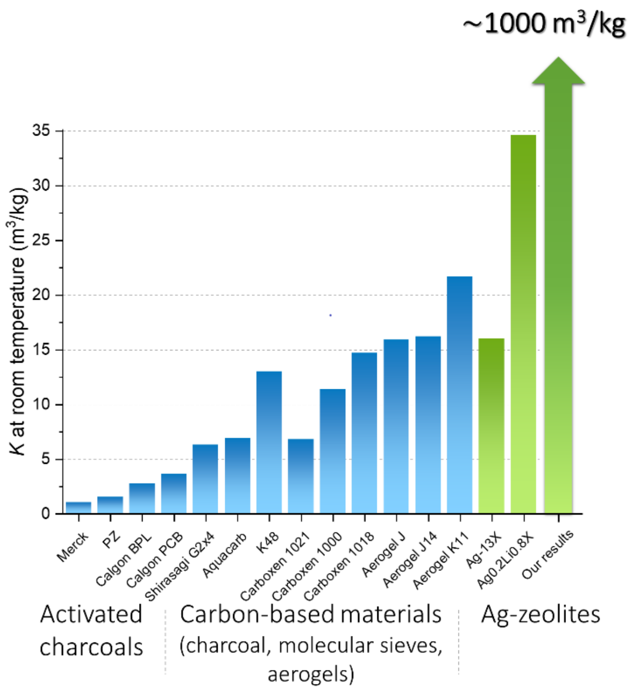

Figure 1. K values (K is a factor showing efficiency of radon adsorption) for various carbon-based materials (in blue) and silver-containing zeolites (in green) at room temperature.

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Review of the joint research work between AMU and CEA on the nuclear heating rate measurement in research reactors

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The future Jules Horowitz Reactor under construction (JHR, CEA Cadarache, France) will respond to the needs of industry and research in the field of nuclear energy. This facility will have characteristics unequalled in Europe, such as a nominal thermal power of 100 MW, intense mixed fields of neutrons and photons, significant damage by accelerated aging under irradiation, a nuclear absorbed dose rate (also called nuclear heating rate) of 20 $W.g^{-1}$, etc.

Thus, the challenges associated with the studies conducted in the JHR require the control of experimental conditions inside the experimental channels present in the reactor core thanks to online measurements of key quantities. Consequently, since 2009, Aix-Marseille University (IM2NP, MCI team) and the CEA conduct collaborative research work within a common laboratory called LIMMEX (Laboratory for Instrumentation and Measurement in Extreme Environments). Among these studies, the INCORE (Instrumentation for Nuclear radiations and Calorimetry online in REactor) research program aims, in particular, to design and study sensors and multi-sensor systems embedded in the reactor core.

The work presented will focus on the online measurement of intense absorbed dose rate, also called nuclear heating rate, by calorimetry and more specifically on a review of the optimization, improvement and miniaturization of calorimeters thanks to a comprehensive approach leading to breakthrough technologies in order to obtain better metrological performances. Finally, the importance of an accurate knowledge of thermal properties for the experimental and numerical characterizations of the response of these calorimeters under laboratory conditions and under real conditions (inside the reactor core) will be shown through the preparation of an irradiation campaign inside the MIT reactor within the framework of the CALOR-I project.

Experimental environment for reactors using graphite

Eva Vilímová

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There is a growing demand for new SMRs with a wide range of applications, often classified as a new generation IV. reactors. Unfortunately, no nuclear reactors in operation meet the characteristics of Gen. IV reactors in terms of technical design and features. To support research activities related to the development of new reactor concepts using graphite, a suitable experimental environment at the LR-0 reactor and resources simulating conditions expected in these reactors with graphite are needed. The solution proposes several experimentally and computationally verified variants of LR-0 reactor core arrangements, consisting of graphite prisms placed in the reactor core in various shape modifications.

The future of nuclear energy

Vladimír Wagner

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Nuclear energy is now recognized as one of the key resources in satisfying global demands for power production while mitigating climate change. It is one of the most important low-emission energy sources. The most advanced nuclear reactor designs are efficient, safe to operate and have the potential to generate very little waste. The present nuclear energy industry must solve four basic challenges. The first challenge is transition to Generation III reactors. The second challenge is the introduction of small modular reactors (SMR) and the expansion of nuclear power into decentralized energy. The third challenge the fuel cycle closing and the efficient use of uranium and thorium reserves as well as reducing the volume of nuclear waste. Last but not least, the expansion of heat production for heating and industry must be ensured. In the more distant future, it is also possible to expect the use of accelerator driven transmutation systems or even thermonuclear fusion. Successful exploitation of nuclear energy requires a continuous and expanding commitment to investment in nuclear research, technology and education.

Time resolved laser induced fluorescence spectroscopy study of $OU_2^{2+}/CO_3^{2-}/H_2O$ system

Alena Zavadilová

Czech Technical University in Prague, Faculty of (FNSPE CTU)

Time resolved laser induced fluorescence spectroscopy was used to study the uranium speciation in the pH range 4-12 in the ternary UO_2^{2+}/ CO_3^{2-}/ H_2O system. The measured spectral characteristics were mathematically processed, analysed and compared with the results obtained from speciation calculations. Based on the spectra shapes and lifetimes depending on the pH, the present species were identified.

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