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会议摘要集

COLLECTION OF ABSTRACTS

Organization:

弗兰克中子物理实验室
FRANK LABORATORY OF NEUTRON PHYSICS, JINR, RUSSIA

强脉冲辐射环境模拟与效应国家重点实验室
THE STATE KEY LABORATORY OF INTENSE PULSED RADIATION SIMULATION AND EFFECT, NINT, CHINA

Sponsor:

陕西省先进核能技术重点实验室
SHAANXI KEY LABORATORY OF ADVANCED NUCLEAR ENERGY AND TECHNOLOG, XJTU, CHINA

Frank Laboratory of Neutron Physics

Frank Laboratory of Neutron Physics is one of the seven laboratories of the international intergovernmental organization Joint Institute for Nuclear Research (Dubna, Russia) that investigates the neutron as an elementary particle using various instruments, and employs the neutron as an instrument to investigate the structure and dynamics of condensed matter, including crystals and nanosystems, functional materials, complex liquids and polymers, rocks, etc. so that our findings could find application in molecular biology and pharmacology, engineering diagnostics and in other fields of science and technology.

The basic FLNP scientific facilities are:

- The IBR-2 fast pulsedreactor which with its unique technical approach produces one of the most intense peak neutron flux densities at the moderator surface among the world's reactors: ~10^{16} n/cm^2/s, with a power of 1850 MW in pulse.
- Source of resonance neutrons IREN dedicated to applied investigations and neutron nuclear physics
- Van-de-Graaff Electrostatic accelerator EG-5 dedicated to analytical studies using Rutherford backscattering techniques, methods and techniques of nuclear reactions recoil, study of nuclear reactions with neutrons excited by beams of protons and deuterons and applied research based on the methodology of tagged neutrons
- Multimodal optical platform – "CARS" microscope which allows to perform Raman spectroscopy and microscopy study of different materials (solids, liquids, powders, various biological samples) using spontaneous and coherent anti-Stokes Raman scattering options, surface enhanced Raman scattering (SERS) and photo-/up-conversion luminescence investigations.

The IBR-2 reactor hall

I. Frank

F. Shapiro

FLNP has cooperation agreements in the field of neutron investigations with almost 200 scientific institutes and universities from more than 40 countries from all over the world. A significant contribution to this cooperation is made by the JINR Member States.

The FLNP staff consists of more than 500 employees in this about 170 less than 35 years of age. The scientific staff includes 94 Ph.D. and 19 D.Sci. researchers and 112 researchers and specialists from 19 of the JINR Member States (besides the Russian Federation).

The annual scientific output is about 200 papers majority of them published in international ISI journals.

State Key Laboratory of Intense Pulsed Radiation Simulation and Effect

The State Key Laboratory of Intense Pulsed Radiation Simulation and Effect (SKLIPRSE) was established in October 2012. It was authorized by Ministry of Science and Technology of the People's Republic of China, and operated by Northwest Institute of Nuclear Technology (NINT). It provides a fundamental support for development of intense pulsed radiation simulation and effect research in China.

The research fields include:

- Generation of intense pulsed radiation fields, including high power electrical pulse, intense pulsed beam and high power pulsed electromagnetic field, etc.
- Radiation effects, including mechanism, simulation, and experimental techniques of radiation effects, radiation hardening and its evaluation.
- Radiation measurement and pulsed radiation field diagnosis.

Flash II Accelerator

Qiangguang I Accelerator

Chenguang Accelerator

Xi'an Pulsed Reactor

A series of accelerators and facilities have been developed in SKLIPRSE, including ChenGuang accelerator-the first high power accelerator in China, Flash Ⅱ accelerator-the strongest electron beams accelerator in China, the Qiangguang I accelerator-the first multifunction simulator with 11 kinds of radiation states. Some space radiation simulators, such as Co-60 and Cf-252 radioactive sources, have also been developed. Study has been carried out on various radiation effects, including space radiation effects, nuclear radiation effects, electromagnetic pulse effects, and so on. A series of radiation effects testing systems have also been developed.

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Nuclear data for applied and scientific purposes

Nuclear Data and neutronics study for Long-lived Radionuclides (A ~ 50-60) in Fusion Reactor Technology

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High quality nuclear data for upcoming fusion reactor is one of the fundamental pre-requisites in order to model the reactor designing and to predict the activation heating, shielding and material damage induced by nuclear reactions. Nowadays there is a greater demand for the Cross-sections and Activation data for long-lived radioisotopes in the mass region A~50-60 and their impact in Fusion Reactor Technology. Long-lived radionuclides in the mass region 50-60 may be of great concern from the view point of the radioactive nuclear waste, enhancement of extra helium and hydrogen generation during reactor operation, which may affect the neutronics of the fusion reactor up to certain extent. Present study highlights the need, impact and first time experimental measurement of cross-section performed specially for the long-lived radionuclides in the medium mass region. Landmark steps which have been taken in this direction includes : (i) the measurement of neutron induced cross-section of radionuclide ^{59}Ni(n,xp) by surrogate ratio method (ii) estimation of the amount of radionuclides formed in fusion reactor environment through different pathways using activation calculations (iii) impact of radionuclides on reactor material i.e. primary knock on atom spectra, number of He and H atoms produced at critical components of the fusion reactor (iv) Neutron transport calculation for a fusion system (v) Activation calculations for structural material of reactor. The surrogate reaction ratio technique has been used for the charged particle emission reaction. Because of the discrepancy in the available nuclear data libraries more experimental measurements are required. The surrogate ratio method can be benchmarked with the reactions that have direct measurement. The accuracy of the deduced cross-section is now well known for certain ranges of incident neutron energy. TALYS-1.8 code has been used to calculate (n,H) (n,He) reaction cross section on ^{55}Fe, ^{59}Ni from 1 keV to 20 MeV. On the basis of the excitation functions, there is an anomalous behavior and therefore it is recommended to include the lower energy neutron induced cross-section calculation with nuclear reaction modular codes TALYS and EMPIRE. It is concluded that the present study contributes substantially to improving the knowledge of the neutron cross-sections, activation and damage data mainly for the long-lived radionuclides which are important to fusion reactor design.

Capture neutron cross sections measurements of rare earth isotopes

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Abstract

Results of TOF measurements for total and capture neutron cross sections on isotope Ho^{165}, conducted on pulsed spallation neutron source RADEX, are presented. Pulse duration of accelerator's proton beam 250 nanoseconds, combined with 100 nanoseconds steps of data acquisition system and 80 nanosecond pulses of (n,γ) detector provided, at 50 meter base of vacuum neutron guide , value of TOF spectrometer resolution 6 nanoseconds per meter.

Measurements were done during linear proton accelerator's work for our task in years 2020 and 2021. Beam parameters were: proton energy 247 and 305 MeV, pulsed proton current 0.01 Amperes, pulse duration 250 nanoseconds, frequency 50 Hz. Average beam power 40 W provided average neutron intensity on Ho^{165} pattern 4000 n/cm^2sec. Recycle neutrons were cut using cadmium filter.

Experimental results were compared with 4 world neutron databases: ENDF /B-VII.1, JEFF-3.1, JENDL-4.0, and ROSFOND. New experimental data on cross section resonance structure of Ho^{165} were achieved and are presented.

The new data on the cross-section of $^{16}O(n,\alpha)^{13}C$ reaction

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The reaction $^{16}O(n,\alpha)^{13}C$ plays a very important role in predicting the criticality of the nuclear power plants and assessing the accumulation of helium in structural materials under the fast neutrons irradiation. The cross section for the inverse reaction $^{13}C(\alpha,n)^{16}O$ plays a role as the background factor in measurements of geo-neutrinos and as a source of neutrons for the s-process in nuclear nucleosynthesis. The existing sets of the experimental data obtained both from the study of the direct reaction and from the measurements of the reverse reaction, differ significantly from each other in the entire range of neutron energies. The result of the work of the CIELO collaboration was the emergence of a new evaluation, which became the basis for the evaluation of the cross section of this reaction in the ENDF/B-VIII.0 library. However, there is no experimental data to support this evaluation.

The aim of the work carried out in IPPE was the experimental study the excitation function of the $^{16}O(n,\alpha_0)^{13}C$ reaction in a wide range of neutron energies with good energy resolution. For this, a method was chosen based on measuring the cross section of the reverse reaction $^{13}C(\alpha,n_0)^{16}O$ and then reconstructing the cross section of the forward reaction using the reciprocity theorem. The measurements were carried out using the digital time-of-flight neutron spectrometer based on the para-terphenyl single crystal. This approach made it possible to suppress the contribution of neutrons from the excited states of the residual nucleus, and, accordingly, to significantly expand the energy range of measurements. The thickness and characteristics of the ^{13}C target, as well as the state of the target during the measurements, were determined using nuclear microanalysis methods. The analysis of the influence of multiply-scattered neutrons on the measurement results is carried out. The obtained results showed that the cross section for the reaction $^{16}O(n,\alpha_0)^{13}C$ corresponds to the new evaluation of this reaction given in ENDF/B-VIII.0.

Neutron detection & Methodical aspects

Measurement of neutron induced reaction cross sections with covariance analysis

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Abstract

The cross section of $^{65}Cu(n,\alpha)^{62m}Cu$, $^{41}K(n,\alpha)^{38}Cl$ and $^{65}Cu(n,2n)^{64}Cu$ reactions have been measured at 14.92 ± 0.02 MeV neutron energy with $^{27}Al(n,\alpha)^{24}Al$ as a monitor reaction using the neutron activation technique followed by off-line γ-ray spectrometry. The neutron irradiation was carried out using the neutrons produced via D-T fusion reaction based neutron generator and the γ-ray spectra of the residue product measured off-line with the pre-calibrated lead-shielded HPGe detector. The measured cross sections have been reported with their detailed fractional uncertainties and inter-correlation matrix. The cross sections measured in the present work are compared with the earlier reported cross sections available in the EXFOR database. Theoretical calculations have also been performed from the reaction threshold to 20 MeV using EMPIRE-3.2 and TALYS-1.9 codes and its results are compared with present obtained results along with the evaluated data from TENDL-2019, JENDL-4.0, JEFF-3.1/A and ENDF/B-VIII.0. The detailed measurement technique and primarily results of data analysis will be presented during the conference.

A dE/dx-E charged particle spectrometer based on hybrid pixel detector -Timepix

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Hybrid pixel detectors- Timepix are very promising detectors considering their advantages getting simultaneously information about the position, energy, and time of arrival of a particle hitting the detector. These types of multi-parameter detectors can be effectively used to study and/or reinvestigate some fission processes such as the rare fission modes (ternary, quaternary, quinary), which are planned. In studying nuclear reactions, it is necessary to consider the following features: the energy resolution of the detecting system, angular distribution information, coincident timing, discrimination of different particles, background problem etc. Silicon solid-state detectors are commonly used for measuring the specific ionization (dE/dx), in instruments designed for identifying energetic nuclei using the dE/dx versus total energy technique. Using Timepix detector as E detector in this method gives the possibility to get simultaneous measurement of energy, coordinate, interaction time and the type of charged particles. This work is devoted to application of multi-parameter detectors- Timepix in dE/dx-E particle identification measurements. In constructing tailor-made dE/dx-E spectrometers, our requirement is the measurement of angular distributions, energy spectra, coincident time, yield of rare fission mode products. In order to test the spectrometers, a spontaneous fission source ^{252}Cf was used as a light particle source, since LCPs (mainly alpha particles) are formed along with the heavy fragments in ternary fission. The tailor-made dE/dx-E spectrometers consist of transmission type ΔE detectors and the Timepix detector. The particles (^{1}H, ^{3}H, ^{4}He, ^{7}Li, and ^{8}Be) have been identified by the method dE/dx-E, since the dE/dx-E value is unique to the type of particle. The specific energy loss (dE/dx) is measured using the transmission type ΔE detector (16 or 150 um thicknesses) ordered from the company Micron Semiconductors, while the residual energy (E) is measured by a Timepix detector with thicknesses of 300 and 600 um. Timepix is assembled with the special FITPix COMBO device which is used to read out a signal from a common and pixel part of Timepix (both in parallel). A special developed Spectrig device (a modified version of FITPix COMBO), however, is used for the acquisition of signal from ΔE detectors. The Timepix detector is powered and controlled by the integrated readout interface FITPix which is plugged directly to any PC via USB port. The interface and the detector are controlled via Pixelman software. The Spectrig device, however, is controlled by IEAP spectrometry (software). Moreover, a synchronization bus has been developed to realize coincidence triggering and acquisition.

Uncertainty quantification of optical model parameters using Unscented Transform Kalman filter technique

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Abstract:

Uncertainty quantification of the optical model parameters is important for the nuclear data evaluation because it allows us to calculate the uncertainties associated with the optical model predictions. These uncertainty estimates also provide us further insight about the uncertainties associated with the model itself. Model parameters are generally determined by comparing the model predictions and the experimental data. There have been few attempts for determining the correlations of the optical model parameters in past few decades, but these methods require to calculate the Jacobian of the model equations with respect to the model parameters, which is a difficult task and also approximates the uncertainties only up to the first order of the Taylor series expansion. In the present study we have used the Unscented Transform Kalman filter for the estimation of optical model parameters and their correlations. This method does not require to calculate the Jacobian matrix and also approximates the uncertainties at least up to the second order of the Taylor series expansion. We have estimated the optical model parameters and their correlations for the spherical nuclei of A~50 by comparing the experimental differential cross sections of the elastically scattered neutrons with the DWBA calculations. We have used the Talys nuclear reaction code to perform the DWBA calculations. Unscented Transform Kalman filter technique works well and provide good estimates of the parameters and also shows that some parameters are heavily correlated. This method also has the potential to be used for various nuclear reaction models other than the optical model and also it can be used for the charged particle reactions. Methodology and the results of this study will be presented in detail during the conference.

Fast Neutron Response of 4HCB Organic Semiconductor Detector

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Abstracts: The development of organic semiconductor detectors provides a new way of fast neutron detection based on recoil proton method, so it is important to analyze the fast neutron response characteristics of organic semiconductor detectors. With the Monte Carlo simulation tools, the pulse height spectra of recoil protons and other types of reactions in 4HCB organic semiconductor detectors under different energy fast neutron incidence conditions are studied, and the pulse height spectra are analyzed. It lays a foundation for the fast neutron measurement of organic semiconductor detector.
Key words: fast neutron response; organic semiconductor detector

Measurement of the neutron flux with small collimator of Back-n #ES1 at CSNS

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Back-streaming neutron beam line, named Back-n, is a newly constructed facility at China Spallation Neutron Source (CSNS). Back-n is a white neutron source providing neutrons from 0.5eV to ~200 MeV for nuclear data measurement, neutron radiography, neutron irradiation and detector calibration based on the time-of-flight (TOF) method. The knowledge of the neutron flux is of crucial importance for feasibility study and data analysis of all the experiments and measurements to be conducted at Back-n. This work will report the first measurement of the neutron flux with small collimator at Back-n end station 1 (#ES1). The neutron flux is characterized by three different detection systems in different energy regions: a fission ionization chamber (FIXM) for full energy region (0.5 eV–200MeV), a silicon array (^{6}Li-Si monitor) for low energy region (below 10 keV) and recoiling proton telescopes for high energy region (above 10 MeV). The measurement and the analysis of above three detection systems will be reported. The preliminary results of the neutron flux from 0.5 eV to ~200 MeV will be presented.

Characteristics of position-sensitive plastic scintillation detectors

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At the Joint Institute for Nuclear Research (JINR, Dubna, Russia), within the framework of the TANGRA project (TAgged Neutrons and Gamma RAys) [1], experiments aimed at investigation of inelastic scattering of fast neutrons are continuing [2]. Various types of detectors are used to study reactions with neutrons, including plastic scintillators. Obtaining reliable experimental results always relates to choice, careful preparation and adjustment of equipment.

The present work is devoted to the calibration of plastic scintillation detectors and the comparison of their parameters. Long plastic detectors with PMTs at either end were chosen for the study. The choice stems from the goal to obtain a position resolution using the timing information from both PMTs.

The measurements were carried out for two types of detectors with the same dimensions (5×10×100cm), but different manufacturers: (1) by «EPIC CRYSTAL», Shanghai, China[3], equipped with the PMTs, model CR105 from HAMAMATSU [4] and (2) by «ELJEN TECHNOLOGY», USA [5], equipped with the PMTs, model ETEL 9266KEB from ELECTRON TUBES [6].

The purpose of this study was to determine the main characteristics of the detector: gamma and neutron efficiency, energy, time and position resolution, selection of the optimal voltage on the PMTs. The tests were carried out with point-size standard ^{137}Cs and ^{60}Co gamma-ray sources, a portable neutron generator ING-27 and a PuBe / AmBe neutron source. For the acquisition and preliminary analysis of data, the digitizer - DSR-2/32 was used.

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CHARACTERISTICS OF NEUTRON AND GAMMA-RAY DETECTORS

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Abstract

At the Joint Institute for Nuclear Research (JINR, Dubna, Russia), within the framework of the TANGRA project (TAgged Neutron and Gamma RAys) [1], we continued experiments to study inelastic fast neutron scattering from some isotopes important for nuclear science and technology [2]. We have used several different types gamma detectors such as: NaI (Tl), BGO, Stilbene, HPGe, Plastic scintillators, and $LaBr_3$(Ce) [3–5]. The design of the experimental setup, including a ring of gamma detectors and a neutron generator, allowed us to measure the angular distribution of gamma quanta with good accuracy. The HPGe gamma spectrometer and the ING-27 neutron generator were used to determine the cross section for inelastic neutron scattering reactions. Information about the cross section, energy of gamma rays and their angular distribution allows testing various theoretical models describing neutron-nuclear reactions, as well as increasing the accuracy of elemental analysis with fast neutrons.

This article presents some characteristics of experimental facilities, such as: the efficiency of registration of gamma quanta and neutrons, energy and time resolution obtained at various source-detector geometries, using standard point sources of gamma radiation (^{137}Cs, ^{60}Co, ^{22}Na, ^{152}Eu, ^{228}Th) and 14.1 MeV neutrons generated by ING-27.

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Experimental setup for elemental analysis using prompt gamma rays at research reactor IBR-2

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Abstract

The new experimental setup has been built at the 11b channel of the IBR-2 research reactor at FLNP, JINR, to study the elemental composition of samples by registration of prompt gamma emission during thermal neutron capture. The setup consists of a curved mirror neutron guide and a radiation-resistant HPGe high-purity germanium detector. The detector is surrounded by lead shielding to suppress background gamma level. The sample is placed in a vacuum channel and surrounded by a LiF shield to suppress the background generated by scattered neutrons. This work presents the diagram and characteristics of the experimental setup. An example of hydrogen concentration determining in diamond powder of detonation synthesis is given and on its basis, the sensitivity of the setup is calculated.

A novel energy resolved neutron imaging detector based on a time stamping optical camera with high spatial resolution at CSNS

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China Spallation Neutron Source(CSNS) is a pulsed neutron source because the neutrons are produced by the accelerators with a repetition rate of 25 Hz. This provides a opportunity for energy-resolved neutron imaging. At present, an energy resolved neutron imaging instrument (ERNI) is being built at CSNS. ERNI can be used to carry out Bragg edge imaging, neutron transmission imaging and neutron diffraction imaging of samples at the same time. The various advanced neutron imaging techniques can be combined with neutron diffraction techniques to obtain the microstructure, the crystal structure, residual stresses, and so on by the neutron transmission spectrum, the neutron image and the diffraction information. The wavelength resolution can reach 1‰ when the Bragg edge imaging of sample is carried out. ERNI requires a neutron imaging detector of a spatial resolution of less than 100 μm, as well as a microsecond-scale timing resolution simultaneously.

An energy resolved neutron imaging detector is constructed based on a time stamping optical camera, TPX3Cam. The time resolution is sub-microsecond scale for the detector. The detector setup is shown in Fig. 1 (a), and this detector is composed of dark chamber, scintillation screen, reflecting mirror, optical lens, image intensifier, and movable platform. The spatial resolutions are tested by using the scintillation screen including ZnS and GOS scintillation screen. It is shown in Fig. 2 that the spatial resolutions are about 100 and 50 μm for ZnS and GOS scintillation screen respectively. Thus, this detector can meet the requirement of ERNI and be applied in the pulsed neutron source. More details related to this detector can be seen in this paper " Yang, Zhou, et al. A novel energy resolved neutron imaging detector based on a time stamping optical camera for the CSNS, NIMA, 2021, 6, 1000"

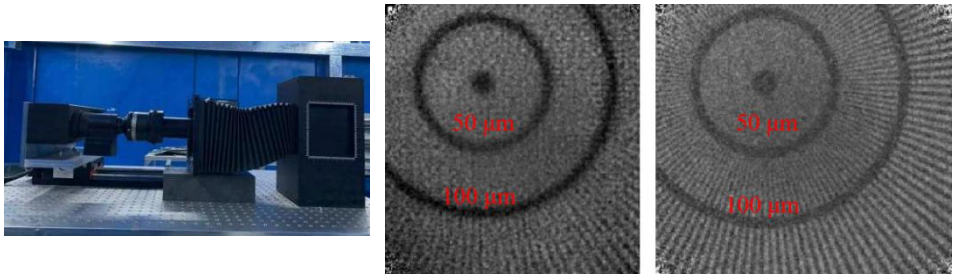

Figure 1 (a) The detector setup at CSNS (b) The imaging result using ZnS scintillation screen (c) The imaging result using GOS scintillation screen

The possibility of applying unfolding techniques to photo-nuclear reactions

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Unfolding numerical techniques are developed primary for use in neutron induced reactions. In this work two possible applications of standard unfolding procedures are demonstrated: for determination of cross section for photon-induced nuclear reaction, as well as for determination of energy spectra of incident photons. Cross-section function for the $^{115}In(\gamma,\gamma')^{115m}In$ reaction was determined in the energy range up to 10 MeV using the bremsstrahlung beam of MT25 Microtron, JINR, Dubna. The obtained results were compared with TALYS 1.9 calculation and published experimental data. Preliminary photo-activation data of ^{209}Bi exposed by bremsstrahlung during commissioning of LINAC200 Laboratory of Nuclear Problems, JINR, Dubna were used to reconstruct energy spectra of used photon beams. Four different energies were used: 40 MeV, 60 MeV, 80 meV and 100 MeV. Reconstructed photon spectra were compared with Monte-Carlo simulation of bremsstrahlung spectra of thick target. Obtained results suggests that the application of unfolding technique opens possibility to acquire unknown excitation functions of photon-induced reactions and can provide reliable information about photon spectra as well.

DIGITIZERS DSR (DIGITAL SIGNAL RECORDER) AND THEIR APPLICATION FOR NUCLEAR PHYSICS RESEARCH

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A waveform digitizer is an electronic data acquisition device that digitizes analog signals using fast analog-to-digital converters (ADCs) at a specified clock frequency and stores the resulting digitized data to disk or memory for subsequent processing.

The use of digitizers in modern experiments as the main component of a data acquisition system in many cases allows significant gains in compactness and cost, and also provides more opportunities for the data analysis.

The report discusses the characteristics and features of the DSR-2, DSR-32, DSR-8/16, and DSR-128 digitizers with a high-speed USB3 interface, developed at FLNP JINR.

Improvement of trapezoid pulse shaping technique for nuclear pulse

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Abstract: Nuclear pulse shaping of is one of the core techniques for energy spectrum analysis instruments of radiation or particles. As we all know, up to now, trapezoid shaping is the most suitable pulse processing technique for digital computation with wave-filtering function. Under high input count rate condition, measurement need very high requirement of the computation precision and speed. In conventional trapezoid pulse shaping technique, the ballistic deficit correction step is performed based on sampling cycle unit. This will apparently add the burden of digital computation if keeping high precision measurement. Especially in high input count rate condition, to solve this problem, very high chipset is required. This leads to remarkable rising cost or no matching chipset. In our paper, using SDL (Single delay line) shaping technique to replace the first difference step and the ballistic deficit correction step, an improved trapezoid pulse shaping arithmetic was updated. The simulation shows that the improved trapezoid pulse shaping technique has the same spectrum resolution comparing with the conventional one, but remarkably decreases the digital computation burden. It is more suitable for real time spectrum measurement with high input count rate.

Keywords：Nuclear pulse shaping，trapezoid shaping，high input count rate，SDL，digital computation

A digital photon-photon coincidence system for ^{125}Xe measurement

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Abstract: The radioactive xenon measurement in samples of atmospheric airis crucial for verification system of the Comprehensive Nuclear-Test-Ban Treaty (CTBT).Four radioactive xenon isotopes ^{131m}Xe, $^{133m/g}$Xe, and ^{135}Xe that are of interest are produced in large quantities from fission of a uranium or plutonium bomb.In addition to the four radioactive xenon, background contributions can also emerge from neutron activation of stable xenon in air, and it has been shown that the irradiation of natural xenon results in a large fraction of ^{125}Xe. Thus it is important for CTBT mission to develop ^{125}Xe measurement method. In this paper, a digital photon-photon coincidence measurement system for ^{125}Xe was developed. Two high purity germanium (HPGe) detector with high energy resolution were combined for the coincidence system, and a fully digital spectrometer Hexagon(CAEN Inc.) was used to process pluses from the preamplifiers of HPGe detectors. ^{125}Xe was produced by irradiating stable ^{124}Xe gas in Xi'An Pluse Reactor. The energy and time stamp information were stored into list file event by event for off-line analysis. The off-line analysis was accomplished by ROOT, and two-dimensional photon-photon coincidence histogram was obtained. The coincidence efficiency was calibrated to be 7.5%, and the minimum detectable activity (MDA) of coincidence system for ^{125}Xe was determined to be 5mBq after one day measurement.

Keywords: coincidence measurement, ^{125}Xe, radioactive xenon

Implementation of the REGATA-2 pneumatic transport system at the IREN research facility

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The REGATA-2 pneumatic transport system (PTS) was set into operation at the IREN research facility, Frank laboratory of neutron physics (FLNP), Joint Institute for Nuclear Research, Russia. PTS was created in the Laboratory for technical development in physics, Bulgarian academy of sciences. The PTS includes two neutron channels that are used to irradiate samples with neutrons when doing neutron activation analysis (NAA). The samples were placed manually on the surface of the IREN moderator before the implementation of this system. REGATA-2 can automatically deliver containers with samples to irradiation positions and back without stopping the facility operation. PTS significantly expands the capabilities of NAA: now researchers have access to the determination of the elemental content in samples using short-lived isotopes, in addition to the previously carried out experiments on medium- and long-lived isotopes. REGATA-2 allows seriously simplify the process of irradiation, to reduce the negative effects of radiation on a human body.

Also, a module for placing a sensor signaling the presence of a container at the irradiation position was developed and successfully implemented during collaboration of the Design engineering bureau and the NAA group FLNP. It became possible to automatically notify the experimenter about the arrival of the container at the irradiation position thanks to this module. The optical sensor placed in this module shows stable radiation resistance: the sensor remains in full working condition for more than three months since placed in service. The program for the controller that operate the movement of the container was significantly improved, which made it possible to adapt the PTS to the peculiarities of the IREN facility.

Using the PTS, the first experiment was carried out: the elemental composition of archaeological ceramics from Kazakhstan was studied by short-lived isotopes. The mass fractions of 7 elements are calculated.

A Primary Design of Neutron Beam Shaping Assembly for AB-BNCT

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Boron neutron capture therapy (BNCT) is a unique type of radiation therapy that enable cancer to be targeted at the cellular level. It was devised in 1936 and the very first attempt was performed in a patient diagnosed with Malignant Glioma in 1951. In last century, reactor-based BNCT (RB-BNCT) was mainly used. The incompatibility between reactor and hospital is one of the obstacles of BNCT development. Around 2010, the first accelerator-based BNCT (AB-BNCT) system developed by Japanese scientists, which was steadily pioneering the new era of BNCT.

The reactions of ^{7}Li(p,n)^{7}Be and ^{9}Be(p,n)^{9}B are commonly used in accelerator driven neutron source for BNCT. But the neutron emits in all angles and the neutron energy is too high to apply to patients directly. So a beam shaping assembly (BSA) is needed to moderate the neutrons to proper energy and make them shoot out at the beam port. This work will show some design and simulation results of BSAs with different materials and structures. Specifically, we assumed an accelerator driven neutron source that works by 2.8 MeV protons hitting a solid lithium target. Based on the recommendation values of the IAEA-TECDOC 1223 report, we compared with different moderation materials, such as magnesium fluoride, Fluental, aluminum fluoride, calcium fluoride and so on, and different reflection materials, such as lead, nickel, graphite and so on. We also compared different BSA structures, such as cylindrical and cone structure from the points of epithermal neutron flux, fast neutron and gamma contamination. We found that lithium oxide has a good performance to get a high epithermal neutron flux. However, it easily absorbs vapor and reacts with carbon dioxide, which is negative to BSA. Cone structure is more effective to reflect neutrons to get more neutrons at the beam port. In the near future, we will design and modify the collimator system and the beam port to get a complete BSA system with good performance.

Development of the Light charged Particle Detector Array (LPDA) at Back-n white neutron source

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Abstract: The "Back-n" white neutron source of China Spallation Neutron Source (CSNS) is a good platform for nuclear data measurement and nuclear technology application. A light charged particle detector array (LPDA) with sixteen ΔE-ΔE-E telescopes had been constructed in 2020. Each telescope employs a low-pressure multi-wire proportional chamber (LPMWPC) as the first stage, followed by a silicon PIN detector. A thallium activated Cesium Iodide (CsI(Tl)) crystal readout by SiPM as the total energy detector at the end of each telescope. The 16-channel telescopes are divided into two groups and installed in two sealed gas boxes. Both boxes are placed in a vacuum chamber and arranged in a fan shape to cover more solid angles. With LPDA, the low-energy (n, p) experiment was accomplished in 2020, and a good ΔE-E particle resolution was obtained.

Keywords: ΔE-ΔE-E telescope, "Back-n" white neutron source, particle identification

Influence of the ion fluences to transition layers in SiO_2/TiO_2 multilayer samples implanted Kr^+ ions

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Abstract

$(SiO_2/TiO_2)_2$ with Si substrate was implanted with 250 keV Kr^+ ions with different ion fluence. The atomic mixing was formed and growing between SiO_2 layers and TiO_2 layers in ion implantation process. The thicknesses of these layers in the samples before and after ion irradiation were investigated by Rutherford Backscattering Spectroscopy (RBS). The thickness of transition layers increases when the ion fluence is increased. Using spectroscopy ellisometric (SE) method, the ellipsometic angles Ψ and Δ were determined. The SE and MAIE methods were used in the study of pseudo dielectric function <ε> of the samples.

Keywords: ion implantation, multilayer structures, transition layer, spectroscopy ellisometric, RBS

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Measurement of the Neutron Energy Response Curve of Fission Target Detection System Based on CSNS Back-n

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Abstract

For the sensitivity of fission target detection system, we can only use Cockcroft-Walton accelerator's 14MeV neutrons to calibrate its sensitivity previously. In this work, using time of flight method in the back-streaming white neutron beam line (Back-n) of the China Spallation Neutron Source (CSNS) in Hall 1(with flight path of ~55 meters) with double-bunch mode and single-bunch mode, we acquired the ~0.3-10MeV neutron sensitivity of a detection system based on U-235 fission target and SiC detector (with thickness of about 30μm). A preamplifier with amplitude output and timing output coincidence with accelerator's delayed FCT signal was used as TOF signal, which were all inputted to the CAMAC system as DSP. The gamma-flash signal of a Si-PIN detector with thickness ~300μm placed in the symmetrical "target leg" was use as zero time. The results of single-bunch mode get well compared with that of double-bunch mode.

Research of Neutron Backscattering Radiography (NBR) System

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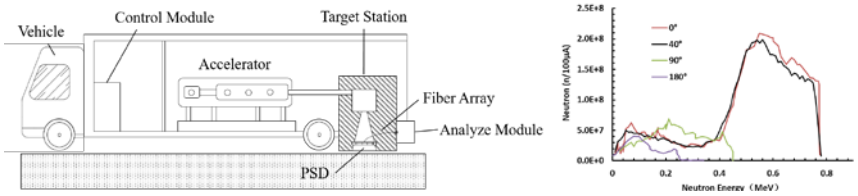
1. Introduction

Neutron is potential to be used as a means for non-destructive testing for infrastructure. However, in some specific situation, like bridge and road detection, the detector is unable to lay out and neutron can hardly penetrate thick concrete. So we need to develop a new method for this situation. Till now, there are very limited studies available on neutron backscattering radiography (NBR). Our group with RIKEN Center for Advanced Photonics first experimented NBR bridge nondestructive testing in 2017. It is verified that backscattering neutron can effectively distinguish water, voids and concrete [1].

Transportable Compact Accelerator-driven Neutron Source (T-CANS) is an effective mean to apply neutron backscattering in infrastructure detection. In this paper, we mainly discuss the neutron backscattering radiography system of T-CANS, simulate the effectiveness of NBR in the field of infrastructure non-destructive testing, and also pre-research the image reconstruction algorithm.

2. Neutron Backscattering Radiography System Based on T-CANS

T-CANS is a potential tool for infrastructure NDT, while the neutron backscattering radiography (NBR) is almost the only way to apply that. Our group has been committed to the development of T-CANS, and make important breakthroughs in key systems. Fig.1(a) shows the structure of T-CANS backscattering radiography system. The source uses 2.5MeV proton and solid lithium target. Fig.1(b) shows energy spectrum of the neutron source.



(a)System Structure (b)Energy Spectrum

Fig.1 Structure of T-CANS NBR System

NBR can effectively distinguish the defects, especially void and water gap. Fig 2 shows the simulation results of defects detection. Defects depth is 10cm, size is 5*5*5cm. Detector size is 30px*30px, pixel size is 0.5cm. Water can reflect more thermal neutron than other material, while void can hardly reflect neutron, thus, NBR can distinguish void and water by means of backscattering neutron flux and energy.

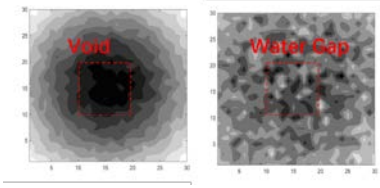


Fig.2 NBR Simulation of Void and Water Defects

3. Super-resolution Reconstruction Based on NT-SRCNN

Super Resolution Convolutional Neural Networks (SRCNN) is a developing super-resolution reconstruction method [2] and already applied in X-ray imaging field. However, due to the lack of neutron image training data, it can hardly apply to neutron imaging. Transfer learning and few-shot learning can effectively overcome this problem. We are developing Neutron Transfer-SRCNN(NT-SRCNN) and successfully apply to transmission imaging [3]. Fig3 is the result of reconstruction, the PSNR has been significantly improved. Furthermore, we will apply this method in neutron backscattering image reconstruction.

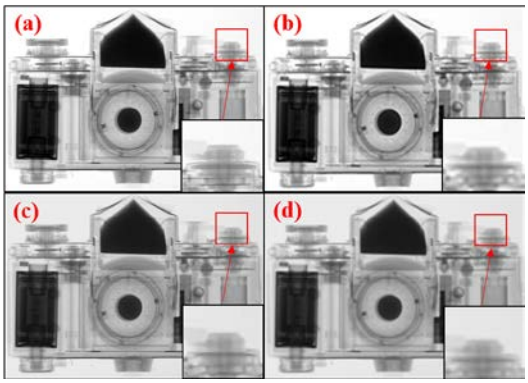


Fig.3 Reconstruction Results

(a) is original image [4], (b) is degrade image of 25% resolution

(c) is NT-SRCNN result with PSNR 32.4db, (d) is Bicubic Interpolation result with PSNR 30.3db

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Comparison between disintegration reactions caused by virtual photons and bremsstrahlung of electron

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Electron neutron source can produce neutrons with shorter pulse-width than photoneutron source because of its target can be as thin as 1mm. Meanwhile, measurement of nuclear de-excitation gamma rays by Coulomb Excitation (CE) can have less background photon compare with Nuclear Resonance Fluorescence (NRF). The fact that real photons do not participate in Coulomb Excitation makes electron excitation have different application potential from photon excitation (especially bremsstrahlung). To compare the yield of electron excitation and photon excitation, disintegration cross section of tantalum with 100 MeV electron and its bremsstrahlung are measured. It is found that the main reactions of electro-disintegration of ^{181}Ta with 100MeV electron are (e, xn) reactions, where x is the number of emitted neutrons, and the observed x ranges from 1 to 8. The ratios of cross sections of (e, xn) reactions to (γ, xn) reactions show a monotonous growth with the increasing x, because virtual photon of electron has a higher proportion of high-energy photons than bremsstrahlung due to the self-absorption when bremsstrahlung is produced. And according to the analysis of Plane-Wave Born Approximation (PWBA), the number of virtual photons transferred by electrons increases with the transition order while the number of bremsstrahlung photons do not change with the transition order, which indicate that compared with photon excitation, electron excitation is more conducive to the excitation of nuclei to high energy level and high angular momentum level.

A neutron detector based on recoiled proton and MCP

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Abstract

A new neutron detector based on recoiled proton and micro channel plate has been developed for measurement of ultrafast pulse neutrons. The neutron sensitivity of the detector was investigated through simulation and experiment. A model of Monte Carlo simulation was set up for neutron sensitivity simulation. In this model, the yields and average energy of protons emitted from different thickness' polyethylene were calculated as a function of neutrons energy. Then, the yields of secondary electrons produced by the recoiled protons in micro channel of MCP were also calculated. The neutron sensitivity of the detector was finally obtained. The results show that the detector can achieve neutron sensitivity of more than 10^{-15} C•cm^2 at the neutron energy above 1 MeV. Experiments were performed to test the neutron sensitivity on the K600 accelerator at Institution of Atomic Energy. The simulated results agreed with the experiments considering the uncertainties.

Key words: MCP, recoiled proton, secondary electron, neutron detector, neutron sensitivity

Re-construction of a HPGe detector modeling for efficiency calibration

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High purity germanium (HPGe) detector is a prior choice for determining the activity of the radioactive samples for nuclear diagnostics of Inertial Confinement Fusion (ICF) experiments. Efficiency calibration of gamma rays at a close distance from the surface of a HPGe detector is a crucial issue. So far as the detector structure is precisely clarified, a model of the detector can be well developed, based on which Gamma-ray detection efficiencies can be calculated accurately using Monte Carlo method. In this paper, internal geometry and structure except for dead layers of the HPGe detector is obtained by X-ray radiography and 3D reconstruction. The optimal dead layers of the germanium crystal are determined by tracing the minimal sum squared residual (SSR) of gamma-ray efficiencies between calculations and measurements for standard planar sources.

Development status of the neutron detectors for instruments at CSNS

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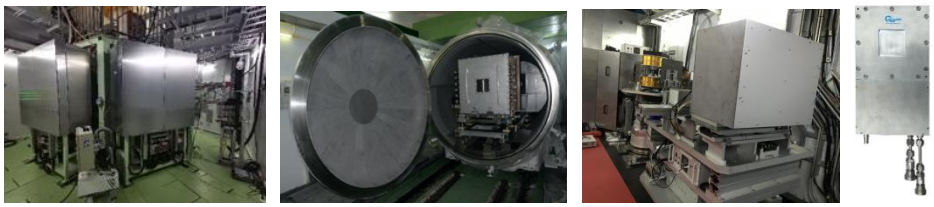
Neutron science and technology plays an irreplaceable role in national defense and industry. China spallation neutron source (CSNS) is a major science and technology platform for multidisciplinary applications. As one of the most expensive core equipment of neutron instruments, the neutron detector suffers from the technical blockade from the developed countries, and has become a neck bottle problem restricting the construction and operation of neutron instruments at CSNS. Based on the requirements of the instruments, many common key technologies of neutron detectors have been solved, a detector system of large-scale engineering application has been preliminarily established. A professional and young team has been cultivated to be engaged in developing the advanced neutron detectors. The team has completed the construction of neutron detectors for General Purpose Powder Diffractometer (GPPD), Small Angle Neutron Scattering (SANS) and Multifunctional Reflectometer (MR). The team developed a large area of scintillator detector (5 m^2) (shown in Fig.1 (a)), a large area of ^{3}He tube detector (1 m^2) (shown in Fig.1 (b)), ^{3}He MWPC detector (shown in Fig.1 (c)), high flux two-dimensional GEM neutron detector, neutron imaging detector and seven GEM neutron beam monitors (shown in Fig.1 (d)). These detectors passed the national acceptance in August 2018 and the performances reach or even exceed the international advanced level. In the next research, the detectors will be further developed to realize better performances including a larger area, a higher spatial resolution, a higher detection efficiency and a higher integration. These detectors will be provided for many neutron sources in China and this will promote the vigorous development of neutron science and technology in China.



(a) The scintillation detector for GPPD (b) The ^{3}He tube detector for SANS (c) ^{3}He MWPC detector for MR (d) The GEM neutron beam monitor

Figure 1 The neutron detectors during Phase I

Fundamental interactions & symmetries in neutron induced reactions

FINE STRUCTURE OF β-DECAY STRENGTH FUNCTION $S_\beta(E)$

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The strength function $S_\beta(E)$ governs [1-3] the nuclear energy distribution of elementary charge-exchange excitations and their combinations like proton particle (πp)–neutron hole (νh) coupled into a momentum I^π : $[\pi p \otimes \nu h]I^\pi$ and neutron particle (νp)–proton hole (πh) coupled into a momentum I^π : $[\nu p \otimes \pi h)]I^\pi$. The strength function of Fermi-type β-transitions takes into account excitations $[\pi p \otimes \nu h]0^+$ or $[\nu p \otimes \pi h]0^+$. Since isospin is a quite good quantum number, the strength of the Fermi-type transitions is concentrated in the region of the isobar-analogue resonance (IAR). The strength function for β-transitions of the Gamow–Teller (GT) type describes excitations $[\pi p \otimes \nu h]1^+$ or $[\nu p \otimes \pi h]1^+$. At excitation energies E smaller than Q_β (total β-decay energy), $S_\beta(E)$ determines the characters of the β-decay. For higher excitation energies that cannot be reached with the β-decay, $S_\beta(E)$ determines the charge exchange nuclear reaction cross sections, which depend on the nuclear matrix elements of the β-decay type.

Development of experimental technique allows application of methods of nuclear spectroscopy with high energy resolution for $S_\beta(E)$ fine structure measurement [3-5]. The combination of the total absorption spectroscopy (TAS) with high resolution γ-spectroscopy may be applied for detailed decay schemes construction [3]. It was shown [3-5] that the high-resolution nuclear spectroscopy methods give conclusive evidence of the resonance structure of $S_\beta(E)$ for GT and first-forbidden (FF) β-transitions in spherical, deformed, and transition nuclei. High-resolution nuclear spectroscopy methods [3-6] made it possible to demonstrate experimentally the reveal splitting of the peak in the $S_\beta(E)$ for the GT β^+/EC-decay of the deformed nuclei into two components. Resonance structure of the $S_\beta(E)$ for β-decay of halo nuclei was analyzed in [7-9]. It was shown that when the parent nucleus has *nn* Borromean halo structure, then after Gamow-Teller (GT) β^- - decay of parent state or after $M1$ γ-decay of Isobar Analogue Resonance (IAR) the states with *np* tango halo structure or mixed *np* tango + *nn* Borromean halo structure can be populated.

In this report the fine structure of $S_\beta(E)$ is analysed. Resonance structure of $S_\beta(E)$ for GT and FF β – decays, structure of $S_\beta(E)$ for halo nuclei, quenching of the weak axial-vector constant g_A^{eff} are examined. Splitting of the peaks in $S_\beta(E)$ for deformed nuclei connected with the anisotropy of oscillations of proton holes against neutrons (peaks in $S_\beta(E)$ of GT β^+/EC – decay) or of protons against neutron holes (peaks in $S_\beta(E)$ of GT β^- – decay) are considered. Influence of such splitting on delayed particles emission and delayed fission are discussed.

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Search for TRIV in the interaction of polarized neutrons with polarized targets

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In this talk, the current efforts of the NOPTREX collaboration to perform TRIV studies in different neutron - compound nucleus systems will be presented. I will describe the experiments we are currently performing and planning for the near future to better characterize PV asymmetries and *s*, *p* wave resonance parameters. The mixing between these energetically close resonances is responsible for the observed amplification in PV effects, and the same mechanism should enhance any TRIV effect as well.

Final Results for the n3He Parity Violating Asymmetry Measurement

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Abstract: The n3He experiment made the first high precision measurement of the directional parity violating asymmetry in the proton emission direction relative to the initial neutron polarization in the reaction $^3\mathrm{He}(\vec{n}, \mathrm{p})^3\mathrm{H}$. This asymmetry is a result of the weak interaction between nucleons, which remains one of the least well-understood aspects of electroweak theory. Data taking for n3He was completed at the end of 2015 at the SNS of the Oak Ridge National Laboratory, and the asymmetry was measured to be $A_{PV}=[1.55\pm0.97(\mathrm{stat})\pm0.4(\mathrm{sys})]\times10^{-8}$. I will discuss the n3He experiment, data analysis, methods used to calculate the asymmetry, and compare the result of this experiment and the NPDGamma experiment with theoretical predictions.

Systematical Analysis of (n,2n) Reaction Cross Sections for 14-15 MeV Neutrons

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Fast neutron induced nuclear reaction cross section data are necessary for both nuclear energy technology and the understanding of fundamental nuclear physics problems. The information of (n,2n) cross sections is quite essential in nuclear technology as a significant portion of the fission neutron spectrum lies above the threshold of (n,2n) reaction for most of the reactor materials. These cross section data are required in radiation shielding and nuclear fuel breeding calculations. On the other hand, systematics of fast neutron induced reaction cross sections is useful to clarify nuclear reaction mechanisms. In addition, it is often necessary, in practice, to use the systematical analysis for evaluation of the neutron cross sections of the nuclides, for which no experimental data are available.

In this work, in the framework of the statistical model we deduced some theoretical formulae for the (n,2n) cross section using the evaporation model, constant nuclear temperature approximation and Weizsäcker's formula for binding energy. The model formulae were utilized for systematical analysis of known experimental data of the (n,2n) cross sections at 14–15 MeV neutrons.

Intermediate and fast neutron induced reactions

The measurement of $^{35}Cl(n, a)^{32}P$ reaction cross section for neutron energy range from 3.5–6 MeV

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IPPE JSC, Obninsk, Russia

Abstract

The existing experimental data on $^{35}Cl(n,a)^{32}P$ reaction cross-section are bounded by the neutron energy range from 2-4 MeV. There are several data sets in 14 MeV region. The big differences between JENDL-4.0u and ENDF/B –VIII.0 evaluations take place. In this work cross section of $^{35}Cl(n,a)^{32}P$ reaction was investigated for the neutrons energy range from 3.5 to 6 MeV. The measurements were carried out using the Frisch-gridded ionization chamber. Neutrons were produced by $D(d,n)^3He$ reaction at the tandem accelerator. The $^{238}U_3O_8$ layer was used as a neutron flux monitor. Influence of background neutrons on monitor chamber count rate was evaluated by measuring time-of-flight neutron spectrum, for each value of neutrons energy. The used solid chlorine target with thickness 174 ug/cm^2 consisted of barium chloride (natural isotopic composition) which was deposited on a molybdenum foil. Ion beam analysis was applied to measure the layer thickness. The obtained cross sections are in a good agreement with the ENDF/B-VII evaluation.

Isomeric Ratios in Some Inverse (γ, n) and (n, γ) Reactions

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Abstract

Two nuclear reactions are so called inverse, when the projectile of one reaction is emission particle of another reaction, for examples (γ, p) and (p, γ); (γ, n) and (n, γ); (γ, α) and (α, γ). Inverse reactions, including photonuclear and thermal neutron capture reactions play important role in astrophysics and study of nuclear structure and nuclear reaction mechanism. It is well known that the isomeric ratio provides diverse information about nuclear structure and nuclear reaction mechanism as well. In this work, we investigate isomeric ratios in some inverse (γ, n) and (n, γ) reactions, which lead to the same residual nucleus with near the same excitation energy by activation method using off-line gamma spectroscopy. Namely, they are ^{138}Ce(γ, n)^{137m,g}Ce and ^{136}Ce (n, γ)^{137m,g}Ce; ^{116}Cd(γ, n)^{115m,g}Cd and ^{114}Cd(n, γ)^{115m,g}Cd^{116};^{110}Pd(γ, n)^{109m,g}Pd and ^{108}Pd(n, γ)^{109m,g}Pd; ^{82}Se(γ, n)^{81m,g}Se and ^{80}Se(n, γ)^{81m,g}Se. The data analysis and necessary corrections as the self-absorption and summing cascade effects were made in gamma rays radioactivity measurements to improve the precision of the isomeric ratio determination. The results were discussed and compared with those in the existing literature. The experimental results are expected to explain some aspects of nuclear structure and provide the nuclear data for theoretical interpretation.

MEASUREMENT OF CROSS SECTIONS FOR THE $^{14}N(n, \alpha)^{11}B$ REACTION IN THE MeV REGION

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ABSTRACT

We have measured the cross sections of the $^{14}N(n,\alpha)^{11}B$ reaction in the 3.9-5.3 MeV. Experiments were performed at the Van de Graaff Accelerator EG5 of Frank Laboratory Neutron Physics, JINR. Fast monoenergetic neutrons were obtained from the reaction $^{2}H(d,n)^{3}He$ using a gaseous deuterium target. The gridded ionization chamber was used as an alpha particle detector. Thin solid samples of adenine ($C_5H_5N_5$) deposited on a tantalum backing were used as a target. The absolute and relative neutron flux was determined by two highly enriched $^{238}U_3O_8$ samples inside the GIC. The present results are compared with existing data and libraries.

Theoretical analysis of ^{6}Li(*n*, *t*) reaction at low energies

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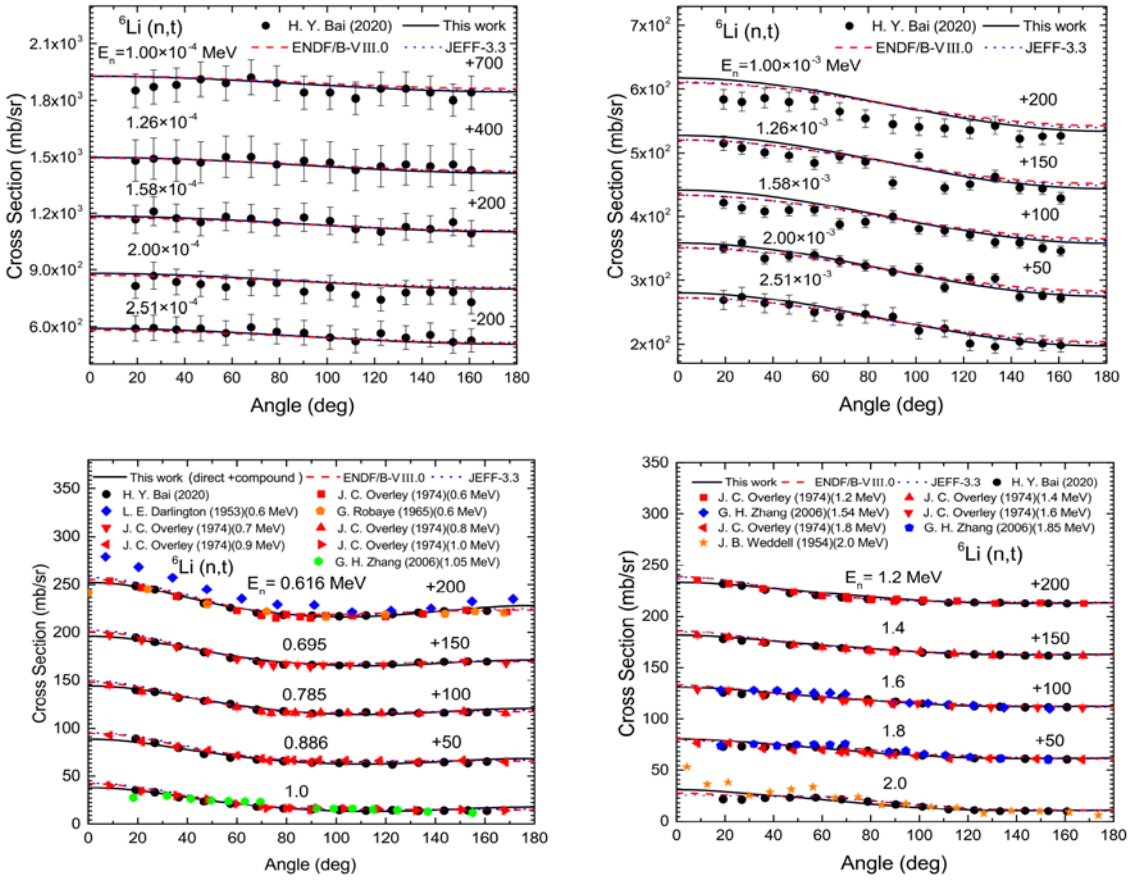
The differential cross sections and angle-integrated cross sections of ^{6}Li(*n*, *t*) reaction were regarded as an important subject in tems of their application value in nuclear technology and engineering. To consider the effects of energy levels of the compound nucleus ^{7}Li on triton emission, an effective excited energy formula was proposed, as a function of energies and widths of the discrete energy levels in this work. The differential cross sections and angle-integrated cross sections of ^{6}Li(*n*, *t*) reaction in energy range from 1.0 eV to 3.0 MeV were calculated by knock-out model with the assumption of ^{6}Li consisting of triton+^{3}He or deuterium+ alpha particle. The calculated results reasonably reproduced the recent experimental data and the evaluated data from ENDF/B-VIII.0 and JEFF-3.3. Furthermore, it is noted that the angular distributions in incident energy range from 0.1 to 1.0 MeV could be successfully explained by the Hauser-Feshbach model.

The comparisons of calculated differential cross section with experiments and evaluations at some energies are given below[1]:



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GENERATION OF RADIOCARBON C-14 IN THE AIR IN CONDITIONS OF THUNDERSTORMS

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The occurrence of lightning is preceded by the fast development of electron avalanche in electric fields with strength of about ~ 300 kV/m [1]. The avalanche growth in number of relativistic electrons ensures an energetic terrestrial gamma-ray bursts, that can ensure the photonuclear reactions on atmospheric isotopes with significant cross sections: so, for E_γ =20–60 MeV the cross section 14N(γ,n)13N (with $E_{threshold}$ ~10.55 MeV) – within the interval (1–10) mb. In turn the neutron flux leads to generation of radiocarbon 14N(n,p)14C, 40Ar(n,γ)41Ar, 14N(n,alpha)11B, 14N(n,γ)15N and another reactions [2, 3].

It was proposed the spherical-layer-model for calculation of radiocarbon C-14 (knowledge of which generation is exclusively important for radiochronology) and other isotope production in the air under thunderstorms. The simulation was realized at the several altitudes of the lower part of the atmosphere at the altitudes: 1, 3, 5, 7, 10, 13 and 15 km. The atmospheric density dependence is taken into account in the model. It was obtained that yield of radiocarbon C-14 cannot compete not only with it cosmogenic production (but it also significantly lower compared to the yield from Sun irradiation) that allows to take off the problematic question on it significant yield to the total production in the Earth atmosphere under thunderstorms.

At the same assumption it was obtained the rate of radioactive 41Ar production which less than radiocarbon C-14 yield in about 10^3 times.

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Multiband coupling and nuclear softness in dispersive Lane-consistent optical model for actinides

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This work presents the current state of a consistently developing coupled channels optical model. It takes into account the dispersive relations for the energy dependent optical potential [1], providing more constraint and realistic predictions. Lane-consistent (isospin symmetric) form [2] of the potential allows using the same parameter set for an unified description of direct neutron and proton scattering, and (p,n)-reactions.

Recent development of the model considers optical potential of a soft deformed target nucleus as an axially deformed potential with linear corrections corresponding to softness and non-axiality of a nucleus [3]. This approach allows coupling to levels from different rotational bands providing good convergence of calculations. Finally, a soft rotator model for even-even nuclei was used to calculate “effective” deformations – matrix elements of quadrupole and octupole deformation operators – with Hamiltonian parameters obtained from low-lying excitations spectrum of a nucleus [4]. Although the soft rotator model does not describe an odd-A nucleus excitations, “effective” deformations may be estimated for levels in rotational bands based on excitation of an even-even core of the nucleus. Therefore, multiband coupling, nucleus stretching, and some other corrections are accounted for actinides [5].

The presented model allows construction of a regional optical potential for actinides with low number of fitting parameters and good description of available experimental data.

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Cross sections of the $^{35}Cl(n,\alpha)^{32}P$ reactions at fast-neutron energies from 3.3 to 5.3 MeV

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ABSTRACT

The reaction cross sections of $^{35}Cl(n,\alpha)^{32}P$ were measured at incident neutron energies in the range of 3.3–5.3 MeV. The experiment was performed at the Van de Graff accelerator EG5 of Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research. Fast neutrons were produced via the $^{2}H(d,n)^{3}He$ reaction. Alpha particles from the reactions were detected by the gridded ionization chamber (GIC) in which different samples of ^{35}Cl (NaCl and $BaCl_2$) on to Ta backing placed back-to-back. The relative and absolute neutron fluxes were determined due to $^{238}U_3O_8$ (99.999%) samples inside the GIC. The obtained data were compared with other experimental data, evaluation libraries and TALYS code.

Measurement of (n,γ) reaction cross-section at different neutron energies

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Abstract:

The cross-section of ^{197}Au(n,γ) ^{186}W(n,γ), and ^{55}Mn(n,γ) reactions were measured in the neutron energy range from 0.5 to 5.0 MeV using activation and offline gamma-ray spectrometric technique. Gold is being used as a flux monitor and Manganese is used as a shielding and structural material in the reactor. Whereas, Tungsten is a prime plasma-facing material used as a diverter component material of fusion reactor. The neutrons of different energies were produced using ^{7}Li(p,n)^{7}Be reaction at different proton energies. The irradiations of samples were carried out at the Folded Tandem Ion-beam Accelerator (FOTIA) facility at BARC, Mumbai, and 14UD Pelletron facilities of BARC- TIFR, Mumbai. The covariance analysis was carried out by taking into account the partial uncertainties in different attributes and correlation among the attributes. The measured cross-sections were compared with the theoretically predicted data using TALYS-1.9 and EMPIRE-3.2.2 nuclear codes. The experimental and theoretical cross-sections have been compared with the evaluated data available in ENDF/B-VIII.0, JENDL-4.0 and JEFF-3.3. The measured reaction cross-section data are found to be consistent with the predictions of the theoretical model codes and results of various evaluated nuclear data libraries. The present measurements help to improve the existing data and provide new data in the neutron energy range where no data are reported.

Keywords: (n, γ) cross-section, Activation and off-line γ-ray spectrometry, TALYS-1.9 and EMPIRE-3.2.2 codes.

Neutron radiation effects &Radiation transportation and simulation

Numerical Simulation on the Short-term Annealing Factor in p-type Si

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Numerical simulation on the short-term annealing factor in p-type Si was presented in this paper. The annealing factors via time were obtained by two steps. Firstly, continuity equations were used to describe the temporary evolution of defects gennerated in p-type Si. Secondly, the minority-carrier lifetime of affected by the defects was computed from the lifetime definition and Shockley-Read-Hall(SRH) recombination rates. The annealing factor then was easily calculated from the minority-carrier lifetime. The comparisons with the numeircal result of other researchers and the experimental result indicated that our results were much closer to the experimental results. In the numerical simulation of other researchers, only the first step decribed above was performed and the minority-carrier lifetime was approximated by the electron concentration. Two-step simulation could make the result more accurate.

Energy Band Bending induced Carrier Recombination Enhancement in Lateral PNP Bipolar Transistor Exposed to Mixed Neutrons and Gamma Rays

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Abstract

Lateral PNP bipolar transistor (LPNP) is the most vulnerable kind of device in bipolar integrated circuits when exposed to the mixed irradiation of neutrons and gamma rays. Under the mixed irradiation, LPNP exhibits ionizing/displacement synergetic effects and has more severe current gain degradation than that under the individual neutron or gamma irradiation. In this paper, a model concerning the energy band bending induced carrier recombination enhancement was developed to simulation the ionizing/displacement synergetic effects in LPNP. Based on the model, the physical mechanism of the synergetic effects was well explained and the influencing factors were deeply analyzed. The results indicate that gamma-induced energy band bending in the subsurface of Si/SiO_2 interface enhances the carrier recombination in neutron-induced displacement defects in bulk silicon, leading to more severe current gain degradation under the mixed irradiation.

INVESTIGATION OF WASTE MANAGEMENT OF CONTROL ROD, IRRADIATION BOXES, AND STEEL LINING OF TEHRAN RESEARCH REACTOR AFTER DECOMMISSIONING

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Abstract: Prediction of the radioactive behaviour of different components of a research reactor during the cooling time is important regarding their waste management and decommissioning. The present work investigate the radioactivity behaviour of control rod, aluminium irradiation box and steel lining of Tehran Research Reactor during the cooling times after the reactor shutdown. MCNPX and ORIGEN computational codes were used to estimate the behaviour. A benchmark study was done to evaluate the conformity of the experimental measurement with the simulation data. The carried out study showed the aluminium parts would be easily handled after at least 6 months after the reactor shutdown by means of the usual shield are used to transfer the radioactive components to the spent fuel pool or radioactive waste storage sites. In the case of the steel lining also after 6 months of cooling the gamma dose rate decreases noticeably. The gamma dose rate of control rods are very high and decreases slowly during the years after the reactor shutdown.

Keywords*: Gamma dose rate, decommissioning, waste components, Tehran Research Reactor*

INVESTIGATION OF HEAVY WATER LOADING IN NEUTRON BEAM CHANNEL OF TEHRAN RESEARCH REACTOR TO DECREASE FAST NEUTRON BACKGROUND AT DIFFRACTION TABLE

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Abstract : To obtain very sharp neutron diffraction pattern using the diffractometer facilities in research reactors, high-efficiency detectors, low fast neutron backgrounds, and high intensity neutron beam in the range of analysis are important factors. To improve the old diffraction system of Tehran Research Reactor, some reformation were investigated to decrease the fast neutron backgrounds at the diffraction table. However, crystalline neutron filters could obtain this aim easily, the homemade high-purity heavy water accessibility in TRR caused the cheap procedure is investigated in the present study. Hence, heavy water usage inside the horizontal channel of TRR was investigated using MCNPX code simulation. The obtained results showed about 10 litres heavy water loading inside the channel would reduce the fast neutrons with $E_n > 1$ MeV about 124 times but the thermal neutron in the range of analysis (0.02 eV $< E_n <$ 0.33 eV) would be reduced about 7.5 times. The calculations showed a donate-shaped heavy water cylinder would allow the thermal neutron reduction is not noticeable (about 21%) while the fast neutron reduction is 1.83 times.

Keywords*: Heavy water, Fast neutron shielding, Neutron diffraction, Tehran Research Reactor*

Simulation Study of the Low Energy Beam Transport with Einzel Lens

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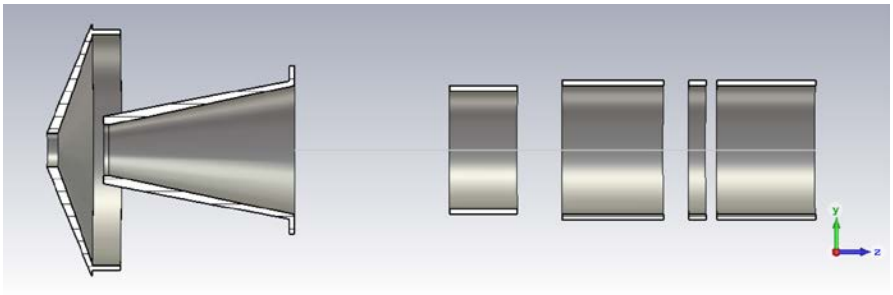
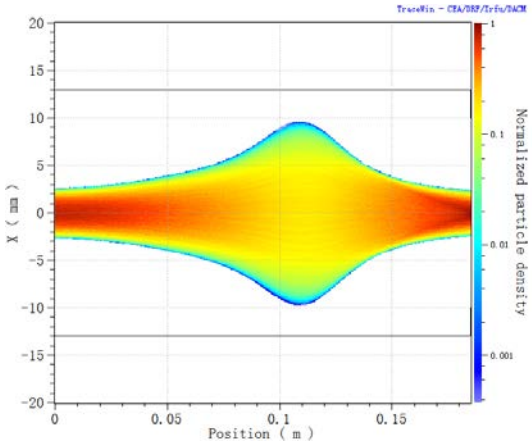
Einzel Lenses are frequently used in low energy beam transport[1]. We design a triple electrostatic lenses in order to transport H+ beam with 30keV energy and 10mA current between ion source and RFQ. The purpose is to focus the beam and match the RFQ. Einzel Lens has the advantages of cheap, compact, easy to machining and operate. The total length of low energy transport system is about 185mm.

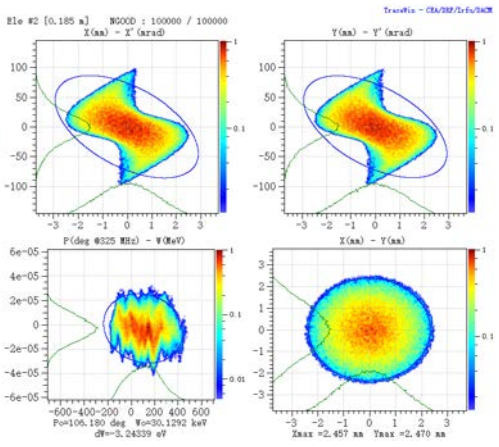
Finite element software CST and PIC program TraceWin are used to simulate the low energy system transport. In the simulation process, we change the electrode shape, gap and electrode voltage to study the influence on beam transport. Finding some regular conclusion for the future design.



Einzel Lenses modeling by CST



Low energy beam transport density



Phase diagram of Einzel Lenses outlet

Reference

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Development and verification of a MOOSE-based neutronics solver for the multi-physics analysis of advanced nuclear reactors

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ABSTRACT:
Multi-physics coupling analysis plays more and more important roles in recent years for the accurately modelling of advanced nuclear reactors. This is especially true for advanced nuclear reactors where strong nonlinear interdependencies exist between neutron transport, heat transfer, mechanics and thermal fluids, etc. In this paper, a neutronics solvers have been developed based on the Multiphysics Object Oriented Simulation Environment (MOOSE) which provides simplified interfaces for specification of partial differential equations, boundary conditions, material properties, and all aspects of a simulation without the need to consider the parallel, adaptive, nonlinear, finite element solve that is handled internally. With the adoption of this platform, all physics applications are developed with a common software design and mesh mapping technique and data exchange become much easier for the coupling codes compared with traditional methods. The developed neutronics solvers are verified by several benchmark problems. The numerical results indicate that the developed neutronics solver is reliable to be applied for the analysis of nuclear reactors.

Testing of Ferroelectric Magnetoresistive and Resistive Random Access Memory Under Reactor Neutron Radiation

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Abstract

New type of non-volatile memory is different from traditional non-volatile memory as it is not depending on charge for storing data. Therefore, the new type of non-volatile memory is considered to have better radiation resistance. This paper mainly evaluates the soft error and hard error resilience of three kinds of non-volatile memory including ferroelectric, magnetoresistive and resistive random access memory. The experimental phenomenon is obtained and the mechanism of neutron radiation effect of three non-volatile memories is analyzed. For MRAM (MR2A16A), there is no soft and hard error during read test and read-write test. And for RRAM (MB85AS4MT), there is no soft error and hard error under static state. For FRAM (FM28V100), soft and hard error are detected during reading process. During reading process, soft error may appear when neutron irradiate at peripheral circuit and hard error may appear when neutron irradiate at memory cell. The difference of memory cells' structure of MRAM, RRAM and FRAM cause the difference in neutron radiation effect.

Investigation of Thermal Neutron Scattering Data Evaluation for H in ZrHx

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Abstract: Traditional evaluation process in the past was usually done by using differential experimental data which was then complemented with nuclear model calculations. This trend is fast changing due to the increase in computational power and tremendous improvements in nuclear reaction models over the last decade. The behavior with the energy of the neutron cross sections of hydrogen in ZrH_x depends on the Thermal Scattering Laws tabulated in terms of S(α,β). However, uncertainties on the corresponding S(α,β) were never reported. And till now no recommended procedure exists for computing covariance of TSLs available in the international evaluated nuclear data libraries. In the previous work, based on differential experimental nuclear data, the phonon model parameters related to a semi-empirical phonon model were adjusted by the uniform Monte Carlo method. The covariance of TSLs for H in ZrH_x was generated ignoring the integral experiments' result. Considering that Monte Carlo method consumes much time in data assimilation, this work presents another deterministic nuclear data adjustment methodology to produce such a covariance matrix-associated to the same phonon model using both differential and integral experiments, in which Generalized Non-Least Square (GNLS) method was used to adjust the phonon model parameters on evaluated data and generate covariance matrices between the phonon model parameters. It can be observed that after data adjustment, the error and uncertainty of the differential cross-section data and integral data are both reduced.

中文摘要：过去的传统评价过程通常是利用微分实验数据，然后再加上核模型计算完成。在过去的十年中，由于计算机模拟水平的增加和核反应模型的巨大改进，这一趋势正在迅速改变。ZrHx中H的热中子散射截面的能量行为取决于用 S（α，β）表示的热散射律。然而，对相应的 S（α，β）的不确定性从未被报道过。到目前为止，还没有推荐的程序可用于计算国际评价核数据库中的S（α，β）的协方差。在以前的工作中，基于微分实验核数据，用统一的蒙特卡罗方法对半经验声子模型的声子参数进行了调整，在不考虑积分实验结果的情况下，生成了 ZrHx中H的S（α，β）协方差。考虑到蒙特卡罗方法在数据同化方面花费了大量时间，本文提出了另一种确定论的核数据调整方法，利用微分和积分实验相结合的方法，基于广义非最小二乘法（GNLS）对热中子散射数据上的声子模型参数进行调整，并在模型参数之间生成协方差矩阵。从结果中国可以观察到，经过数据调整后，微分截面数据和积分数据的误差和不确定度都减小了。

Monte Carlo calculations for active personal neutron dosimeters

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An active personal neutron dosimeter has been developed for neutron radiation warning in special environments. The dosimeter consists of polyethylene as the moderator, a boron film covering the polyethylene surface as the transformer, and the final measurement is performed using a silicon carbon detector. By setting different thicknesses of boron film and polyethylene, the detection neutron energy interval is divided. The dose equivalent response matrix and angular response of the personal neutron dosimeter to incident neutrons of different energies are finally simulated by comparing the deposition energy simulation of Geant4 with SRIM for non-stop materials to determine the thickness of each material.

Analysis of X-ray Transport Process in Multi-layer Medium by Monte-Carlo

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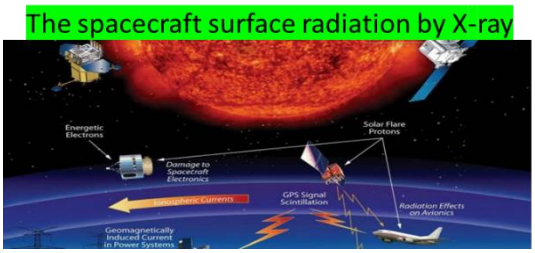
Abstract: Multi-layer medium materials are widely used in the study of the protection and reinforcement of X-ray thermodynamic effects. Monte Carlo method for particle transport is an effective way to simulate the physical process of irradiation effects. According to the structure characteristics of multi-layer medium materials, it was improved the processing method of materials interface in numerical program, and increased the adaptability of the program to the repeated interface of various materials, and raised the calculation accuracy. By using the method of combining continuous slowing approximation and single large collision, it was equivalent simulated multiple actual collision compression between photons and atoms, and solved the simplified approximation of X-ray transport process. By judging the trajectory of path of the collision, it was obtained the method the energy deposition process of the multi-layer medium materials and energy loss through the interface position and collision scattering path. Based on energy deposition, it has established the coupling algorithm combined Monte-Carlo method and collision compression, and realized the simulation integration of X - ray transport and radiation effect in multilayer medium.
Keywords: X-ray; Multi-layer Medium; Monte-Carlo; Energy deposition.

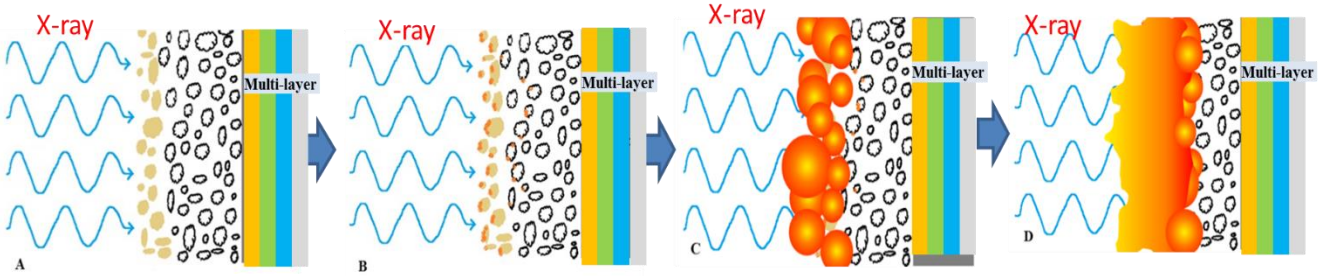
Condensed historical method: $E_{n+1} = E_n - \int_{s_n}^{s_{n+1}} \left|\frac{dE}{ds}\right| ds = kE_n$

Single Large Collision: $\mu_c = \frac{\rho N_a Z C}{AE}\left[\frac{1}{\varepsilon_c} - \frac{1}{1-\varepsilon_c} + \left(\frac{\tau}{\tau+1}\right)^2\left(\frac{1}{2}-\varepsilon_c\right) - \frac{2\tau+1}{(\tau+1)^2}\ln\frac{1-\varepsilon_c}{\varepsilon_c}\right]$

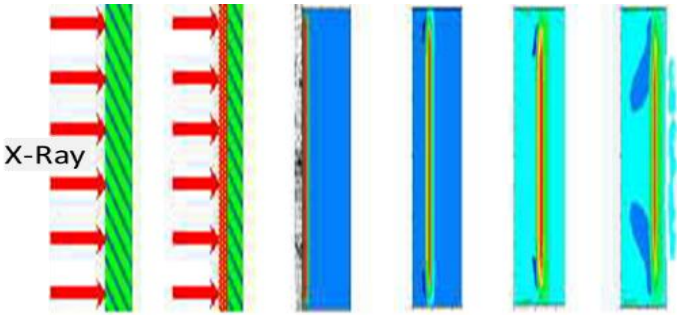


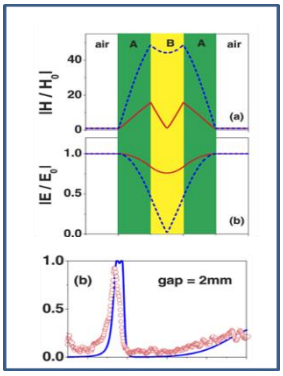
X ray parameter

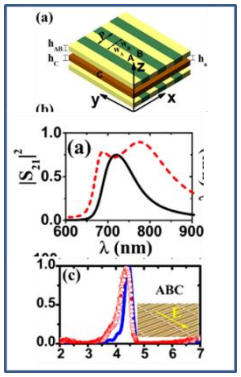
X-ray energy	124-0.124kev
X-ray wavelength	(0.1-100) x 10^{-10}m
Pulse width	Tens of nanosecond
Radiation energy	<100J/cm^2



X-ray Transport Process in Multi-layer Medium







Development and applications for the thermal neutron transport library NCrystal at CSNS

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Institue of High Energy Physics/China Spallation Neutron Source

Originated from the European Spallation Source, the thermal neutron transport library NCrystal has been widely used for novel neutron detector design. With the close collaboration between the China Spallation Neutron Source and the European Spallation Source, the number of thermal scattering models and the user community of NCrystal are growing continuously. In this talk, a full list of physics models in NCrystal is briefly reviewed. In addition, development activities at the China Spallation Neutron Source for supporting the Monte Carlo simulations on small-angle scattering, single phonon coherent scattering and nanomaterial neutron reflectors are introduced.

Neutron Induced Interface Traps Passivation on Bipolar Transistors

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Abstract

The neutron radiation effect of bipolar GCPNP transistor is studied in China Spallation Neutron Source (CSNS), and the ionization damage characteristics are analyzed by using gate-controlled charge separation method, the degradation characteristics of minority carrier lifetime, oxide trap charge and interface state were obtained, respectively. The effect of displacement damage defect on the charge accumulation of oxide trap is analyzed by using tcad simulation tool. The mechanism of neutron induced interface traps passivation on bipolar transistors is analysed and verified by comparison experiment between the post-neutron irradiated TID effect and the single TID effect in the GCLPNP transistors.

The results show that the damage of neutron displacement has no significant effect on the accumulation of oxide trapped charge, the effect of neutron displacement damage on N_{OX} can be neglected in the level of neutron fluence involved in the study. On the other hand, neutron irradiation can reduce the density of the primary interface traps by passivating, so that the total charge of Si-SiO_2 interface decreases and the peak voltage of the gate scan exhibit positive shift. Neutron irradiation can passivate the primary interface traps of the device, the passivated product is Si-H bond. The effect mechanism of pre-neutron irradiated transistors is verified by TCAD simulation and different order irradiation test. Results show that the pre-neutron irradiated transistors have more serious interface state damage in the subsequent total dose effect. In addition, the gate-controlled sweeping test results show that the coupled effect may occur when the displacement damage and the ionization total dose effect act on the bipolar transistor simultaneously, and lead to the deterioration of the synergistic effect.

Advanced neutron sources and perspective experiments

Dubna Research Reactors: A Look into the Future

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Abstract

The concept of a new pulsed reactor NEPTUN (serial number IBR-3) is presented, which in terms of its parameters is superior to the existing pulsed sources, as well as to those which are being constructed, for research on extracted beams. A scientific program, the implementation of which is difficult or impossible with existing sources, as well as the infrastructure for supporting experiments, are briefly discussed.

Optimization Study of Moderation System and Shielding Design for Compact Accelerator-driven Neutron Sources

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Neutron has important applications in both science and engineering. The scarcity of neutron beam has become a severe problem in neutron applications. Compact accelerator-driven neutron source (CANS) is complementary to large neutron source because of its high flexibility, short construction period. However, because the neutron beam intensity, especially the cold neutron intensity of CANS is lower than that of the large neutron source, it is difficult to carry out the low energy neutron scattering experiments on CANS. The optimization of the moderating system for CANS has become urgent. If the CANS could be designed further compact and realized transportable, the nondestructive inspections of special equipment such as roads, bridges, pipes, nuclear power facilities, aircraft, rocket, and other facilities can be easily realized on site. Therefore, the demand for light-weight and compact shielding optimization design has become one of the key topics for CANS.

Firstly, we adopted mesitylene as the cold moderator and systematically optimized the structure of the pre-moderator, reflector and target station structure. The optimized results showed that the moderating system of mesitylene had the same cold neutron intensity and nearly twice thermal neutron intensity as much as that of solid methane. The developed moderating system has been successfully applied on RIKEN Accelerator-driven Neutron Source (RANS).

Secondly, we developed a multi-objective shielding optimization method NSGA-MC. By coupling a multi-objective genetic algorithm and the Monte Carlo code, NSGA-MC can obtain a set of non-dominated optimal solutions. The application of NSGA-MC on RANS target station showed that the optimized shielding structure can reduce the shield weight by at least 60% without sacrificing the shielding performance. Compared with weighting method, NSGA-MC could provide diverse optimal solutions and largely save calculation time.

Finally, to experimentally prove the validity of NSGA-MC, two multilayer shielding structures of PE/B_4C/Pb and PE/B_4C/Pb/PE/B_4C/Pb were optimized by NSGA-MC with two objectives of minimized dose rate and shield weight. Three solutions on the Pareto optimal front and a non-optimized shielding structure based on the existing RANS target station were selected to be tested on RANS. The experimental results and simulation results agreed well with each other. The results show that the shielding effect and weight of the optimized shielding structure are greatly improved compared with the non-optimized shielding structure. Better shielding performance can be achieved by adopting a finer shielding structure.

The optimization design of moderation system provides guidance for other CANS which need to design or upgrade cold neutron moderation systems. The developed multi-objective optimization method, NSGA-MC, has laid a strong foundation for the application of light and compact radiation source devices such as transportable neutron sources, nuclear submarine, and space reactor.

NEUTRON RESONANCES AND QUANTUM CHAOS

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After a long search, the main source of classical chaos was stated to be the instability of the system's trajectories in the phase space with respect to the small variations of the initial conditions. The trajectories of the chaotic system diverge with time according to the exponential law as $\exp(\Lambda t)$, where the rate of divergence is defined by the Lyapounov exponent Λ.

However, the uncertainty relation in quantum mechanics deprives the trajectory of the necessary precision. Therefore, the modern definition of quantum chaos as "dynamics of the quantum systems which are chaotic in the classical limit" is quite vague. It is also proposed to search in these quantum systems for "the quantum signatures of the classical chaos". During the almost 40 years of this search the only more or less generally recognized such signature turned out to be the system's level distribution law. For the quantum analogs of the chaotic systems the level spacing distribution turned out to be close to the Wigner law with its characteristic level repulsion, which was experimentally established for the neutron resonances of compound nuclei. It is also often claimed that the level distribution of the quantum analogs of the classical regular systems is governed by the Poisson law.

It can be easily shown [1] that the level distribution criterion is a rather weak "signature" of quantum chaoticity or regularity. Wigner's law describes the chaotic system only if one selects a sequence of levels with fixed values of quantum numbers, while the Poisson law just shows that we have a mixture of many independent sequences of energy levels with different quantum numbers (irrespective of the system's regularity or chaoticity).

To avoid all these ambiguities and difficulties we suggest (see e.g. [1–3]) to use for the definition of regular and chaotic systems both in classical and quantum mechanics the Liouville-Arnold theorem, which states that the system is regular if the number N of its degrees of freedom equals the number M of its first integrals of motion associated with the symmetries of the system. If the symmetry of the system is broken so that M becomes smaller than N, the system becomes chaotic. Unlike the trajectory, the concept of symmetry applies both in classical and quantum mechanics. The quantum analog of the first integral of motion is a "good" quantum number. It was shown [4] that while applying the Liouville-Arnold theorem to quantum systems one should not include in the M number purely quantal characteristics (e.g., parity), which disappear in the classical limit.

This approach shows that neutron resonances of compound nuclei are indeed nice examples of the quantum chaos signature since for the compound nucleus the number N of its degrees of freedom is always much larger than M. An example of the regular quantum system is given by the shell model of independent particles moving in a spherical potential field. The existence of the neutron strength-function maxima shows that some remnants of the regular shell model motion symmetries destroyed by the pairwise nuclear interaction still exist in the compound nucleus. It is shown that the single-particle resonance spreading width Γ_{spr} (to be exact, $\Gamma_{spr}/\hbar$) is a measure of quantum chaoticity, which transforms into the Lyapounov exponent in the classical limit $\hbar \to 0$.

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Electrostatic accelerator EG-5: promising neutrons source

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The Van de Graaff generator EG-5 is a single in JINR electrostatic accelerator of charge particles with energy range up to 4/1 MeV. At the moment, it is capable of accelerate a beams of protons, helium ions and deuterons up to energies of 2.1 MeV at a beam current of up to 10 μA. At the moment the preparations are going to the modernization of EG-5, after which it will reach a 4.1 MeV at a beam current of up to 200 μA.
The relatively small ion beam current makes it possible today to obtain a fast monochromatic neutrons with energy range of up to 5 MeV (reaction D (d, n) ^{3}He). After modernization, the beam current will be increased to 100-150 μA, which make it possible to obtain neutrons with energies up to 20 MeV (reaction D (T, n) ^{3}He). According to the Nuclear Data High Priority Request List [1], this energy range is highly demanded in modern nuclear physics research. At the moment, a scientific program for the post-modernization period of the accelerator operation is planning.
The study was performed in the scope of the Poland-JINR and the RO-JINR Projects within the framework of themes FLNP JINR: 04-4-1140-2020/2022, 04-4-1143-2021/2025 and 03-4-1128-2017/2022.

[1]Nuclear Data High Priority Request List: https://www.oecd-nea.org/dbdata/hprl/search.pl?vhp=on.

28th International Seminar on Interaction of Neutrons with Nuclei

Fundamental Interactions & Neutrons, Nuclear Structure,
Ultracold Neutrons, Related Topics

"The n_TOF facility at CERN: upgrade of the new target and the new NEAR Station"

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for the the n_TOF Collaboration

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[2] Tenured Professor, Universidad de Granada, Granada, Spain

Abstract

The neutron time-of-flight (n_TOF) facility at CERN was designed and constructed with the aim of measuring accurate neutron-induced reaction cross-sections data and the related physical quantities in a wide energy range. Since the startup of the facility in 2001, the measurements and instrumental developments led to more than 160 publications in refereed journals in several fields. The results of the measurements are continuously disseminated to the scientific community through the EXFOR (Experimental Nuclear Reaction Data) database with more than 116 data sets. Such datasets are often adopted for cross section evaluation by the major nuclear data libraries, such as JEFF (Joint Evaluated Fission and Fusion File), ENDF (Evaluated Nuclear Data File) and JENDL (Japanese Evaluated Nuclear Data Library). Along the years, the n_TOF physics program has been wide-ranging and, at present, covers several fields. The data provided by n_TOF, the theoretical investigations and the applied studies have been of interest in nuclear astrophysics, in advanced fission technologies with several cases covering large energy ranges, in fundamental physics and in medical investigations.

During the CERN's Long Shutdown 2 (LS2), several upgrades of the n_TOF facility have been carried out to improve the performances of the existing experimental areas and further exploit their potentials. The most important one is the construction and installation of a new third-generation spallation target. A thorough commissioning of the target and the experimental areas with beam is therefore proposed. In the first phase, the performance of the new target assembly under proton irradiation at different intensities will be studied in order to complete the target commissioning. In a second phase, a complete characterization of the neutron beam in the two experimental areas will be carried out. The upgrades of the facility will allow increased flexibility in the respective configurations of the collimator and moderator systems in both experimental areas.

In addition, a new experimental area will be available in 2021. Taken advantage of the revision of the n_TOF target pit shielding, it has be done now movable and allows direct access to the target assembly. This modification has opened the possibility of exploring the potential for a near-target irradiation as well as for a measuring station close to the spallation target (NEAR station). This would take advantage of the extremely high instantaneous neutron fluence available close to the target, few centimeters, and also at around three meters from the target. The first step in this new development would be the commissioning of the new shielding around the target with beam. NEAR station will be dedicated to studies on neutron effects on materials, electronic devices, and detectors. Also, studies on nuclear astrophysics by means of the activation technique will complement the possibilities at EAR1 and EAR2 by the TOF technique.

Development and Applications of HINEG High Intensity Neutron Sources

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Neutron sources are the important experimental platforms for the R&D of advanced nuclear energy and nuclear technology applications. The High Intensity Neutron Sources (HINEG) have been developed in China with different missions including neutronics design validation, materials & components irradiation test, nuclear waste burning and nuclear technology applications, etc.

According to the characteristics, HINEG can be divided into two series: Miniaturized series and High intensity series. The miniaturized series of HINEG include mini neutron generator with 25mm diameter and intensity of 10^8-10^9 n/s, mobile neutron source with intensity of 10^{10}-10^{11} n/s, etc. These neutron sources are developed for application in neutron logging, security inspection, radiography, etc. The high intensity series of HINEG include HINEG-I, HINEG-II and HINEG-III.

HINEG-I has achieved the fusion neutrons with the yield of 6.4×10^{12} n/s at maximum, and has been coupled with the Lead-based Zero Power Critical/Subcritical Reactor named CLEAR-0, which is actually an accelerator-driven Fusion-Fission Hybrid System. Series of typical experiments have been carried out on HINEG-I, including neutronics and code validation, core physics study of advanced reactors, neutron radiography, neutron detectors calibration, neutron biological effects, neutron radiation hardening, and so on.

HINEG-II is an accelerator-based neutron source with the yield of 10^{14}-10^{15} n/s. It aims to apply to multi-purposes, e.g. neutron capture therapy, isotope production, etc. The design and R&D for key technologies of HINEG-II are performed on-going.

HINEG-III is initially conceived as a GDT-based or accelerator-based neutron source with the intensity of 10^{17}-10^{18} n/s. The objectives of HINEG-III are to conduct test of nuclear materials, components test and reliability data collection of nuclear components, nuclear waste burning test, etc. This contribution presents an overview of the series recent activities.

Development of High Intensity Neutron Source at the European Spallation Source: the HighNESS Project

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The European Spallation Source (ESS), presently under construction, in Lund, Sweden, is a multi-disciplinary international laboratory that will operate the world's most powerful pulsed neutron source. Supported by 3MEuro Research and Innovation Action within the EU Horizon 2020 program, a design study (HighNESS[1]) is now underway to develop a second neutron source below the spallation target. Compared to the first source, located above the spallation target and designed for high cold and thermal brightness, the new source will provide a higher intensity (the total number of neutrons from the moderator), and a shift to longer wavelengths in the spectral regions of Cold (4–10 Å), Very Cold (10–40 Å), and Ultra Cold (several 100 Å) neutrons. The features of this new source will boost several areas of condensed matter research and also will provide unique opportunities in fundamental physics. Part of the HighNESS project is also dedicated to develop the future instruments that will make use of the new source and will complement the initial suite of instruments already planned at ESS. The HighNESS project started in October 2020. I will show the goals of the project, the ongoing developments and the first results obtained.

[1] https://highnessproject.eu/

Operation and Experiments of the CSNS Back-n Facility

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Abstract: CSNS (China Spallation Neutron Source) is a large scientific facility which was completed in the construction and open to general users in 2018, aiming for multidisciplinary research mainly based on neutron scattering techniques. The CSNS Phase-I includes a high-power proton accelerator complex, a target station and three neutron scattering instruments, with a proton beam of 1.6 GeV and 100 kW, which will be upgraded to 500 kW at Phase-II and twenty instruments in total. During the Phase-I construction, a white neutron facility (Back-n) which is mainly for nuclear data measurements was also constructed with multiple support resources. The Back-n makes use of the back-streaming neutrons at the spallation target, which is among the world-class white neutron beams with a very intense flux of 10^7 n/cm^2/s at a flight distance of 55 m, very wide energy spectrum of 0.1 eV to 200 MeV, and a good time resolution of less than 1% for almost the whole energy range. In the first three operation years, the Back-n has provided a beam time of 4500 hours or more per year, for wide applications from neutron-induced nuclear data measurements, detector tests, neutron imaging and element identification analysis to chips irradiations. With nuclear data measurements, five common spectrometers are available for neutron capture cross-section, total cross-section, fission cross-section, and user-owned HPGe detectors for in-beam gamma spectroscopy. More than 40 nuclides have been measured. This talk will give an overview about the operation status and the experiments that have been conducted at the Back-n. The future prospects will be also discussed.

Development of Transportable Accelerator-driven Neutron Source in XJTU

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1. Introduction

Neutrons have been widely used in many applications [1]. Due to the low cost, small size, short construction time, and acceptable neutron yield for many purposes, the development of Compact Accelerator-driven Neutron Source (CANS) technology has progressed worldwide in recent years. And outdoor neutron non-destructive testing is likely to be realized by developing a Transportable Accelerator-driven Neutron Source (TANS) based on existing CANS facilities for some specific situations, like bridge and road detection. The project of TANS in Xi'an Jiaotong University (XJTU) has been carried out. The progress about compact accelerator, target design, shielding structure and neutron backscattering radiography system is stated as follow. And the layout of every consistence is shown in Fig. 1.

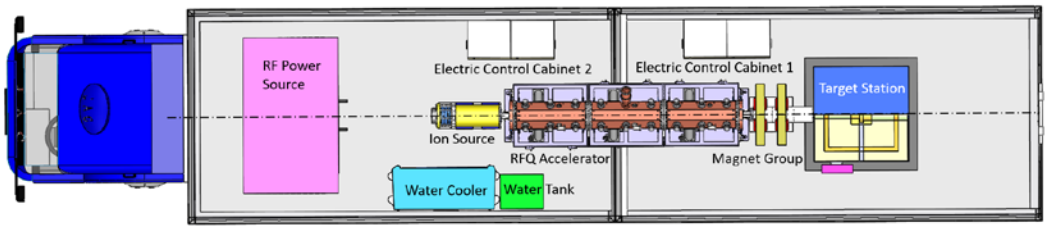

Fig. 1. Structure of the TANS

2. RFQ accelerator, target, and shielding structure

The four-vane RFQ accelerator has been adopted as its compact structure and high transmission efficiency. The whole accelerator system consists of RFQ cavity, RF power source, cooling machine, vacuum as well as generator. The working frequency of 325MHz has been selected with compromise between power consumption, cavity size and weight, as well as feasibility of construction. The RFQ was designed to accelerate the proton beam with peak current of 12mA to 2.5MeV in the acceleration efficiency above 93.2%. The RFQ length and weight were 2.6m and 1.5t, respectively. We chose the ^{7}Li (p, n)^{7}Be reaction due to its high neutron yield. Aiming at minimization on reduction in neutron attenuation and enough cooling, we proposed a new cooling configuration for a target featuring edge-cooling without flowing water in the back side to be applicable for TAN. Based on the simulation by Monte Carle code and finite element method software, the effect on neutron attenuation and cooling effect have been evaluated, and the structure and size are optimized. We optimized the reflector and the shielding design of the target station for TANS. A high-performance reflector material was selected by comparing several candidates, which aimed at enhancing the fast neutron intensity for the non-destructive testing. A compact and light-weight shielding design was optimized through a multi-objective optimization way based on NSGA-MC [2].

3. Neutron Backscattering Radiography System Based on TANS

Fig. 2 shows the simulation results of defects detection. Defects depth is 10cm, size is 5*5*5cm. Detector size is 30px*30px, pixel size is 0.5cm. Water can reflect more thermal neutron than other material, while void can hardly reflect neutron, thus, NBR can distinguish void and water by means of backscattering neutron flux and energy.

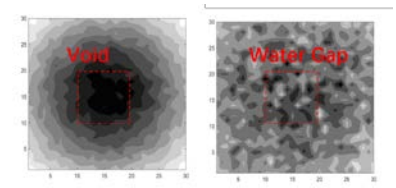

Fig. 2. NBR Simulation of Void and Water Defects

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Simulation Study of cooling system for a lithium target neutron source

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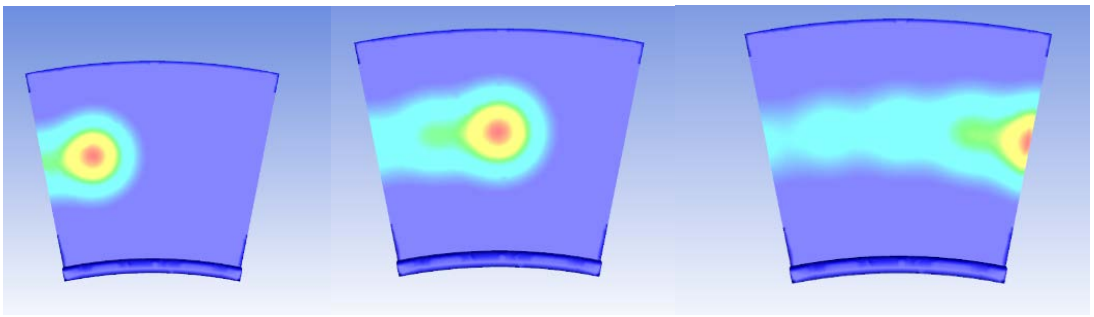
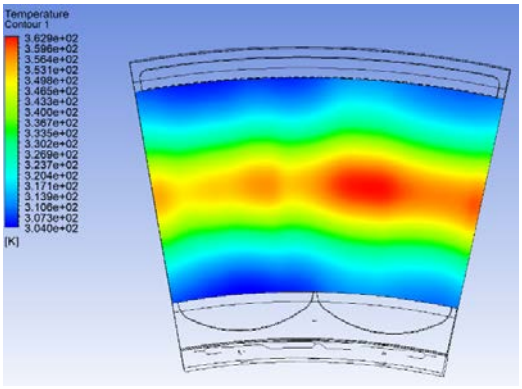
Lithium material is selected as the target of neutron source for BNCT system, which has the advantages of cheap, low energy threshold, and appropriate neutron spectrum. However, as a neutron target, high energy deposition will be formed in the front of the lithium target after low energy proton incident, so the heat dissipation of the target is a difficult problem. We design a cooper backing with micro-channel cooling circuit and trying use rotating target to solve this problem.

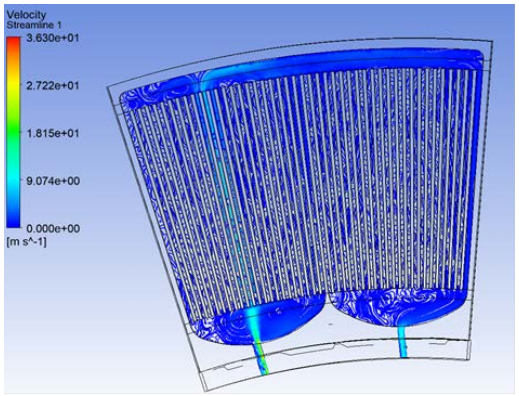
SolidWork and FLUENT are used to established a three-dimensional model and simulate the heat transfer process of the rotating target. Different cooling parameters are studied to research the influence on temperature distribution on the surface. And finding some conclusion for the future design.



Motion simulation of rotating lithium target



Temperature distribution on the surface of lithium target



Coolant flow field

Nuclear and related analytical techniques in environmental and material sciences

Investigation of $x(Fe_2O_3 \cdot Ag_2O)\cdot(100-x)[P_2O_5\cdot CaO]$ glass samples by means of PIXE, PIGE and RBS methods

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In the present work the preparation of new materials with vitreous structure, based on phosphorus and ferrum, and doped with silver, is reported. These materials have antibacterial and antifungal properties and can be used in controlled enclosures such as swimming pools, museums, polluted waters etc.

The obtained systems are new and detailed investigations of the resulted compounds are necessary [1-4].

First, for the confirmation of the compounds composition and stoichiometry, the proton induced X-ray Emission (PIXE), proton induced gamma-ray emission (PIGE) and Rutherford backscattering spectrometry (RBS) measurements with alpha beam on thick samples have been performed at the 3MV Tandetron of IFIN-HH, Magurele.

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MONITORING OF ATMOSPHERIC DEPOSITS OF TRACE ELEMENTS IN THE TERRITORY OF THE RYAZAN REGION BY MEANS OF MOSS BIOMONITORS

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The Ryazan region is a region with a high level of air pollution, which for many years has been among the regions of the Central Federal District of the Russian Federation with the highest rates of malignant neoplasms. The aim of this work is to study atmospheric deposition of trace elements in the Ryazan region in accordance with the rules of the moss surveys of the UNECE ICP Vegetation. Multielement epithermal neutron activation analysis (ENAA) at the reactor IBR-2 of FLNP JINR was used for elemental determination. Mapping based on the obtained data using GIS technologies showed the areas of deposition of heavy metals and other trace elements. Four zones of the Ryazan region are subject to increased chemical impact as a result of anthropogenic pressure caused by the activities of various local industrial, energy and motor transport enterprises, as well as by the influence of transboundary transport. The most polluted territory of the Ryazan region with the contribution of various sources is the administrative center of Ryazan and the Ryazan district. The western part of the Ryazan region is located between two large thermal power plants: Ryazanskaya GRES in the city of Novomichurinsk and Novomoskovskaya GRES in the Tula region. The agricultural south of the Ryazan region is influenced by the enterprises of the neighboring regions and agriculture. ENAA made it possible to reveal the anthropogenic origin of elements present in the atmospheric air of the Ryazan region, which are recognized as environmental pollutants: V, As, Sb, Cr, Fe, Ni, Zn, Al, *etc*. The results obtained were reported to the European Atlas of 2015 (Blinova and Frontasyeva, 2020) and can be used to assess the possible risk to public health and to develop measures for environmental protection.

Keywords: moss biomonitoring, trace elements, heavy metals, air pollution.

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First Results on Moss Biomonitoring of Trace Elements in the Central Part of Georgia

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The moss biomonitoring technique was used for assessment of air pollution in the central part of Georgia in the framework of the UNECE ICP Vegetation. In 2019 four moss species (*Hylocomium splendens* (Hedw.) Schimp. (n=4), *Hypnum cupressiforme* Hedw. (n=12), *Pleurozium schreberi* (Brid.) Mitt (n=5), and *Abietinella abietina* (Hedw.) M. Fleisch) (n=14)) were collected from 35 locations throughout the Central Georgia. Concentrations of 41 elements in mg/kg were determined by two complementary analytical techniques, epithermal neutron activation analysis (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Se, Br, Rb, Sr, Zr, Mo, Sb, I, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Yb, Hf, Ta,W, Th, and U) and atomic absorption spectrometry (Cu, Cd, and Pb).
Principal Component Analyses was applied to show the association between the elements in the study area. Four factors were determined, of which two are of geogenic origin (Factor 1 including Na, Al, Sc, Ti, V, Cr, Fe, Co, Ni, Th, and U and Factor 3 with As, Sb, and W), mixed geogenic–anthropogenic (Factor 2 with Cl, K, Zn, Se, Br, I, and Cu) and anthropogenic (Factor 4 comprising Ca, Cd, Pb, and Br).

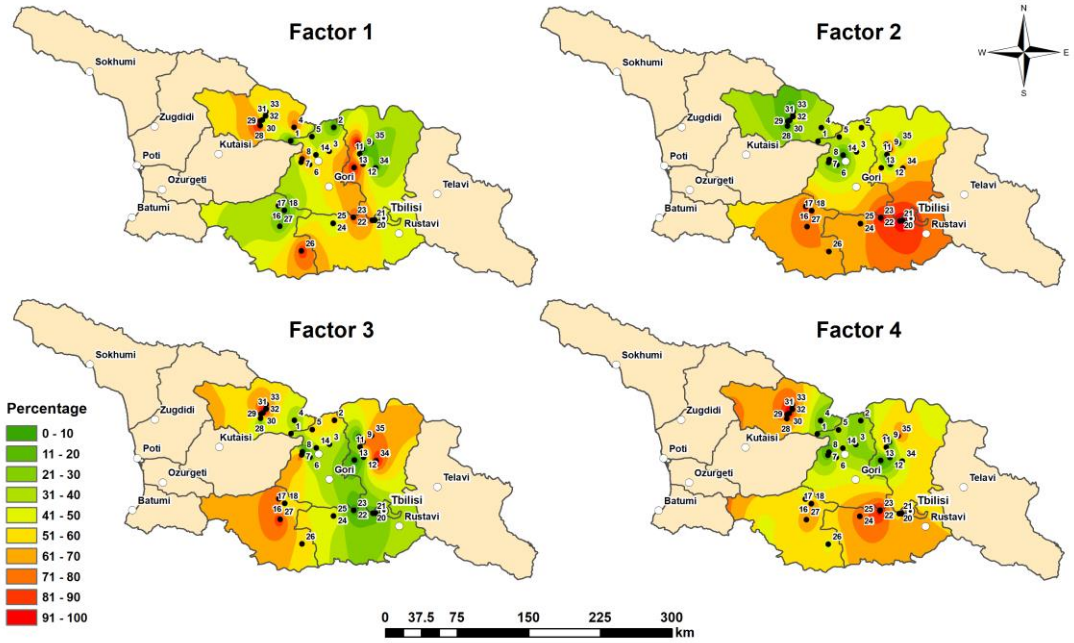

Figure 1. Factor Scores

Geographic information system (GIS) technologies were used to construct distributions maps of factor scores over the investigated territory (Fig.1). The concentrations were compared with the previous survey in Georgia and corresponding values in the literature.

Nuclear and Related Techniques in Environmental Studies

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Environmental studies, as an active field of scientific investigation, have been very actual since 60′, when the influence of an accelerated industrialization and urbanization showed a negative influence on environment and by consequence, on the human society.

Among the different aims, environmental studies have essential contribution to pollution control and mitigation. Consequently, a more high precise and accurate analytical techniques such as Instrumental Neutron Activation Analysis, Graphite Furnace Atomic Absorption Spectroscopy or Gamma-ray Spectroscopy were used in conjunction with advanced statistical methods of data analysis. Such kind of investigations were systematically performed in the past decades at the Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research in Dubna, Russia, as well as in partner research centres.

A significant amount of work was assigned to biomonitoring performed by analysing the content of presumably contaminating elements *e.g.* V, Cr, Mn, Co, Ni, Zn, As, Sb, Sn, Ba, Cd, and Pb in both vascular evergreen and rootless plants as well as lichens collected from a great diversity of environments beginning with pristine Antarctica islands, going through Egyptian densely populated areas, Black Sea euxinic sediments and Moldavian orchards up to Central and Western Tajikistan high montane valleys.

Associated with INAA determinations, Alpha, Beta and Gamma ray radiometric measurements were helpful in identifying the presence of Th and U enriched afloriments in central Tajikistan or the age of recent Black Sea sediments. In the last case it was possible to establish an absolute geochronology of the recent, 1000 y old sediments and to evidence a continuously accumulation of the presumably contaminating elements in the past 150 years, a testimony of the industrial development of Central ans Eastern countries, where the environmental pollution has been completely neglected.

At the same time, INAA trace elements distribution and the corresponding Discriminant Analysis allowed determining the location of the different types of wine according to the vineyards they were picked up.

Inorganic elemental characterization of coastal sediments along the Egyptian Mediterranean Sea

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Abstract

A comprehensive investigation of the elemental compositions of the sediments along the Egyptian Mediterranean Sea was carried out. A total of 99 marine sediment samples were collected from three sectors along the coastal areas (Rashid, Elbrullus, and Ras ElBar) subjected to the instrumental neutron activation analysis. A total of 39 elements namely, Na, Mg, Al, Si, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, As, Br, Rb, Sr, Zr, Mo, Sn, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Dy, Yb, Lu, Hf, Ta, Th, and U were determined. The concentrations of the determined elements in mg/kg were calculated, compared with the corresponding values regionally and worldwide, and statistically treated. Bivariate and multivariate statistical analyses were employed. The quality of the sediments was assessed using different pollution indices such as contamination factor, enrichment factor, geoaccumulation index, and pollution load index. The spatial distribution of the pollution load index and total pollution index was mapped and areas of significant pollution were depicted (River mouth of Damietta, ElBurullus Lake, and curvature of Abu Qir). The obtained results may serve as geochemical background values of the coastal sediments along the Egyptian Mediterranean Sea.

Keywords: *major and trace elements/ coastal sediments/ NAA/ statistical analysis/ pollution indices*

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Distribution and migration of trace elements in industrial soils studied by neutron activation analysis and X-ray fluorescence analysis

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Heavy metals and toxic elements originated from natural and anthropogenic sources are widespread in all the environmental compartments, including soil, and can be transferred in food chains and human body through bioaccumulation and bioconcentration, affecting people's health. Moreover, their migration in soil depth in the regions affected by metallurgical industry could have important impact on underground water and aquatic resources. Thus, the management of soil quality in industrial areas is very important for ecosystems and human health and, for this aim, sensitive techniques should be employed for precise assessment of chemical elements in soil.

In this paper two analytical techniques: instrumental neutron activation analysis (INAA) and X-ray fluorescence analysis (XRF) were used in combination for the determination of total concentrations of 43 major, minor and trace elements (Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Co, Cu, Zn, As, Br, Rb, Sr, Y, Zr, Nb, Mo, Sb, I, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Dy, Tm, Yb, Hf, Ta, W, Au, Hg, Pb, Th and U) in soils located around a large integrated steelworks in Romania.

INAA was applied at IBR-2 nuclear reactor of Frank Laboratory of Neutron Physics (FLNP), Joint Institute of Nuclear Research (JINR) at Dubna, Russian Federation and XRF (Genius spectrometer, Skyray Instruments Inc.) at INPOLDE interdisciplinary international research center of "Dunarea de Jos" University of Galati (UDJG), Romania. Experience in applying non-destructive nuclear analytical technique INAA in industry, geology, materials science and environmental studies was presented in previous joint scientific contributions and Romania-JINR project reports.

The obtained results for various depths were used to assess the migration degree of selected elements in the soil matrix along the depth (0-30 cm) and distribution patterns.

On-going work is carried out to enlarge the elemental range in industrial soils using complementary nuclear and atomic techniques, such as atomic absorption spectroscopy, inductively-coupled plasma mass spectrometry and ion beam techniques.

Multielemental characterization of industrial wastes and soils by ion beam analysis techniques

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Trace and toxic elements present in industrial waste materials and soils negatively affect the environment and ecosystems health and, for their quantification, high precision analytical techniques should be employed.

In this paper two ion beam techniques, Particle Induced X-Ray Emission (PIXE) and Particle Induced Gamma-ray Emission (PIGE), were used in combination for the determination of total concentrations of several major, minor and trace elements in various industrial wastes and soils located around chemical and metallurgical industry in Romania.

Thick target PIXE and PIGE were applied at the 3 MV Tandetron at Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), Romania, using a 3 MeV proton beam as projectile particles. The elements determined by PIXE were: Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Br, Rb, Sr, Ag and Pb. In the case of PIGE, the elements of interest F, Na, Mg, Al, Si, Mn and Fe were determined based on the nuclear reaction of (p,p′γ) type of the protons "p" on the target samples, as well as on the (p,nγ) type reaction in the case of Mn.

The non-destructive multielemental techniques proved to be very useful for the waste management and hazards monitoring in environment and identification of a large series of trace elements in environmental complex studies, some of them being toxic for living organisms and humans and others contributing to the elemental cycling in natural environments.

The obtained results will complete the compositional schemes obtained by using X-ray fluorescence (Genius XRF spectrometer, Skyray Instruments Inc.) for the investigated materials at INPOLDE interdisciplinary international research center of "Dunarea de Jos" University of Galati (UDJG), Romania.

Monitoring long-term and large-scale deposition of air pollutants based on moss analysis

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A brief historical review is given on the development and milestones of the moss biomonitoring technique used to study atmospheric deposition of trace elements, nitrogen, persistent organic pollutants (POPs);d radionuclides of technogenic and natural origin in Europe, as well as cosmic dust. The relevance of these studies to the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP) is shown. Examples of the long-term activity of the ICP Vegetation (International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops) established in 1987 are given to illustrate the tendencies in behavior on a large scale of air pollutants such as heavy metals, nitrogen and persistent organic pollutants (https://icpvegetation.ceh.ac.uk/). In agreement with the long-term strategy of the LRTAP Convention to enhance participation and improve air quality in Eastern Europe, the Caucasus, Central Asia, and South Eastern Europe, efforts to extend the moss survey to former republics of the USSR such as Armenia, Azerbaijan, Georgia, Moldova, Kazakhstan, and Uzbekistan were successfully undertaken. Around 15 teams were formed in Russia to cover moss sampling in Northern and Central Russia, Western Siberia, and the Far East of Russia (Kamchatka and Sakhalin). To date, 42 countries, expressed their desire to participate in the 2020-2021-2022 moss survey. Analytical methods and approaches to data interpretation are reviewed. China is very welcome to join the UNECE ICP Vegetation.

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NEUCLEAD AND RELATED ANALYTICAL TECHNUQUES FOR STUDYING THE PROSPECTS OF USING ECHINOCHLOA FRUMENTACEA FOR PHYTOREMEDIATION OF SOILS WITH GEOCHEMICAL ANOMALIES

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The prospects of using japanese millet on urban soils with polyelement anomalies have been studied using nuclear and related analytical techniques INAA and ICP-MS. The plants were grown for six months in a model laboratory experiment on the soils of the sanitary protection zones of metallurgical industries and highways of the city in closed ornamental flowerpot under laboratory conditions: lighting was natural, temperature was 20-25 °C. To avoid possible additional introduction of elements with irrigation, the plants were watered with distilled water. Characteristics of the urban soils on which the plants were grown: the Kosogorsky metallurgical plant (KMP) soil was characterized by a high content of Fe (78100 mg / kg), an excess of MPC for Mn (3.8 - 4.4 times), and Zn (41%); Tulachermet soil was characterized by a very high content of Fe (120600 mg / kg), exceeding the MPC (APC) for V-Mn (by 40-50% for V and 10% for Mn), Ni (by 110-175%), Cu (by 127%), Zn (by 29-192%), As (by 115-220%) and oil products (by 4 times); the soil of Lenin Avenue. was characterized by a high content of Fe (37400 mg / kg), exceeding the permissible concentrations of Mn (by 6%), Cu (by 186%). As a control, the soil from the territory of the L.N. Tolstoy Yasnaya Polyana was used. In the background soils, the excess of the MPC and APC for the standardized elements was not observed. In the course of the research, it was found that the content of soil pollutants in the japanese millet shoots was: V- 0.12-12.2 mg / kg of dry matter. Cr - 1.5-18.5 mg / kg of dry matter. At the same time, the accumulation of the element by plants grown on the Tulachermet soil was 100 and more times higher than the control values. Mn accumulation did not depend on the degree of contamination by the soil element and amounted to 107-181 mg / kg of dry matter. The accumulation of Fe in the shoots of japanese millet ranged from 200 to 6470 mg / kg of dry matter, and on the soils of PAO Tulachermet exceeded the average values in the soils of the world by 2 times, the toxic content for plants by 13 times. However, taking into account the abnormally high values of the element in the soils of the SPZ of Tulachermet, the transfer factor of the element was 0.05. The Ni content in the shoots of japanese millet grown on experimental soils was 3.3 - 11.7 mg / kg and was the maximum for Tulachermet soils. The Zn content in the shoots of the japanese millet grown on the soils of the background zone was 30 mg / kg of dry matter. On the soils of the SPZ of metallurgical enterprises it was 4 times higher: 124-126 mg / kg of dry matter. The As content in the japanese millet shoots on soils with geochemical anomalies varied from 0.21 to 2.02 mg / kg dry matter and was maximum for the soils of Tulachermet. The copper content in the japanese millet shoots on the soils of the background zone and KMP differed insignificantly and amounted to 12.5-13 mg / kg. The results of the study made it possible to establish that japanese millet is a promising crop for phytoremediation of soils from V, Cr, Fe and Zn on soils with geochemical anomalies in the complex of heavy metals.

Acknowledgement. *The study was carried out with the financial support by the Russian Foundation for Basic Research project No 19-29-05257 "Technogenic soil pollution with toxic elements and possible methods for its elimination"*

ENAA and SEM Investigations of Carbonaceous Meteorites of Potential Relevance to Astrobiology and the Distribution of Biospheres

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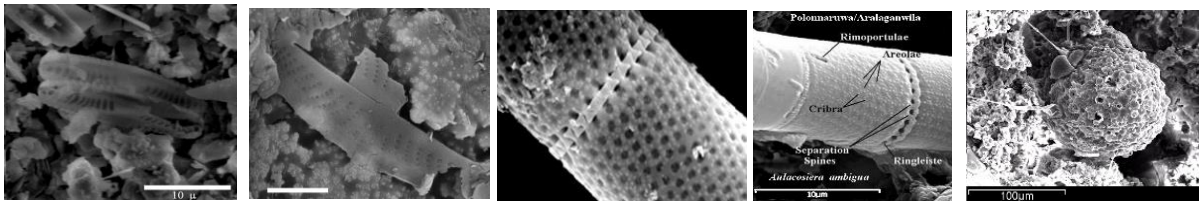
The origin and distribution of biospheres is one of the great unanswered questions of Science. The accepted paradigm is that Earth's biosphere arose after long, slow process of abiotic synthesis of organics and complex biomolecules in the primordial atmosphere and oceans resulted in the development self-replicating living cells. The alternative Hoyle-Wickramasinghe cometary panspermia hypothesis has gained support by recent discoveries of indigenous microfossils in meteorites and biological fractionation of carbon isotopes in clasts entombed in 4.4 Ga Jack Hills zircons. Evidence for life on Earth soon after the planet cooled leaves no time for a long, slow chemical and molecular evolutionary process anywhere in our Solar System. Hence the possibility that Earth life may have originated in ancient extrasolar planets and was delivered to Hadean Earth by interstellar comets merits consideration. SEM studies [**1**] at NASA/MSFC, Cardiff Univ. and LRB/JINR have shown the Orgueil (CI1), Murchison (CM2) and Polonnaruwa (C-Ung.) meteorites contain astonishingly well-preserved indigenous remains of extinct diatoms, cyanobacteria and hystrichospheres (Fig. 1).



a. **b.** **c.** **d.** **e.**

Fig. 1. Fossil diatoms in **a. b.** Orgueil; **c.** terrestrial diatom *Aulacoseira segariana*; **d.** Polonnaruwa morphotype of *A. segariana*; **e.** Hystrichosphere embedded in Polonnaruwa/Aralaganwila meteorite.

Epithermal Neutron Activation Analysis (ENAA) of carbonaceous meteorites at FLNP/JINR revealed the low-density Polonnaruwa stones have extremely high levels of long-lived, incompatible radiogenic Heat Producing Elements (^{40}K, 1.2 Ga; ^{238}U, 4.5 Ga; ^{232}Th, 14 Ga) [**2**]. They are unlike all known meteorites, but possess non-terrestrial oxygen isotope ratios, fractured zircons and Maskelynite consistent with asteroidal impacts bearing similarities to the Apollo 14 VHK Lunar KREEP basalts **[3]** and low-density boulders on asteroid Ryugu. These discoveries provide important insights for a possible mechanism for the interstellar cometary transfer of viable biospheres between extrasolar planets within the Galaxy and beyond.

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Effect of thermal annealing on the depth distributions of the atoms and optical constants of near surface layers the implanted GaAs with In^+ ions

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Abstract

SI (100) GaAs surfaces were irradiated with indium ions. The dose and energy of implanted ions were $3x10^{16}$ cm^{-2} and 250 keV. The implantation process was performed at room temperature. The surfaces of all samples were covered with layers of Si_3N_4. The protective layers had the thickness about 100 nm. Thus prepared samples subjected to thermal annealing. The heating time was equal to 2h and the annealing temperatures were 700 ^{o}, 750 ^{o}, 800 ^{o}, 820 ^{o} and 850^o C. The material prepared in this way was subjected to Spectroscopic Ellipsometry (SE) measurements and were obtained the optical constants for implanted and virgin GaAs. In the next step of the investigations carried out Rutherford Backscattering Spectrometry (RBS) method measurements. Based on RBS spectra, the sub-surface atom depth profiles for the all samples were determined. As the annealing temperature increases, the optical constants values of the individual samples are changing. This effect can be attributed to the reconstruction of the material after the implantation process and possibly the formation of new chemical compounds. The last problem will be the subject of further research.

Keywords: ion implantation, Rutherford backscattering spectrometry (RBS) Spectroscopic ellipsometry (SE).

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Application of Nuclear and ICP-AES analytical techniques in atmospheric deposition study

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Abstract: Neutron activation analysis (NAA) is a multi-element non-destructive method, characterized for good detection limits for most of the elements, and a matrix-independent method with the absence of the analytical blank that makes it very useful in environmental studies. NAA shows high accuracy, low systematic error, and low detection limits during the quantitative analysis that makes it very efficient in trace analysis of the elements in environmental samples such as soil, water, biota, and air samples. ENAA and ICP-AES analysis in combination with the moss biomonitoring were used to assess the air quality in Albania. Air pollution is a global problem that may cause undesirable consequences to human health and environmental ecosystems. It is responsible for the increase of the greenhouse effect in the atmosphere, global warming, climate change, and acid rain.

The analysis of 54 elements in moss samples of Albania was determined by INAA method in Frank Laboratory of Neutron Physics Joint Institute for Nuclear Research, Dubna, Russian Federation. ICP-AES analysis of was performed in the Institute of Chemistry, Faculty of Science, Ss. Cyril and Methodius University, Skopje, North Macedonia. Moss biomonitoring survey in Albania started on 2010 and continued on 2015, in the same period with the European moss survey for trace metals in atmospheric deposition. Due to the isolation from the global Covid-19 pandemic, the sampling of 2020 moss survey is postponed to the summer 2021. Toxic metals that present high risk to human health via different exposure pathways and to the environment, as well as the metals derived from soil dust mineral particles in the atmosphere are discussed in this study. Moss biomonitoring of atmospheric deposition involves the content of the metals in the green and/or green-brown parts of the moss tissues that represents the 3–5 years of moss growth period. In such a way, it represents the spatial and temporal trend of the integral survey of the deposition, and the exposure concentrations should be representative as a long-term average.

Significant differences were found onto the concentrations of Al, As, Cd, Cr, Co, Ni and Pb in moss samples, followed with various distribution patterns for different elements that present diverse geographical variability in the moss metal concentrations and metals atmospheric deposition. The anthropogenic emission sources and soil dust associated with the windblown fine mineral dust particles are pointed as possible local emitting sources of trace metals atmospheric deposition. The median values of the carcinogenic risk CR_{2010} and CR_{2015} are compared with the carcinogenic target risk value (1×10^{-6}), and the CR unacceptable value ($CR > 1 \times 10^{-4}$). Recent studies onto air pollution are discussing the relationship between the Covid-19 mortality and air pollution from all anthropogenic sources. A reasonable correlation between the number of Covid 19 infected people and the air PM content of European countries is suggested in this study.

Keywords: Neutron activation analysis, ICP-AES analysis, trace metals, air pollution, moss biomonitoring, health effects, Albania

Impact assessment of copper salts on various plants

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Copper salts are used in many different commercial products, such as fertilizers, fungicides and bactericides, and can enter soil as a result of contamination after production, distribution and industrial use or use as fertilizer. Introduction to soils can occur in the form of pesticides due to their antimicrobial properties, as well as fertilizers to increase the load of basic metals in plant tissues.
Fertilizer use should ensure that application rates do not result in phytotoxicity. Dose-dependent phytotoxicity has been observed in several crops, including wheat, *Triticum aestivum*, when grown hydroponically or in sand. On the other hand, copper is an essential element for the normal growth of plants, playing an important role in a number of physiological processes. In excessive amounts, copper is very toxic to plant growth, which leads to physiological disturbances that impede plant growth. In this work, we studied the effects of copper salts on biologically active compounds and ultrastructure of various plants. Changes in the elemental composition, concentration of assimilating pigments, concentration of polyphenols, antioxidant capacity, and ultrastructure of plants grown in the presence or absence of copper salts were evaluated.

Acknowledgment: The work was financed in the framework of Romanian-JINR cooperation.

Distribution patterns of major and trace elements in gold mines using neutron activation analysis - Egypt

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Abstract

The present work was conducted to outline the elemental composition of soil samples from some selected gold mines in Egypt namely; Sukari and Hamash mines. Sukari and Hamash granitoid pluton are situated in the Central Eastern Desert of Egypt and is considered one of the best examples of the gold-bearing granites in the Arabian Nubian Shield. A total of 19 and 20 soil samples were collected from Sukari and Hamash, respectively. The samples were collected according to the International Atomic Energy Agency TECDOC-1415. The samples were subjected to neutron activation analysis at the reactor IBR-2 Frank Laboratory of Neutron Physics FLNP – Joint Institute for Nuclear Research JINR. A total of 32 and 26 elements were determined in Sukari and Hamash, respectively. In addition, the concentrations of the determined elements in mg/kg were calculated using a developed software at FLNP – JINR. The quality of the measurements was weighted using certified reference materials. The basic descriptive statistics was performed and the obtained concentrations were found to be considerably high for rare earth elements and U in both gold mines. The obtained data are considered as a baseline data for characterizing the gold mines in terms of the elemental content of the soil.

Keyword**:** *neutron activation analysis/ major and trace elements/ gold mines*

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Macro and microelements in soft tissues and shells of South African mussels: from consumption risks to regional patterns

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Neutron activation analysis performed at the REGATA facility of the reactor IBR-2 was used for determination of macro- and microelements in soft tissues and shells of 12 sets of mussels from the South African coastal zone. The method fits well for determination of specific groups of elements, which allows estimation of the significance of terrigenous and anthropogenic factors, found by key element-markers. Moreover, the neutron activation analysis could be useful for the analysis of threshold levels of elements in the meat of mussels in the study of risks of their consumption by population.

Wild and farmed South African mussels in coastal zone grow under the constant pressure of anthropogenic loadings. The mussels from the key zone of our study in Saldanha Bay (West Coast of South Africa) undergo influences of natural storms and tidal activities and could accumulate the suspended material from sources of pollution in the harbor. In previous biomonitoring studies (Bezuidenhout et al., 2020) it was found that the levels of trace elements, which indicate pollution in mussels collected at the farms and relatively pristine areas decreased for the last decade.

Regional patterns could be revealed by analysis of ranges of specific groups of elements. According to our study (Nekhoroshkov et al., 2021), the high concentrations of the elements of terrigenous origin, Al, Sc, Ti, V, Cr, Mn, Fe, Co, Th, U, in soft tissues of mussels collected from the East Coast of South Africa could be associated with the climatic features of the subtropical zone.

At the same time, the soft tissue of mussels could be used as a food source, especially in rural areas. Based on our study (Nekhoroshkov et al., 2021) the levels of Al, Cr, As, and I can increase the health risk when the consumption of mussel meat exceeds 250 g/week per person.

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Analysis of PM_{10} from the air quality monitoring using INAA

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Even though the air quality in the studied region (the Czech-Polish region located in the northeast part of the Czech Republic) has improved since 2000, the level of PM_{10} concentration is not satisfactory and still exceeds the air pollution limits. Pollution in this area varies due to meteorological conditions, pollution sources, and geographical conditions. Measured data were gained by the high-volume sampler (SAM Hi 30 AUTO WIND) which captures PM_{10} on glass fiber filters (Whatman GF/A, Ø 150 mm) depending on wind conditions. Thus, the sampler can collect particles from eight basic wind directions, during calm and smog situations. The sampling device is located cca at 90 m above the ground level. Due to that, the local pollution sources (such as public transfer) do not affect the measurement, and the transmission of the pollution within the region can be investigated.

Instrumental neutron activation analysis was used to determine the elemental composition of sampled PM_{10}. Twenty samples and two field blank filters (from September and December 2019) were analyzed. Mass fractions of 21 elements from September and 19 from December were determined. Because the glass fiber filters have high blank values not all elements could be used for further analysis. Elements were processed using a PCA and correlation analysis, which enabled together with meteorological data, to find out the pollution sources. It was found that pollution came from the southwest/west direction during September and originated most likely from the metallurgic complex (steel and iron production, coking plant, metal foundry, generation plant). In December pollution came from the north/northeast direction. This pollution is connected to the transboundary transfer from Poland and originated possibly from local heating, coal combustion, and metallurgy.

The present work may be served as baseline data to follow up any potential dynamics in the future.

USE OF NEUTRON ACTIVATION ANALYSIS TO CHARACTERIZE PM_{10} SAMPLED ON THE TOP OF A FORMER MINING TOWER

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ABSTRACT

In order to characterize the pollution in a heavily polluted region in the Czech-Polish borderland (Ostravsko-karvinská agglomeration) and to identify the pollution origin, the Instrumental Neutron Activation Analysis (INAA) was employed. Specially designed high-volume sampler (SAM Hi 30 AUTO WIND) was used to collect PM_{10} samples in dependence on airflow conditions. The sampler was located on the top of a former mining tower in 90 m AGL. This allowed the elimination of the influence of local sources and investigation of the regional pollution transport. From April 2018 to March 2019, 111 PM_{10} samples from eight basic wind direction, calm and 2 smog situations were sampled. The sampled particulate matter was analysed using the neutron activation analysis providing information on the content of 34 elements. This information – together with the PM_{10} concentrations and meteorological data (measured and modelled) – was used to characterize the pollution origin in the region. A significant difference in the element composition was observed – elemental concentrations were dependent on both the season and the sampling direction. Contribution of three industrial sources, two ironworks and a cement plant was identified, showing that – though not detected by ground air pollution monitoring – these sources have a significant impact on the pollution transfer in the region. The measurements also confirmed that the PM_{10} cross-border pollution inflow from Poland plays a crucial role during the winter season and contributes significantly to the air pollution in the studied region.

Complex investigation of the 12th-century wall painting in Pskov Mirozhsky Monastery by complementary physical and chemical methods

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Mirozhsky Monastery is the 12th-century Russian Orthodox monastery complex in Pskov, Russia. Murals of its Christ's Transfiguration Cathedral are unique monument of ancient Russian art. The integrity of frescoes complex is the most complete among the monumental painting of the 12th century. The history of the study and restoration of Christ's Transfiguration Cathedra goes back more than 150 years. During the XX century, murals have undergone all the stages of the formation of restoration science. Despite the fact that the monument was always in the cross hairs of researchers, some of the ancient paintings are still hidden under a layer of renovation, and restoration work has not been completed. A comprehensive scientific study of the monument is of great importance not only to analyze how murals were performed, but also to understand what mark have been left by the materials used by restorers throughout the 20th century, and predict the consequences.

To achieve veracious results a complex of four physical and chemical methods was used: X-ray fluorescence analysis (XRF), optical microscopy (OM), Fourier transform infrared spectroscopy (FTIR) and spot qualitative test microanalysis.

More than 180 spectral data were collect directly in the cathedral using portable XRF spectrometer Tracer 5i (Bruker). The elemental composition of more than 80 pigments plaster bases and mortars has been determined. The analysis of the elemental composition revealed the main pigments used. They are yellow and red ocher, green earth, lapis lazuli, lime white, red lead and others.

Seven samples were examined with optical microscope Polam-215 (Lomo) to determine the number of used pigments or to detect several layers of painting. So, the main component of green color is glauconite. The required hue was achieved with small additions of goethite, lapis lazuli and malachite. The burgundy color was obtained using a composition of hematite and lapis lazuli.

About twenty samples were analyzed using FTIR spectrometer Invenio-R (Bruker) to define the type of organic binders. To concentrate the micro-content of organic substances, water and chloroform solutions were prepared which make it possible to extract polar and non-polar substances, respectively. For painting of different centuries various organic binders have been identified, such as casein, egg white, egg yolk, oil. Vegetable glue based on polysaccharides/ carbohydrates was found in various plaster samples.

Spot test microanalysis based on different anions qualitative reaction was performed. Sulfates and carbonates were found, but nitrates were not detected.

Also of great importance is a comprehensive study of the scientific study of the monument, not only in order to analyze how the paintings were made, but also what mark the materials used by the restorers have left during the 20th century, and to predict the consequences.

On-line analysis of the mineral materials on conveyer by tagged neutrons method

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Tagged neutron method (TNM) was used for elemental analysis of the mineral materials, (sinter, phosphorus ore, coal etc) on conveyer. The neutron module was situated under the conveyer belt. It comprises the neutron generator with in-built alpha detector and two blocks of gamma-detectors.

The neutron generator is a sealed tube portable neutron generator with a built-in alpha-detector. The generator provides a continuous neutron flux of 14.1 MeV with an intensity of 5×10^7 s^{-1}. Power consumption of the neutron generator is 40 W. The lifetime of the generator is 800 hours. The built-in silicon alpha-detector is a 3 × 3 matrix with a pixel size of 10 × 10 mm.

To register γ-quanta arising from irradiation of ore by fast tagged neutrons, we used 14 γ-detectors based on BGO crystals with a diameter of 76 mm and a thickness of 65 mm. The γ-detectors was placed in two thermostat modules.

For analysis, the gamma spectrum of each sample was decomposed into individual components by fitting it with the sum of the reference gamma spectra from 8 elements: Si, Mg, Fe, Al, Ca, C, O, P, which were measured in advance.

Thus, the mass concentration of an individual element was initially determined, then, for comparison with the data of chemical analysis, a conversion into masses of oxides was made.

The results of measurements are discussed.

ACTIVE MOSS BIOMONITORING STUDY IN DONETSK REGION (UKRAINE)

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The active moss biomonitoring technique was applied to assess the environmental pollution in the Donetsk region and to compare the biomonitoring capacity of acrocarpous *(Ceratodon purpureus)* and pleurocarpous (*Brachythecium campestre)* moss transplants. Moss bags were exposed for six months in the surroundings of two steelworks, a power station, and two parks. The concentrations of 19 elements were determined in the moss transplants by neutron activation analysis and atomic absorption spectrometry. Various environmental indices − relative accumulation factor, contamination factor, pollution load index, enrichment factor, and ecological risk index were used to quantitatively assess the degree of ambient contamination. The RAF values indicate that the most prevalent elements in *Brachythecium campestre* and *Ceratodon purpureus* were Na, Al, Ca, Fe, Ti, V, Cr, Mn, Co, Ni, Zn, Ba, Sr, Pd, and Cd. The results showed a significant difference between metal accumulation by *Ceratodon purpureus* and *Brachythecium campestre* indicating various mechanisms of uptake. All elements were highly correlated in *Ceratodon purpureus*. The main air pollution sources in the region can be considered the Zuivska power station (Zuivska TES), Donetsk Metallurgical Plant, Yenakiieve Iron and Steel Works.

Key words: active moss biomonitoring, *Ceratodon purpureus*, *Brachythecium campestre*, air pollution, urban area, neutron activation analysis, atomic absorption spectrometry, Donetsk region

Application of neutron resonance capture analysis for the investigation of the element composition of the panel of the triptych (presumably 17th century)

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The method of Neutron Resonance Capture Analysis (NRCA) is currently being developed at the Frank Laboratory of Neutron Physics (FLNP) [1]. The method is fully non-destructive it can be used to determine the bulk composition of objects without preparation or sample taking. The NRCA is based on the registration of neutron resonances and the measurement of the yield of reaction products in the resonances.

In this work we describe the application of NRCA for the investigation of an archeological object transferred to the FLNP by the Museum and Exhibition Complex (MVK) "Volokolamsk Kremlin". The object was the panel of the triptych (presumably 17th century) which was found in the Moscow region, Volokolamsk district, village Chubarovo.

The experiment was carried at the Intense Resonance Neutron Source (IREN) facility with a multi-sectional liquid scintillator detector which was used for the registration prompt gamma-quanta and was created at FLNP JINR [2, 3].

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Elemental composition and toxicity of waters of the transboundary rivers of Kazakhstan

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Since spring 2007, the INP ME RK jointly with the RSE "Kazhydromet" has been performing the activities on survey and monitoring of the radiation and environmental situation in 15 border sections of the rivers flowing into the territory of Kazakhstan (see Figure 1). The methodology, developed by the team of the scientists from Central Asia (Kyrgyzstan, Uzbekistan, Tajikistan, Kazakhstan) and the United States, is used in the process of survey of the transboundary rivers Syrdariya and Amudariya under the International Project "Navruz". Sampling of the environmental objects at the specified control points (CP) is carried out annually, in spring and autumn. The radionuclide and elemental composition of soil, bottom sediments and water samples is determined in the laboratory conditions using the IGS, RChA, NAA, XRF, MS-ICP and OES-ICP methods

The report provides the results of the study of elemental composition of the water samples collected at these 15 CPs in the period of 2016-2020. The values of more than 30 elements were determined by the NAA, MS-ICP and OES-ICP methods. According to the obtained data, it was established that the highest concentrations of such toxic elements as As, Ba, Li, Mo, Sb, Sr, U correspond to the waters of the rivers of South and South-East Kazakhstan (Emel, Shu, Syrdariya and especially Karabalta). The highest content of Cr, P and the high content of Sb and As were revealed in the waters of the Ural, Chagan and Ilek rivers. It was also established that the waters of the Tobol and Ayat rivers are characterized by the highest content of Ni, Co, Zn and Fe. The content of Ca, K, and Mg in most of the studied water samples significantly exceeds the corresponding clarke values.

The values of total toxicity (the limiting hazard indicator - K_{HL}) of all studied waters were calculated in accordance with the methodology, established by the "Sanitary Rules of the Republic of Kazakhstan". The calculations were performed based on the concentration of U (element of hazard class 1) and As, B, Ba, Li, Mo, Pb, Sb, Sr (elements of hazard class 2) in these waters. The values of MAC_{WHO} (for Li and Sr – MAC_{RK}) were used for most of them. The result, based on the average values of these elements in spring and autumn are provided in Figure 1. From the scheme it follows that the K_{HL} indicator at most of the control points exceeds the sanitary standard of 1.0. The waters of these rivers are in critical condition in terms of chemical toxicity and exposed to many risks of additional contamination in the neighboring countries (Russia, China, Kyrgyzstan, Uzbekistan and Tajikistan).

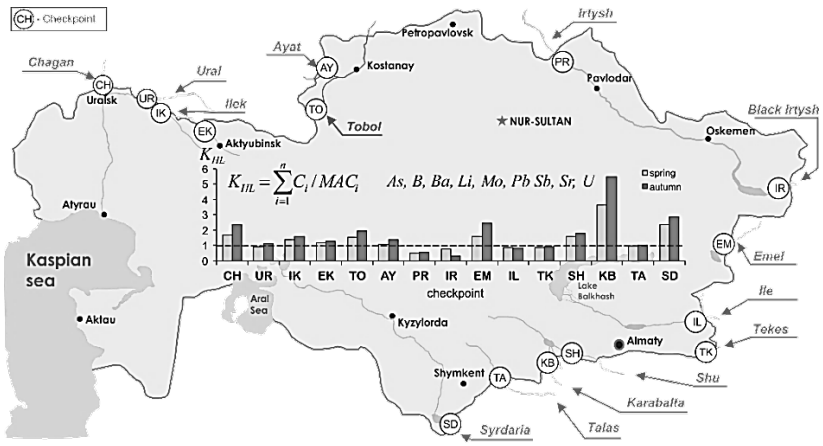

Figure 1. Scheme of the transboundary rivers monitoring in Kazakhstan. Chemical toxicity of waters of these rivers (center)

Temporal trends of heavy metals air pollution in Romania assessed by neutron activation analysis, complementary atomic techniques, and moss biomonitoring

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The first moss survey at the Romanian scale was conducted in 2010 and has been repeated after five years, in the framework of the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation).

An international research network was developed for the investigation of heavy and trace element atmospheric deposition, based on the research projects jointly implemented by the Romanian partners "Valahia" University of Targoviste (UVT) and "Dunarea de Jos" University of Galati (UDJG), and Joint Institute for Nuclear Research (JINR) at Dubna, Russian Federation.

The moss surveys undertaken in 2010/2011 and 2015/2016 campaigns comprised 303 and 214 sampling sites, respectively, over the Romanian territory.

A total of 29 elements: Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu*, Zn, As, Rb, Sr, Cd*, Sb, Ba, Cs, La, Ce, Sm, Tb, Pb*, Th and U, were determined in mosses samples, in the large-scale concentration range: from 10000 mg/kg for Al, Fe, Ca and K to 0.001 mg/kg for some rare earths — by two complementary methods: INAA at the IBR-2 reactor in JINR and GFAAS/FAAS* in 2010 and ICP-MS* in 2015 at Institute of Multidisciplinary Research for Science and Technology of UVT, Romania.

The temporal trends for median concentration of selected metals revealed a decrease in 2015 for all elements; in the case of mean concentration, there was a decrease in 2015 for Zn, Cd, Cu, and Pb and a slight increase for V, Cr, Fe, and Ni.

Statistical processing of data was carried out at INPOLDE research center of UDJG. Maps of metal load in mosses were generated by Data Management System on the cloud platform of JINR Dubna.

A new campaign already started in the summer of 2020 and moss samples were collected from 128 sampling sites, the sampling work continuing in the summer of 2021. Through the existing research network, the heavy metals concentrations in mosses will be determined to complete the temporal trends of heavy metals air pollution and report to ICP Vegetation.

Instrumental Neutron Activation Analysis (INAA) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for the Analysis of Bones of Prehistoric Animals and Humans

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Bones of prehistoric animals and humans have always been a precious source of archeological information and can be frequently abundant in archeological sites. Much of interest is in their elemental composition because it can open the way for better understanding of the prehistoric environment, including climate, and also the biochemistry of the species of that time. Due to long-term contact of skeletons with soils, up to several millions of years, to decipher the true elemental composition, it is important to understand the processes of migration and accumulation of these elements from soil, as well as, possible, radiation effects e.g. spontaneous and neutron induced uranium fission these specimens could have experienced.

Instrumental Neutron Activation analysis (INAA) in which samples are irradiated by the thermal neutrons (KE<0.025 eV) followed by detection of the induced gamma activities of the radionuclides, has been a golden standard in analysis of elemental composition of various artefacts. Although being a multi-elemental technique capable of analysing the samples regardless of their chemical composition, a very high cost and low sensitivity for some elements e.g. Li, Be, B, F, S, Fe, Cu, Nb, Pb, and others, has been the main limitations. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) has been recently developed by the various vendors of the scientific equipment to become a relatively low cost product that offers table-top instruments, in some cases, equipped with several mass filters and collision/ reaction cells for manipulation of molecular beams pushing the sensitivity down to *ppb* -level for many elements. In case of bone samples, the acid digestion for under an hour is required to bring the samples into the liquid phase prior to the ICP-MS analysis which itself takes <10 min.

In this work we have applied both INAA and ICP-MS methods and analysed the elemental composition (64 elements) of bones of dinosaurs, South mammoths, prehistoric bear and archanthropus as well as the samples of surrounding soils; everything collected in different parts of Uzbekistan [1-3]. A reasonable agreement between the two methods has been observed, with expected better precision of ICP-MS for some trace elements, and INAA [4] as being more suitable for bulk analysis of e.g. Na, Ca and P. The correlation of the bone/soil elemental ratio with the age of the sample (accumulation coefficients or mobility) of several elements have been studied. The most accumulated elements are U, Cr, Zn, Sr, and lanthanides which can be due to either a long period of time the samples spent in the soil or attributed to some anomalous phenomena in the past. Cr, Co, and Ba are least mobile elements. A high concentration of uranium we detected in the bones of dinosaurs (122 mg/kg), South mammoth (220 mg/kg), prehistoric bear (24 mg/kg) and archanthropus (1.5 mg/kg) compared to surrounding soils (3.7-7.8 mg/kg) and standard bones (<0.01 mg/kg) is a bit of a puzzle. The uranium fission elements (La, Ce Nd, Sm, Eu, Tb, Yb, Lu, As, Br and Mo) have been also detected in these bones.

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Evaluation of the Results of Neutron Activation Analysis of the Moss-Biomonitors Samples Collected in the Industrial Areas on the Czech-Polish Border

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The goal of the research was the analysis of spatial data gained by biomonitoring with the use of mosses. A partial goal was set to characterize the regional atmospheric deposition of pollutants in the air based on the results of the analyses and simultaneously verify the suitability of using mosses as an alternative for monitoring air quality in smaller industrial areas. In total, 93 samples of moss were collected from the area of the Moravian-Silesian Region in the Czech Republic and the area of the Silesian Voivodeship in Poland throughout the years 2015 and 2016. The samples were analyzed using instrumental neutron activation analysis. Based on the analyses performed, 38 elements, which had been evaluated using the PCA, HCPCA, factor analysis, correlation analysis, contamination factor, geoaccumulation index, enrichment factor, and pollution load index, were found.

The analyses resulted in a division of elements into a group which with its concentrations neared the level of values of the natural background and a group of elements identified as emissions likely originating from anthropogenic activity (Sm, W, U, Tb, and Th). The likely dominant source of emissions for the studied area was identified to be the metallurgical industry. Simultaneously, the results pointed to sources of local importance. The area of interest was divided into clusters according to the prevailing type of pollution and long-distance transmission of pollutants was confirmed. Biomonitoring of air using mosses proved to be a suitable method for characterizing atmospheric deposition.

Variation of TiO_2/SiO_2 transition layers induced by ion irradiation

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Abstract

Ion beam mixing (IBM) is a processing technique recently developed and used for modification the structure and composition of thin layers of materials. A large number of studies on effects induced by IBM in metal/metal or metal/semiconductor bilayers have been presented for understanding atomic transport mechanisms and phases formation processes. IBM for these structures is well understood but the same is not the case for metal/ceramic or ceramic/ceramic systems. Moreover, by mixing models the mixing amout depending on the ion fluence or temperature can be predicted, but mixing degree is not a simple function for energy and mass of incident ions. Therefore this correlation could be determined only by experimental investigation. In our work, mixing of the TiO_2/SiO_2 bilayers have been produced by the noble gas ions. The main objectives are to determine how mixing depend on energy, mass of the incident ions and how it different from thin and thick systems. There were 2 groups of studied TiO_2/SiO_2 samples, in which layers thickness of the samples in the group1 is lower than that of the sample in group 2. The samples were irradiated by the Ne^+, Ar^+, Kr^+ and Xe^+ ions at four diffrent energies 100, 150, 200 and 250 keV. The atomic mixing at TiO_2/SiO_2 interface was characterized by the spectra of Rutherford Backscattering Spectrometry (RBS) method. Mixing amount indicated by relative thickness of the TiO_2/SiO_2 transition layers which was deduced from the elemental depth profiles. It has been found that mixing amount increase linearly with increasing of the ions energy while mixing increase strongly as a function of ions mass. By use of SRIM simulation the effects could be interpreted by changing of the ion energy loss, energy tranferred to the recoils as well as number of ions interact at the interface. Displacement per atom (DPA) was calculated for comparing mixing degree of different-thickness structures. Although the ion loss more energy after penetrate the thicker TiO_2 layers, the penetration depth and number of interacted ions were higher, as a consequence the higher value of DPA was observed for transition layer of thick structure. The thickness obtained from the RBS is in good agreement with that measured using the Ellipsometry Spectroscopy method. Based on these obtained results, the optical constants of implanted and non-implanted TiO_2/SiO_2 structures were also investigated.

Acknowledgments

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AGE-RELATED CHANGES OF IODINE/TRACE ELEMENT CONTENT RATIOS IN INTACT THYROID OF MALES INVESTIGATED BY ENERGY DISPERSIVE X-RAY FLUORESCENT ANALYSIS

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The endocrine organs, including the thyroid gland, undergo important functional changes during aging and a prevalence of thyroid dysfunction is higher in the elderly as compared to the younger population. Advancing age is known to influence the formation of adenomatous goiter and thyroid cancer. The prevalence of thyroid nodules is increased in the elderly, reaching a frequency of nearly 50% by the age of 65. Both prevalence and aggressiveness of thyroid cancer increase with age. Women are affected by thyroid nodule and cancer two to five times more often than men, but in age over 65 years a prevalence of thyroid cancer is higher in men.

In our previous studies the high mass fraction of iodine (I) and some other trace element (TE) were observed in intact human thyroid gland when compared with their levels in non-thyroid soft tissues of the human body. However, some questions about the age-dependence of TE mass fraction and their relationships in thyroid of adult and, particularly, elderly males still remain unanswered. The findings of the excess or deficiency of TE contents in thyroid and the perturbations of their relative proportions in glands of adult and elderly males, may give an indication of their role in a higher prevalence of thyroid cancer in the elderly males

In present study TE contents and the effect of age on TE contents in intact thyroid of apparently healthy male 2-80 year old was investigated. Mass fractions of Br, Fe, Cu, I, Rb, Sr, and Zn in thyroid tissue samples were determined using radionuclide-induced (^{241}Am and ^{109}Cd) energy-dispersive X-ray fluorescence analysis (EDXRF). For these TE contents and calculated I/TE content ratios some basic statistical parameters such as arithmetic mean, standard deviation, standard error of mean, minimal and maximal values, median, percentiles with 0.025 and 0.975 levels were estimated in thyroid samples of all subjects (n=72) and in two age-groups of males 2-35 (n=36) and 36-80 (n=36) years old. Age-related comparison of data in two groups using the Student's *t*-test did not show any statistically significant differences in TE contents and I/Br, I/Fe, I/Cu, I/Rb, I/Sr, and I/Zn content ratios, however the significant positive association between age and I/Fe ratio in thyroid tissue was found by the Pearson's coefficient of correlation. Obtained results for TE contents were in good agreement with most reported data for thyroid tissue.

The developed methods of radionuclide-induced EDXRF are an efficient technique for the determination of many important TE in thyroid tissue. The methods are simple, fast, multielemental, and non-destructive. Our results for Fe, Cu, I, Rb, Sr, and Zn mass fractions in intact thyroid tissue may serve as indicative normal values for males of the Russian Central European region.

MEASUREMENT OF Ca, Cl, K, Mg, Mn, Na, P, Sr CONTENTS AND Ca/P RATIO IN THE ENAMEL OF PERMANENT TEETH OF TEENAGERS USING NEUTRON ACTIVATION ANALYSIS

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An examination of teeth condition requires exact knowledge of the nature and variation of the mineral matrix including the contents of some apatite and related bulk chemical elements such as Ca, P, Mg, Na, K, and Cl. Data of Ca and P content allow calculate Ca/P ratio with is a very important parameter of teeth apatite. It is known also that apatite phases can apparently be affected by trace element incorporation into teeth with effects on the physicochemical properties. This is why deficiency or excess of some trace elements, for example, such as Sr is one of the factors which determine the degree of susceptibility to caries and other dental diseases. So, chemical element analysis of teeth expands the knowledge of etiology of dental diseases and may be used for diagnostic, therapeutic and preventive purposes. Furthermore, teeth have been suggested as monitors for human exposure to elements which concentrate in calcified tissues.

In present study chemical element contents and the effect of gender on chemical element contents in intact enamel of permanent teeth of apparently healthy teenagers 11-13 year old was investigated. Mass fractions of Ca, Cl, K, Mg, Mn, Na, P, and Sr in tooth enamel samples were determined by instrumental neutron activation analysis (INAA) using activation by neutrons of nuclear reactor with next a high resolution spectrometry of gamma-radiation of activated short-lived radionuclides.

For all investigated chemical elements and Ca/P ratio some basic statistical parameters such as arithmetic mean, standard deviation, standard error of mean, minimal and maximal values, median, percentiles with 0.025 and 0.975 levels were estimated for tooth enamel in group of males and females separately and combined. Gender-related comparison using the Student's *t*-test did not show any statistically significant differences in Ca, Cl, K, Mg, Mn, Na, P, and Sr contents in tooth enamel, however the significant difference was found for Ca/P ratio.Obtained results were in good agreement with most reported data for tooth enamel.

The developed method of INAA is an efficient technique for the determination of many important chemical elements in tooth enamel. The method is simple, fast, multielemental, and non-destructive. Our data for Ca, Cl, K, Mg, Mn, Na, P, and Sr mass fractions in intact tooth enamel may serve as indicative normal values for teenagers of the Russian Central European region.

LITHIUM LEVEL IN THE PROSTATE OF THE NORMAL HUMAN: A SYSTEMATIC REVIEW

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Knowledge of the etiology and pathogenesis of most prostate malfunctions and pathologies is very limited. Despite advances in medicine, the differential diagnosis of benign hypertrophic and carcinogenic prostate has steadily increased in complexity and controversy. It has been suggested that the prostate lithium (Li) level may help solve these problems related to prostate disorders, especially as an indicator of prostate cancer risk, as an elevated Li level in the prostate may be a sign of prostate cancer in the future. These suggestions promoted more detailed studies of the Li level in the prostate of healthy men.

In present review we analyze data published concerning Li prostatic levels in healthy persons. In all 2312 items in the literature of the years dating back to 1921 were identified in the following databases: PubMed, Scopus, Web of Science, the Cochrane Library, and ELSEVIER-EMBASE. This data was subject to an analysis employing both the “range” and “median” of means.

In this way the disparate nature of published Li content of normal prostates was evaluated. Of the articles examined, 23 were selected for objective analysis of data from 1190 healthy subjects. The contents of prostatic Li (on a wet mass basis) spanned the interval from 0.0053 mg/kg to 0.0200 mg/kg with 0.0074 mg/kg as median for their means.

The data included a wide range of values and the samples were small, hence it is advisable that further studies with strong quality control of results be performed.

Assessment of atmospheric deposition in Central Russia: Vladimir and Yaroslavl regions, using moss biomonitors, neutron activation analysis and GIS technologies

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Moss biomonitoring technique was applied to study peculiarities of the spatial distribution of atmospheric deposition of heavy metals on the territory of the Vladimir and Yaroslavl regions. During the summer 2018, samples of the terrestrial mosses *Pleurosium shreberi* were collected at the 126 sites evenly distributed over the territory of investigated regions. The combination of neutron activation analysis and atomic absorption spectrometry allowed to determine more than 30 elements in moss samples. To identify the main sources of air pollution multivariate data analysis technique – factor analysis was applied, while the deposition patterns of pollutants was illustrated using GIS technology. Median values of the elements were compared with the results obtained for other regions in Russia, which participated in moss survey studies. The contamination factors, Geo-accumulation Index and pollution load index were calculated for the following elements As, Sb, Pb, V, Cd, W, Fe, Cr, Ni and Co. Ni. The dominant anthropogenic sources of air pollutants in studied regions can be considered industrial activity and transport.

RBS METHOD FOR STUDYING OBJECTS WITH A NON-PLANAR SURFACE

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Traditionally, the RBS method is used to study samples with a flat surface, but it is often necessary to study samples with a cylindrical surface. To improve the corrosion properties of fuel tubes in nuclear reactors, their structural phase state is modified. The purpose of this study is to develop a method for the analysis of cylindrical samples by the RBS method.

The objects of study were samples of zirconium alloy E110 of different geometric shapes: R1 - flat, R2 - cylindrical. A metal coating of Cr, Al, Ni was applied to a flat sample R1. Then, to improve the adhesion of the metal coating to the substrate, ionic mixing was performed with argon ions with energy of 30 keV. The cylindrical sample has a thin oxide film that appeared after ion polishing with argon ions energy of 5 keV.

The study of the elemental composition of the modified surface of the samples was carried out by the RBS method. The energy of helium ions was E_o = 2 MeV, the scattering angle θ = 170°, the angle of incidence of alpha particles α = 30° and 60°. A gallium phosphite (GaP) sample was used for calibration. After obtaining experimental data, modeling and analysis of the spectrum was carried out using the SIMNRA program. Figure 2 shows the RBS energy spectra of planar (a) and cylindrical (b) samples from the E110 zirconium alloy.

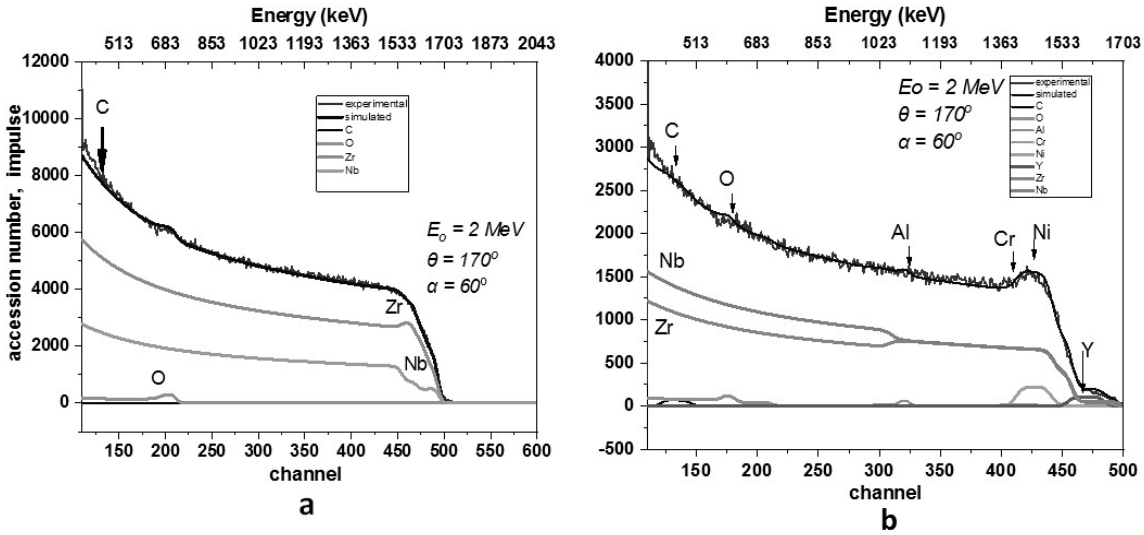

Figure 2 Energy spectra of RBS samples: a) flat b) cylindrical.

Thus, the spectral analysis showed the possibility of studying cylindrical samples with a modified structural phase state of the surface of cylindrical samples by the RBS method.

The study was performed in the scope of the RO-JINR Projects within the framework of themes FLNP JINR: № 04-4-1140-2020/2022 and № 03-4-1128-2017/2022.

Ion-beam analysis of thin-multilayer films on the PET, PES polymer substrate

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The study of the elemental composition and radiation resistance of polymeric functional materials intended for work in a comos is an urgent scientific and technological problem. A deep element profiles of a three types of organic-inorganic functional layers: phthalocyanine (zinc phthalocyanine/ZnPc), non-metallic phorphyrine 95,10,15,20-tetra (4-pyrydil) 21H,23H-porphyne /TPyP) and nucleic acid base (cytosine/C) deposited on the polymer substrates were investigated by RBS method on the EG-5 accelerators (JINR, FLNP). The studies were carried out on beam of He^+ ions (2.0 MeV) at incident angles 10^0 and 40^0 and scattering angle $\theta = 170^o$. A SiO_2/Si plate was used as a calibration sample.

The concentrations of the main elements of functional coatings were determined. The RBS spectrums of three groups of samples (fig. 1) have some similar characteristic and common features. The bands of oxygen (O) about channel 400 and carbon (C) about channel 300. These elements exist in the surface layers of the samples. The other observed common characteristic is the shift of the certain elements of the spectrum to low energy region. The destroy occurred in all samples after RBS experiment was observed. This effect can lead to changes the chemical composition on the surface of samples, it also can lead to the formation of an extra layer which enriched with carbon (C) on the surface of samples and the loss of elements such as oxygen (O), hydrogen (H) and nitrogen (N) on the surface of samples.

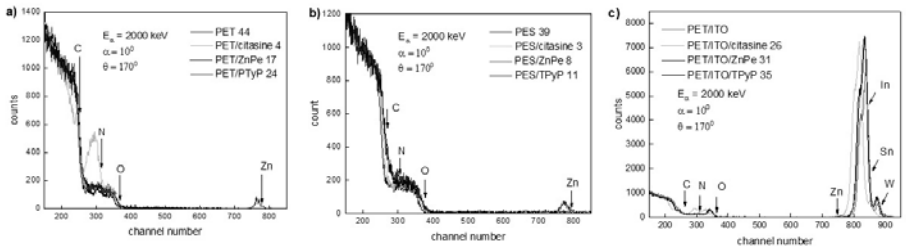

Fig. 1: RBS spectra a) PET samples; b) PES samples; c) PET/ITO samples.

The study was performed in the scope of the Poland- JINR and RO-JINR Projects within the framework of themes FLNP JINR 03-4-1128-2017/2022.

BASIC METHODS FOR RESEARCHING ARCHAEOLOGICAL OBJECTS FROM PRECIOUS METAL AND THEIR POSSIBILITIES IN SOLVING THE PROBLEM OF ANCIENT SOURCE BASE

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Finds from precious metals on the territory of the European part of Russia are most widely presented in the materials of the Andronovo and Scythian-Sarmatian archaeological cultures, in the monuments of the Northern Black Sea region. One of the fundamental problems in the study of the oldest archaeological finds from precious metals found in this area is the problem of the source base. If Pb-Pb isotope analysis works well to solve the problem of silver sources, then to search for sources of ancient gold, it is necessary to rely on data on the content of trace impurities.

There are several methods for studying the chemical composition of gold, the most often used in archaeological practice is the XRF method. With its help, the collections of archaeological gold objects of the 4th century B.C. – II-III centuries A.D. were investigated, data on the nomenclature of the main elements contained in ancient gold were obtained. This method made it possible to determine a number of elements contained in gold, which may be signs of specific ore occurrences (for example: Zaikov et al., 2012). However, this method is often unable to provide a nomenclature of a number of elements that indicate other types of gold ore formations.

Such possibilities are provided by other research methods, among them – classical neutron activation analysis (NAA) and prompt gamma activation analysis (PGAA). We analyzed two samples (foil of the 4th century B.C.), irradiation of both samples within the framework of NAA and PGAA was carried out at the IBR-2 reactor. One of the samples was additionally studied by the NAA method at the stationary WWR-K reactor at the Institute of Nuclear Physics, Almaty, Kazakhstan.

As a result of the experiment, the mass fractions of 10 elements were determined in the first sample, 10 by means of NAA, 4 by PGAA and 3 by XRF. In the second sample, the mass fractions of 8 elements were determined, 6 using NAA, 4 – PGAA.

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NEUTRON ACTIVATION ANALYSIS IN ENVIRONMENTAL STUDIES

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Neutron activation analysis due to its high accuracy, nondestructive nature and possibility to determine concentrations of more than 45 elements is widely used in the environmental studies, archeology and medicine. The principle of the method will be discussed. Types of neutron activation analysis will be briefly characterized in order to depict the most important information. Examples of application of neutron activation analysis at the IBR-2 reactor (Dubna, Russia) for wastewater treatment, nanotoxicology, medicinal plants and foodstuff samples analysis as well as determination of the elemental content of archeological and extraterrestrial objects will be presented.

Nuclear fission

Neutron–induced fission of actinides at energies up to 200 MeV: Problems of describing fission cross sections and angular anisotropy of fission fragments

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The standard description of the total σ_f and differential $d\sigma_f/d\Omega$ fission cross sections of nuclei is based on the use of A.Bohr's concept of transition states of a nucleus at fission barriers. The ratio of the differential to the total cross section determines the angular distribution of fission fragments $dw(\theta)/d\Omega = (d\sigma_f/d\Omega)/\sigma_f$. Since the non-isotropic component in the expansion of the angular distribution in terms of Legendre polynomials is usually determined by the 2nd polynomial, $dw(\theta) = (1+A_2P_2(\cos\theta))/(4\pi)$, then the angular distribution is actually specified by the A_2 parameter. In practice, it is convenient to use the angular anisotropy $w(0°)/w(90°) = (1 + A_2)/(1 - A_2/2)$.

Using currently available software packages, which include, in particular, TALYS [1], it is possible to calculate the energy dependence of the cross sections for fission of heavy nuclei by projectile particles, including neutrons at low and intermediate energies (up to 200-300 MeV). The calculations use a model description of fission barriers and the density of transition states as a function of spin J and its projection K onto the deformation axis of the nucleus. In fact, everything that we know about fission barriers and transition states was obtained from the analysis of data on fission cross sections, since none of the available software packages contain the possibility of calculating the angular distribution of fragments. Meanwhile, an analysis of the available data on the angular anisotropy of fission fragments can provide additional information both on the fission mechanism of various isotopes, including those far from stability, and on the relationship between equilibrium and preequilibrium processes at different energies [2].

We have modified the TALYS complex to be able to calculate the angular distribution of fission fragments along with the total fission cross section in the framework of A.Bohr's model of transition states. This work is a continuation of our experimental studies of the angular distributions of fragments from fission of nuclei ^{nat}Pb, ^{209}Bi, ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{237}Np, ^{239}Pu, ^{240}Pu by neutrons with energies up to 200 MeV (see [3,4] and references therein); recently, measurements were carried out for the ^{236}U isotope. The first results on a joint description of the fission cross sections and angular distributions of fission fragments for ^{237}Np and ^{240}Pu actinide nuclei are presented in [3,4]. This work is devoted both to a discussion of the problems arising in such a description and to the new results we obtained.

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The estimation of the angle of fission axis rotation in binary fission of ^{235}U induced by polarized neutrons with energies 60 meV and 270 meV

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After discovery the T-odd effects in the ternary fission [1-3] the analogous effects for gammas and neutrons in fission of ^{235}U and ^{233}U was also observed [3-6]. It is predicted that the change in the magnitude of the ROT effect depending on the energy of the incident neutrons, considering likewise proportionality of these effects to the effective angular velocity of the compound nucleus at the moment of scission. Moreover, it is interesting performing the experiment by polarized neutrons with energies, in which only one spin state of the compound nucleus is dominated. So, the effects depend on spin states of the compound nucleus and their projects on the fission axis. Our team continues to carry out a series of experiments by polarized neutrons with different energies. Recently, our group obtained the ROT effect results measured in the angular distribution of gamma quanta from fission of ^{235}U by polarized "warm" (60 meV) and "hot" neutrons (270 meV) at the POLI facility of the FRM II reactor in Garching. Experimental dependencies of γ-quanta versus the angle of their emission was measured in the experiments in order to determine the coefficient of angular anisotropy A from which it is estimated the angle of fission axis rotation. The coeffcient of angular anisotropy A was found to be equal to $A=0.1570 \pm 0.0053$ for the prompt γ-rays from binary fission of ^{235}U by "warm" (60 meV) neutrons, while this value in case of "hot" neutron equal to $A=0.1632 \pm 0.0129$. The appropriated angle of fission axis rotation was determined to be equal to $\delta_{FF} = 0.069 \pm 0.008$ deg and $\delta_{FF} = 0.021 \pm 0.009$ deg, respectively.

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Identification of fission fragment via prompt γ-ray spectroscopy

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The fission fragments of neutron-induced nuclear fission are in a highly excited state after emitting 2-5 prompt neutrons, and then emit 6-8 prompt γ photons in 10^{-14}s-10^{-7}s. By employing the characteristic γ-ray energy spectra, it is possible to identify the fission fragment and even estimate the independent fission yield.

In this work, fission fragment and prompt γ-ray coincidence measurement method is exploringly employed to identify the fission fragments. A typical schematic diagram of detection system is shown in Fig.1. The charged particle detector system consisting of a time-of-flight spectrometer and an ionization chamber is used to obtain the mass of primary fission products. At the same time, the γ-ray detector array is employed to obtained the γ-ray energy via the Compton scattering process coincidence. The time spectrum of prompt γ-ray is obtained through the coincidence measurements between the relevant fission fragments and prompt γ-ray. The prompt γ-ray associated with fission fragments can be selected through the time window, then the characteristic γ-ray energy spectrum of the fission fragments is obtained. The measurement scheme can greatly reduce much of irrelevant γ-ray background which includes the delayed γ-rays and γ-rays produced from the other interaction between neutrons and fission materials.

Keywords: fission fragment; prompt γ-ray; coincidence measurement

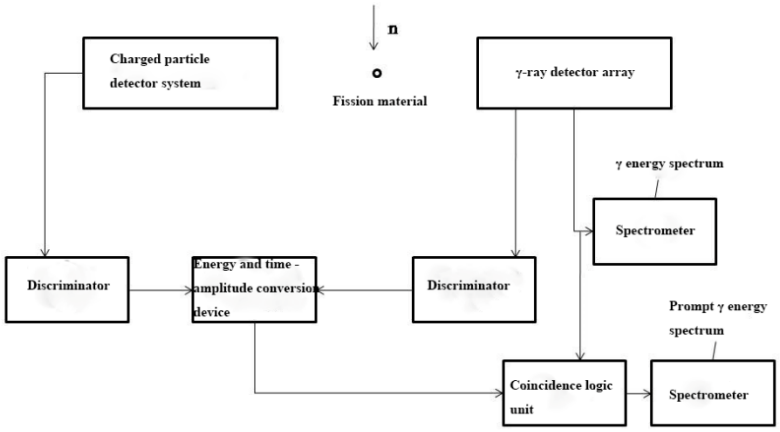

Fig.1 A typical schematic diagram of detection system.

P-even T-odd asymmetries in differential cross sections of fission reactions of nonorientied nuclei by cold polarized neutrons with emission of prescission and evaporation light particles

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In the quantum theory of fission [1] P-even T-odd asymmetries in differential cross sections $d\sigma_{nf,\alpha}/d\Omega$ for fission reactions of nonoriented nuclei by cold polarized neutrons with the emission of prescission α-particles can be connected with triple $A_{\alpha,3}(\theta)=\left(d\sigma^1_{nf,\alpha}(\theta)/d\Omega\right)_3 = B_{\alpha,3}\left(\cos^2\theta\right)\left(\boldsymbol{\sigma}_n[\mathbf{k}_{LF},\mathbf{k}_\alpha]\right)$ and quinary $A_{\alpha,5}(\theta)=\left(d\sigma^1_{nf,\alpha}(\theta)/d\Omega\right)_5 = B_{\alpha,5}\left(\cos^2\theta\right)\left(\boldsymbol{\sigma}_n[\mathbf{k}_{LF},\mathbf{k}_\alpha]\right)(\mathbf{k}_{LF},\mathbf{k}_\alpha)$ scalar correlators that appear in the component $d\sigma^1_{nf,\alpha}(\theta)/d\Omega$ of cross section $d\sigma_{nf,\alpha}/d\Omega$ linearly related to the neutron polarization vector $\boldsymbol{\sigma}_n$. These correlators can be built taking into account the influence of Coriolis interaction of the total spin of fissile compound nuclei with orbital momenta of emitted particles: $A_{\alpha,3,5}(\theta)=\Delta_{\alpha,3,5}\,d\left(d\sigma^0_{nf,\alpha}/d\Omega\right)_{3,5}/d\theta$ (1), where $\left(d\sigma^0_{nf,\alpha}/d\Omega\right)_{3,5}$ are odd and even components of cross section $\left(d\sigma^0_{nf,\alpha}/d\Omega\right)$ of fission reaction with nonpolarized neutrons and $\Delta_{\alpha,3,5}$ are angles of the rotation of α- particle wave vector $\mathbf{k}_\alpha$ relatively to analogous vector $\mathbf{k}_{LF}$ of light fragment. Taking into account that correlators $A_{\alpha,3}(\theta)$ and $A_{\alpha,5}(\theta)$ are proportional to $\sin\theta$ and $\cos\theta\sin\theta$ correspondly and have symmetries $A_{\alpha,3,5}(\theta)=\pm A_{\alpha,3,5}(\pi-\theta)$, they can be presented as $A_{\alpha,3,5}(\theta)= 1/2\left[d\sigma^1_{nf,\alpha}(\theta)/d\Omega \pm d\sigma^1_{nf,\alpha}(\pi-\theta)/d\Omega\right]$ (2). Using in (2) experimental values of cross section $d\sigma^1_{nf,\alpha}(\theta)/d\Omega$ the calculation of the experimental values $A^{\exp}_{\alpha,3,5}(\theta)$ were produced for target nuclei ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu. The comparison on the base of the χ^2-method of $A^{\exp}_{\alpha,3,5}(\theta)$ with theoretical values (1) makes it possible to find the values of the rotation angles $\Delta_{\alpha,3,5}$. The calculated values of $A_{\alpha,3,5}(\theta)$ (1) coincide with $A^{\exp}_{\alpha,3,5}(\theta)$ (2) for all nuclei ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu with the exception of $A_{\alpha,3}(\theta)$ for ^{233}U. This description can be associated with the influence of transverse vibrations of compound fissile nuclei in the vicinity of their scission points [2]. In the case of prescission α-particles the angles $\Delta_{\alpha,3}$ have positive values for ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu, but angles $\Delta_{\alpha,5}$ change signs from positive for ^{235}U, ^{239}Pu,^{241} Pu to negative for ^{233}U. The negative signs of $\Delta_{\alpha,5}$ in principle is not possible for the quasi-classical method of trajectory calculations [2], in contrast to the quantum approach [1], where due to the taking into account of interference effects the signs $\Delta_{\alpha,3,5}$ can have negative values. In the case of the evaporation neutrons and γ- quanta emission in cross section $d\sigma^1_{nf,n,\gamma}(\theta)/d\Omega$ only quinary scalar correlations $A_{5,n,\gamma}(\theta)$ can appear because of properties of $d\sigma^0_{nf,n,\gamma}(\theta)/d\Omega$. The signs of $\Delta_{n,5}$ and $\Delta_{\gamma,5}$ for evaporation neutrons and γ- quanta coincide with each other for ^{233}U and ^{235}U, but for passing from ^{235}U to ^{233}U they change signs from positive to negative. Signs of $\Delta_{n,5}$ and $\Delta_{\gamma,5}$ for evaporation neutrons and γ -quanta coincide with signs of $\Delta_{\alpha,5}$ for prescission α-particles for nuclei ^{233}U and ^{235}U. This coincidence is indicated by the unit quantum mechanical nature of P-even T-odd asymmetries for prescission α-particles and evaporation neutrons and γ-quanta.

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Multi-stage virtual nuclear decays

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Using the technique of Feynman diagrams and the R - matrix theory of nuclear reactions, as well as the results of articles [1-4], general formulae for the amplitudes of multi-stage decays of parent nucleus A_0 of the type $A_0 \to b_1 + A_1 \to b_1 + b_2 + A_2 \to ... \to b_1 + b_2 + ... + b_n + A_n$ with the appearance of real (observed) states of finite nucleus A_n and particles $b_1, b_2, ..., b_n$ were constructed. By introducing the internal energies $E(A_i)$ and $E(b_i)$ of nuclei A_i and particles b_i, the heats $Q_i = E(A_i) - E(A_{i+1}) - E(b_{i+1})$ of binary nuclear decays $A_i \to A_{i+1} + b_{i+1}$ that appear in the analyzed multi-stage decays were calculated. In the case of positive values of $Q_i > 0$ these decays and states of nuclei A_{i+1} can be really observed. However, at negative values $Q_i < 0$ the states of nuclei A_{i+1} lie outside the mass surface of the considered multi-stage decays and therefore have a virtual character. The experimental observation of such decays is possible only in its combinations with the decays of intermediate nuclei formed at the subsequent stages of the analyzed multi-stage decays with sufficiently larger positive values of heats. Using the introduced above formulae for experimentally observed nuclear decays the multi-stage virtual decays were distinguished and their characteristics were successfully described.

It is shown that the group of two-stage virtual nuclear decays includes the double beta-decays of nuclei [5–7], two-proton decays of nuclei [1,3], as well as spontaneous and low-energy induced ternary fission of nuclei with the escape of alpha particles from the neck of the fissile nuclei [4]. It is demonstrated that the group of three-stage virtual nuclear decays includes the spontaneous and low-energy induced quaternary fission of nuclei with the emission of the first and the second alpha particles from the neck of the fissile nuclei [8].

In conclusion, it should be noted that the concept of the multi-stage virtual nature of ternary and quaternary fission of nuclei with the emission of tritons and a large group of light nuclei as light particles is valid too.

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IMPROVEMENT OF THE EXPERIMENTAL CAPABILITY IN STUDIES OF THE CLUSTER EFFECTS IN HEAVY NUCLEI

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In accordance with our previous experiments [1–3], at least some of the fragments of binary fission of low excited actinides are born in the state of shape isomers. A strongly deformed fragment is a weakly bound binary system (shape isomer) which breaks up with a certain probability in an inelastic scattering in a solid foil. Both decay products fly in the same direction, with a very small angle between them, in the range of 0.3^0-2^0 (experimental estimate). Moreover, one of them has an energy of several MeV or less, which makes it extremely difficult to separately detect them with the measurement of the mass of each of the products.

To construct an adequate model of the observed effects, *a kinematically complete experiment* with the measurement of masses, energies, and velocity vectors of all nuclei involved in the process is required. For this purpose, joint work with a group from the Czech Republic has begun on the use of Timepix3 two-coordinate pixel detector with 55μ spatial resolution in studies of multibody decays. Heavy ion mass spectrometry using this detector is a non-trivial methodological problem. The results already obtained are presented.

New experimental approach which allows to estimate the life time of the shape isomer states in fission fragments is based on use of the electrostatic guide system at the beam of the MT-25 microtrone in FLNR. A current status of the experiments is discussed.

Special attention in the presentation is also paid to the new off-line timestamp algorithm which allows to obtain the unbiased values of time-of-flights in the wide range of heavy ions masses and velocities.

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Use of Hidden Variables in Modern Calculations of Angular Correlations of Gamma Quanta and Neutrons Emitted from Fission Fragments

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The hidden-variables (HV) theory was once put forward by opponents of the probabilistic interpretation of the wave function (EPR paradox). It was assumed that the state of the system could be predicted with a less uncertainty than this is admitted by the Heisenberg uncertainty principle, if one knew additional, that is HV. This theory is rejected by the community. However, examples can be given of how HV suddenly appear, for example, in modern simulations of the angular distributions of gamma quanta or neutrons emitted from fission fragments. This happens if one considers the spin of each fragment to have a definite direction in the plane perpendicular to the fission axis, and then averages over the directions of the spin in the azimuthal plane. In this way, the well-known phenomenon of the alignment of the spins of fragments in a plane perpendicular to the fission axis might be erroneously treated. Then the supposed direction of the fragment's spin appears as a HV. Contrary, in a consecutive quantum-mechanical approach, the state of the fragment is characterized by two quantum numbers: the spin and its projection onto the quantization axis *z*, which is along the fission axis. Then the alignment of the fragments merely means that the projection of their spins onto this axis is close to zero. And in the general case of incomplete alignment, it is necessary to use the density matrix.

Let us consider for illustration a simple two-level scheme of neutron decay. Let the initial nucleus in an excited state be characterized by the quantum numbers of an odd neutron: the orbital angular momentum L and the total angular momentum $J = L + 1/2$. Suppose that by emitting a neutron, it transfers to the ground state of an even-even nucleus with $J = L = 0$. Then the neutron is emitted with the orbital angular momentum L. If $L = 0$, the neutron is emitted isotropically, and no question arises. Let us consider the variants with $L = 1$ and $L = 2$. In the HV model, the angular distribution of the emitted neutrons in the internal coordinate system will be $|Y_{LL}(\theta, \varphi)|^2 \sim \sin^2\theta$ and $\sin^4\theta$ in the cases of $L = 1$ and 2, respectively. After transformation to the angle ϑ relative to the fission axis z in the laboratory system and averaging over the azimuthal angle ϕ of the spin in the (x,y) plane, one arrives at the angular distributions in the labsystem, calculated within the HV-theory: $\Psi_{\text{h.v.}}(\vartheta) = 1 + \cos^2\vartheta$ if $L = 1$, and $\Psi_{\text{h.v.}}(\vartheta) = 1 + \frac{2}{3}\cos^2\vartheta + \cos^4\vartheta$ if $L = 2$. Contrary, within the framework of the quantum-mechanical approach one obtains $\Phi(\vartheta) = \left|Y_{10}(\vartheta,\varphi)\right|^2 \sim \cos^2\vartheta$ at $L = 1$, and $\Phi(\vartheta) = \left|Y_{20}(\vartheta,\varphi)\right|^2 \sim 1 - \frac{2}{3}\cos^2\vartheta + \frac{1}{9}\cos^4\vartheta$ at $L = 2$. The difference speaks for itself.

Among the other examples of use of HV, I point out the use of the immeasurable parameter ξ in the method of specific differences for the elimination of the Bohr—Weisskopf effect in the study of the hyperfine splitting in heavy ions of ^{209}Bi [1]. In [2], the angular distribution of conversion muons from fragments of prompt fission was calculated within the framework of the quantum-mechanical approach. The monograph [3] also considers the emission of "prompt" muons, which are analogous to prompt – that is, scission neutrons.

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Parameterization of neutron yields for first chance photofission fragments

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The dependence of the average number of prompt neutrons emitted from fission products for each mass number *(A)* of photofission of actinide nuclei 232Th, 235U, and 238U in the giant dipole resonance energy range have been parameterized. This approach allows us to describe the observed changes of "saw-tooth" behavior of neutron yield from the light and heavy fragments using few energy and nucleon composition-dependent free parameters and to predict *(A)* for other actinide isotopes. To estimate the number of neutrons emitted by corresponding fission fragments of atomic mass, A, the phenomenological Wahl method [1] was applied. The total averaged number of prompt neutrons [2] needs to construct the parametrizing function, which reasonably reproduces the characteristic features of its behavior and parameterization of average number of prompt neutrons. This method can calculate the expected values of prompt neutrons yield for arbitrary neighboring actinides, such as 237Np or 239Pu. It allows estimating the possible values of fission neutrons yield from light and heavy fragments with known total yields just through the mass distributions of fission fragments using the modified Terrell method [3].

The obtained results of estimating the dependence of the prompt neutron yields from light and heavy fragments for the first chance of actinide photofission are compared with the results of calculations (modeling) by the program codes GEF and Talys1.9.

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The angular and spin distributions of low-energy nuclear fission fragments and collective wriggling - and bending - vibrations of the fissile nucleus in the vicinity of its scission point

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Using the concept [1] about zero wriggling vibrations of a compound fissile nucleus in the vicinity of its point of scission into fission fragments the angular distribution $P(\theta')$ of this fragments for spontaneous and low-energy nuclear fission can be presented in the internal coordinate system (i.c.s.) of axially symmetric fissile nucleus as $P(\theta') = \left|\sum_L \psi_L Y_{L0}(\theta')\right|^2$, where ψ_L is the wave function of wriggling vibrations in *L*–representation, where *L* is relative orbital moment of fission fragments. This function can be presented [2] as $\psi_L = \sqrt{L/C_w}\exp\left(-L^2/4C_w\right)$, where the average value of parameter C_w is equal [1] $\overline{C_w} \approx 132\hbar^2$ for actinide nuclei. Then the average value $\overline{L}$ of orbital momenta L has a sufficiently large value $\overline{L} = 14.4$, that allows to approximate the distribution $P(\theta')$ to the delta-function form, which ensures a good accuracy of the implementation of A. Bohr's hypothesis [3] about the angular distribution $P(\theta')$.

The spin distributions of the fission fragments are traditionally described in terms of the temperature Gibbs distributions $\rho_i(J_i)$: $(2J_i+1)\exp[-\hbar^2 J_i(J_i+1)/\Im_i kT_i]$, $\Im_i$, T_i and J_i are the moment of inertia, temperature, and spin of the *i*-th fission fragment (*i* = 1, 2). For spontaneous and low-energy induced fission the compound fissile nuclei and primary fission fragments in the vicinity of the scission point are in cold nonequilibrium states [3], so it is necessary to take into account [2] only zero transverse bending - and wriggling-vibrations of the specified fissile nuclei when constructing the spin distributions of these fragments. Expressing the normalized distribution function $W(\mathbf{J_1}, \mathbf{J_2})$ of the fission fragments over the spins $\mathbf{J_1}$ and $\mathbf{J_2}$ through the product of the squared modules of the wave functions of the zero bending and wriggling vibrations, and integrating over the variables J_2 and ϕ, one can obtain [2] the normalized spin distribution of the first fission fragment: $W(J_1) = 4J_1/(C_b + C_w)\exp\left[-2J_1^2/(C_b + C_w)\right]$ (1). For a fissile nucleus at the values [1] of energies $\hbar\omega_w$ = 2.3 MeV; $\hbar\omega_b$ = 0.9 MeV; and it follows that the vibrational quantum energies $\hbar\omega_w$ and coefficients C_w for the wriggling vibrations are noticeably larger than the analogous values for the bending vibrations. This means that the main contribution to $\overline{J}_1$ is given by wriggling vibrations. Then the calculated value $\overline{J}_1$ = 8.6 correlates well with the experimental [4] average values of the spins of the fission fragments $\overline{J}_1$ = 7-9. However, due to the conservation law of the total spin of the fissile system, the spin distributions of these fragments remain non-equilibrium and are determined with a good degree of accuracy by the formula (1). This conclusion contradicts the concept widely used in the fission theory [3] about the temperature Gibbs character of these distributions.

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Anisotropy in pre-fission and (n,n'γ) neutron spectra of ^{239}Pu+n

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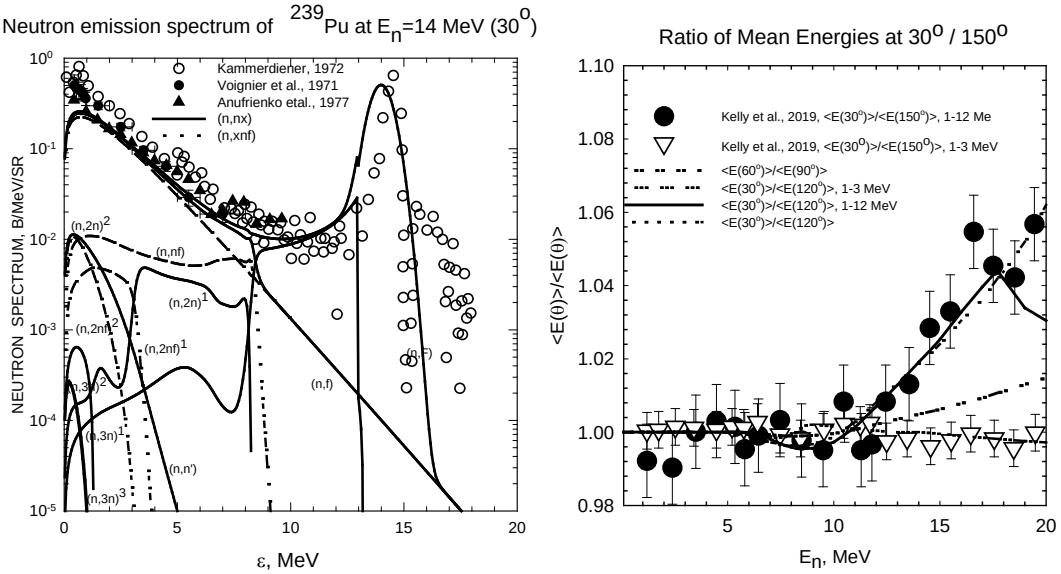
Strong anisotropic component was observed [1] in ^{239}Pu(n,F) pre-fission neutron spectra at E_n~12–20 MeV. Neutron emission spectra of n+^{239}Pu interaction at E_n~14 MeV are strongly anisotropic, while residual nuclide ^{239}Pu excitations are 1~6 MeV [2–4]. These peculiarities could be attributed to the pre-equilibrium/semi-direct emission of the 1st neutron, which is tuned to reproduce (n,F) and (n,xn) reaction cross sections and neutron emission spectra consistently. The angular dependence was approximated as $d\sigma^1_{nnx}/d\varepsilon \approx d\tilde{\sigma}^1_{nnx}/d\varepsilon + \sqrt{\frac{\varepsilon}{E_n}}\frac{\omega(\theta)}{E_n-\varepsilon}$. The exclusive spectra of (n,nf) and (n,2n)^1 [5–8] reaction appear to be angle-dependent as well. Because of data [2] scattering the approach was tuned on similar data description of ^{238}U+n, where collective levels up to 1.2 MeV were included [9]. The partial neutron spectra for the neutron emission at angle of ~30^o are shown on figure below. The angular dependence of (n,nf) neutron spectra is the strongest, it influences the observed prompt fission neutron spectra and its average energies, The ratio of calculated $\langle E \rangle$ for forward and backward emission of (n,xnf)-neutrons is compatible with measured data [1]. Ratio of $\langle E \rangle$ depends on the averaging range, at low angles ^{239}Pu(n,xnf) neutrons at E_n >18 MeV are harder.



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Prompt fission neutron spectra and TKE of ^{235}U(n, F) and ^{239}Pu(n, F)

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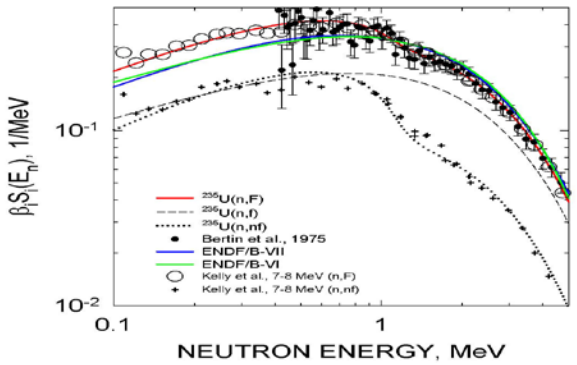
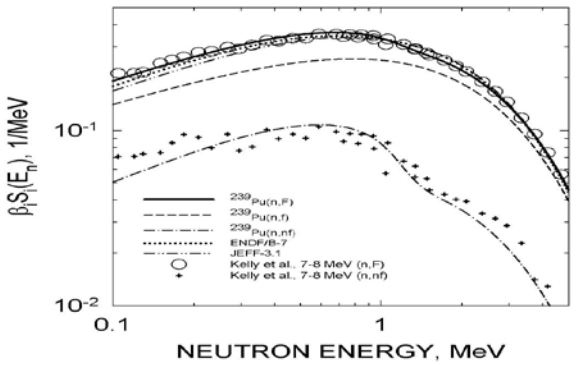
Matrices of prompt fission neutrons spectra of ^{235}U(n,F) and ^{239}Pu(n,F), describing based on /1-5/ all measured data shapes, TKE, average number of prompt fission neutrons and (n,F) and (n,xn) reaction cross sections up to 20 MeV are provided. PFNS of ^{235}U(n,F) and ^{239}Pu(n,F) in the newest data libraries ENDF/B-VIII, JEFF-3.3 and JENDL-4.0 are roughly discrepant as regards the PFNS shapes and average energies. In a number of cases they are discrepant with the newest differential measured data /6-10/.

The correlation of the PFNS shape at $E_n = 10^{-5}$~20 MeV with the target nuclide fissility and excitation energy is investigated. The calculated shapes are consistent with the measured PFNS of 235U(n,F) and 239Pu(n,F) and their ratios in the domain of first chance and emissive fission. That comprises the basis for the (n,xnf) neutrons contribution to the observed PFNS (see /2-5/). Local maxima in observed TKE are correlated with (n,nf) and (n,2nf) thresholds of 235U(n, F) and 239Pu(n, F) /11,12/ reactions. The contribution of the (n,xnf) pre-fission neutrons to the observed PFNS diminishes drastically with the increase of the fissility of the compound nuclide. The contribution of the (n,2nf) reaction neutrons, strong in case of 235U(n,F), influences only slightly on the observed PFNS of 239Pu(n,F) at E>14 MeV /4/. TKE E_f^{post} of fission products are $E_f^{post} \approx E_f^{pre}\left(1-\nu_{post}/\left(A-\nu_{pre}\right)\right), \nu_p = \nu_{post} + \nu_{pre}$.

^{235}U(n,F) PFNS 7 MeV



^{239}Pu(n,F) PFNS 7 MeV



TKE E_f^{post} of fission products are $E_f^{post} \approx E_f^{pre}\left(1-\nu_{post}/\left(A-\nu_{pre}\right)\right), \nu_p = \nu_{post} + \nu_{pre}$. Variation of TKE of fission fragments E_f^{pre} /11,12/, before neutron emission fission fragments are defined as $E_f^{pre}(E_n) = \sum_{x=0}^{X} E_{fx}^{pre}(E_{nx}) \cdot \sigma_{n,xnf} / \sigma_{n,F}$, $E_{nx} = E_n + B_n - \sum_{x=0,1\le j\le x}^{X}\left(\left\langle E_{n,xnf}^{j}\right\rangle + B_x\right)$.

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Post - scission neutron emission and transformation of fission fragments yield: are there regularities?

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The study of fission products provides valuable information about the nature of nuclear matter stability. In practice, there are problems of their exact determination because a post-scission ensemble is a dynamic system influenced by the nuclear particle emission from the fission fragments. The number of either neutron (prompt, delayed) or beta particles depends on the time after nuclear fission: more nuclear particles will be emitted for a longer time interval.

In this report, the “many ensembles” method is proposed to investigate the influence the post-scission nuclear particle emission on mass and charge distributions of fission products. The post fission approximation had been used; each of these ensembles consists of the fission fragments after emission of chains of different lengths, both the beta particles and neutrons. The proposed theory allows one to find the most probable two fragment clusters of fission products and study their evolution after the post-scission emission of nuclear particles. The isotope ^{232}Th was chosen as an example, the fission fragments of which are intensively studied in the experiment. It is shown that the post-scission emission of nuclear particles eventually leads to the convergence of the asymmetric peaks, which looks like enhanced symmetric fission mode over asymmetric one for fission product yields, Table 1. A comparison of the theoretical results and experimental data for the 232Th fission fragments indicates their good matching.

Table 1. The evolution of five the most probable post-scission two fragment clusters, M=1–5, after emission the neutrons of different chains’ lengths: n defines all their sets from the ranges (0, n). There is no beta particles emission

M\n	0	+1	+2	+3	+4
1	$\{^{100}_{40}Zr, ^{132}_{50}Sn\}$	$\{^{100}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{96}_{40}Zr, ^{132}_{50}Sn\}$	$\{^{96}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{96}_{40}Zr, ^{130}_{50}Sn\}$
2	$\{^{102}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{98}_{40}Zr, ^{132}_{50}Sn\}$	$\{^{94}_{38}Sr, ^{134}_{52}Te\}$	$\{^{96}_{40}Zr, ^{132}_{50}Sn\}$	$\{^{102}_{40}Zr, ^{132}_{50}Sn\}$
3	$\{^{101}_{40}Zr, ^{131}_{50}Sn\}$	$\{^{100}_{40}Zr, ^{132}_{50}Sn\}$	$\{^{98}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{94}_{38}Sr, ^{134}_{52}Te\}$	$\{^{94}_{38}Sr, ^{134}_{52}Te\}$
4	$\{^{104}_{40}Zr, ^{128}_{50}Sn\}$	$\{^{101}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{100}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{104}_{40}Zr, ^{128}_{50}Sn\}$	$\{^{98}_{40}Zr, ^{130}_{50}Sn\}$
5	$\{^{99}_{39}Y, ^{133}_{51}Sb\}$	$\{^{101}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{97}_{40}Zr, ^{132}_{50}Sn\}$	$\{^{98}_{40}Zr, ^{130}_{50}Sn\}$	$\{^{97}_{40}Zr, ^{130}_{50}Sn\}$

On history of the Fermi pseudopotential concept in Atomic and Neutron Physics

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It is revealed already in history, that in the same year, 1934, when the Fermi group just discovered the influence of the Hydrogen substances on the radioactivity produced by neutrons, Enrico Fermi published /*Fermi-1934*/ his concept of the pseudopotential in atomic physics, which explained their results /*Amaldi and Segre-1934*/ on the light absorption spectra of alkaline vapors. However, according to numerous reviews and books in neutron physics, Enrico introduced pseudopotential for the first time in his historic paper of the year 1936 /Fermi-1936/ on physics of thermal neutrons behavior in medium like paraffin or water. In an attempt to understand this situation we will report and compare details of both papers, such as introducing the scattering lengths, their application in place of strong but poorly known electron-atom or particle-nuclei interaction potentials and, finally, reducing the problem to an effective potentials but weak enough in magnitude for the application of the first Born approximation to calculate scattering amplitudes and cross sections. Experimentalists accepted this approach trustfully, while theorists - critically enough and started to work on a more 'mathematically correct' ones /*Blatt and Weisskopf-1952*/. The references, which will be provided, show that this work continues. In a parallel developing in Atomic and Molecular Physics the important experimental finding and theoretical approaches /Zinner-2012/, related to Fermi pseudopotentials for neutral ultracold atoms in magneto-optical traps, appeared in the present century. Finally we will draw attention to the status of Ultracold Neutron Physics /*Abele, Lemmel, Jenke-2019*/, where the so-called 'optical' potential based on the Fermi approach is widely used and serves nowadays in precision studies of neutron beta-decay for the Standard Model tests and searches for a 'new physics'.

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A. Bohr's hypothesis for angular distributions of fragments of low-energy nuclear fission and wriggling vibrations of the fissile nuclei

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The A. Bohr's hypothesis [1], widely used in the describing of the fragments angular distributions (FAD) for low-energy fission of atomic nuclei, is based on the concept about the fission fragments emission along or against the symmetry axis of an axially symmetric fissile nucleus. This hypothesis does not take into account the quantum-mechanical uncertainty relation between the operator of the orbital moment of the particle L and the angle of its' escape θ' in the internal coordinate system (i.c.s.), from which it follows that the exact value of the angle θ' leads to the appearance of uncertainty of fission fragments relative orbital momenta $\Delta L \to \infty$. For the approximate validity of A. Bohr's hypothesis, it is necessary that orbital momenta L have large but finite values. The appearance of a such large L values in the framework of the quantum fission theory [2] can be connected with the influence of the transverse wriggling vibrations of the fissile nucleus near its scission point. For binary fission FAD $P(\theta')$ in the i.c.s. can be represented as $P(\theta') = \left|\sum_L \psi_L Y_{L0}(\theta')\right|^2$ (1), where ψ_L [3] is the wave function of the wriggling vibrations normalized to unity: $\psi_L = \sqrt{L/C_w}\exp\left(-L^2/4C_w\right)$ (2), characterized by the parameter C_{w}, which is defined in terms of the stiffness K_{w} and the mass M_{w} parameters as $C_{\text{w}} = M_{\text{w}}\hbar\omega_{\text{w}}$, where $\omega_{\text{w}} = \sqrt{K_{\text{w}}/M_{\text{w}}}$ [4].

The analysis of the experimental deviations of FAD from the A. Bohr's hypothesis [1] are investigated for the case of P-odd asymmetries in the FAD of low energy fission of ^{233}U and ^{235}U nuclei by thermal polarized neutrons [5], as well as the for the anisotropy coefficients in the FAD of aligned ^{233}U and ^{235}U nuclei fission induced by resonance neutrons [6]. For these cases A. Bohr's hypothesis are in good agreement with experiment, and the deviations can be observed in P-odd asymmetries coefficients only when $C_w \le 15$ for ^{233}U and $C_w \le 30$ for ^{235}U, and for FAD anisotropy coefficients of aligned nuclei when $C_w \le 60$ and $C_w \le 80$ for ^{233}U and ^{235}U. These results can be explained by the low experimental accuracy of measured coefficients in mentioned above experiments. But the comparison of the theoretical FAD coefficients, constructed with taking into account wriggling vibrations, and experimental FAD coefficients for the binary photofission of even-even uranium nuclei provided an estimation of the parameter $C_w = 130 \pm 20$ for ^{234,236,238}U nuclei, which is consistent with the values of this parameter in [4]. For this case the A. Bohr hypothesis, corresponding to $C_w \to \infty$, doesn't describe the experimental FAD.

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Fundamental properties of the neutron & UCN

Concerning the possible observation of the Acceleration Effect with UCNs

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The development of the concept of an optical phenomenon, called the Accelerating Matter Effect [1], led to the emergence of a hypothesis about the existence of a very general Acceleration effect [2]. As applied to the physics of the microcosm, its formulation is that the result of the interaction of a particle with any object moving with acceleration should be a change in its frequency ω and energy $E = \hbar\omega$. This change in frequency is determined by a simple relation

$$\Delta\omega = ka\tau\,, \tag{1}$$

where *k* is the wave number, *a* is the object acceleration and τ - interaction time. As an estimate of the latter, we can probably use the so-called group delay time (GDT), [3, 4].

$$\tau = \hbar\frac{d\varphi}{dE}\,,$$

(2) where φ is the phase of the complex amplitude of the wave that has experienced an interaction, such as scattering.

The validity of the acceleration effect hypothesis in quantum mechanics was recently confirmed in [5], which was devoted to the numerical study of the problem of the interaction of ultracold neutrons (UCN) with potential structures moving with acceleration.

If these ideas are true, then they can be fully attributed to the case of neutron scattering on the atomic nuclei of accelerating matter. It is easy to show that the GDT at neutron scattering on the nucleus is determined by a simple relation

$$\tau = \frac{|b|}{v}\,, \tag{3}$$

where *b* is the scattering length, and v is the neutron velocity. In the case of UCN $\tau \approx 10^{-15} s$. Since the interaction time is very short, the observation of the acceleration effect in scattering by accelerating nuclei requires that the nuclei move with a very high acceleration. This goal can be achieved if centripetal acceleration is used as the latter. Some estimates of the experiment of this kind will be given in the report.

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The problem of creating neutron matter and hyperheavy nuclei in the laboratory

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The report discusses possible mechanisms for the creation of hyperheavy nuclei by electron-nuclear collapse [1] and neutron matter by condensation of ultracold neutrons (UCN) [2]. The fundamental possibility of the creation of such objects was previously substantiated by A.B. Migdal, who suggested that the well-known set of proton-neutron nuclei with mass numbers from 0 to 300 and a specific binding energy of about 8 MeV / nucleon at A≈60 corresponds to the first region, behind which (starting from about a charge Z≈1700) there is one more a region of a possible state of nuclear matter stabilized by a pion condensate. In this region the specific binding energy corresponds to 20 MeV / nucleon at A ≈ 100000. Analysis shows that neutron matter, which, due to the Tamm interaction, as well as the Hund beta equilibrium, should be sufficiently stable at the microlevel, can be stable not only at the mega-level (neutron stars) due to gravitational interaction, but also on the scale of "ordinary" macromatter. The formation of such systems due to the effect of neutronization is possible not only during critical gravitational interaction, but also through fundamentally different mechanisms (supercritical increase in the atomic number of elements due to electron-nuclear collapse and condensation of ultracold neutrons), which opens the way to the fundamental possibility of obtaining both neutron matter in laboratory conditions [2] and hyperheavy nuclei [1]. Possibility of existence (and obtaining in laboratory conditions) of stable neutron matter (at Z >> 175, N >> Z, A ≥ 10^3–10^5 with a size of 200–300 femtometers and more) at the microlevel, and not only at the mega-level, as is now believed in astrophysics, based on the works of Migdal, Tamm and Hund. The following technical approaches for the implementation of UCN condensation are considered: 1. Slow isothermal compression; 2. Use of a conical concentrator for UCN focusing (Vysotskii cone) [3]; 3. Magnetic trap; 4. Additional deep cooling of UCN.

Neutron matter is also seen as a potential candidate for cosmological latent mass. The possibility of the formation of fragments of neutron matter as part of a dark matter (neutrality, femto-, pico- and nanoscale, relic cooling complicates their detection at the present time) is considered already at the initial birth of the Universe, which is the dominant process, and not the fusion of the initial smaller number of protons, since neutrons predominate due to the fulfillment of the neutronization conditions in the synthesis of baryons. Further, as it cools, this process can proceed according to the generally accepted scenario of the Big Bang model with thermonuclear fusion (with the formation of light nuclides) and the observable part of the Universe is formed from the residual part of protons and subsequently decayed single neutrons and unstable fragments of neutron matter (with Z > 175, N >> Z, but A <10^3–10^5).

Key words: neutron, neutron matter, superheavy nuclei, electron-nuclear collapse, neutronization, condensation of ultracold neutrons, dark matter.

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Review of the Experiments Related to the Radiative Neutron Decay

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The report gives an overview of the experiments related to the radiative decay of a neutron. Emphasis is placed on our 2005 experiment conducted at the Technical University of Munich at the FRMII research reactor. Our methodology is focused on measuring the spectra of triple coincidences of radiative gamma-quantum, beta electron, and recoil proton and double coincidences of beta electron and recoil proton. The peak on the spectrum of triple coincidences shows the number of radiative neutron decays, while the peak on the spectrum of double coincidences shows the number of regular neutron beta-decays. This methodology enabled us to become the first team to measure the branching ratio (B.R.) of radiative neutron decay B.R. = $(3.2\pm1.6)10^{-3}$ (where C.L. = 99.7% and gamma quanta energy exceeds 35 Kev) [1] in 2005 on our old experimental equipment.

We have now prepared a new experiment on radiative neutron decay with the aim of measuring B.R. with a high degree of precision. The precision of branching ratio measurement is determined using the value of the ion background. The spectrum of double coincidences obtained in our experiment shows a fairly significant ion background, the fluctuations of which indicate the precision of measurement for the number of recoil protons [1,2]. Because the ion background specifically is quite significant, it appears even under super deep vacuum as beta electrons ionize the highly rarified air inside the chamber. The value of the ion background very slowly decreases with decreasing density of air inside the equipment. For example, our experimental data lead to the conclusion that the value of the ionic background is significant when compared with the value of the proton peak and on the other hand decreases only by 5-6 times if the pressure within the chamber goes down by 2 orders of magnitude. Besides, we discovered an additional wide peak on the spectrum of triple coincidences. This peak consists of delayed gamma quanta created during the ionization of rare gas by beta-electrons.

Thus, this experiment allows us to study another important phenomenon, the ionization of rarified gas by beta electrons with emission of gamma quanta. Our last experiment showed that these two phenomena, radiative neutron decay and ionization with gamma quanta emission, are distinguishable in the case of high time resolution and can be studied separately. This is another important result of our last experiment and in this report we mention that the authors of articles [3, 4] registered namely the ionization with gamma radiation events.

This report is dedicated to a discussion of the computer experiment we conducted using the well-known GEANT4 software package. As a result of these calculations, we demonstrated that the value of the ionic background is proportional to the cubic root of the rarefied air density within the equipment, i.e. it changes very smoothly in relation to the pressure within the chamber. Besides, the report presents a comparison of our measurements of double coincidences [2] and triple coincidences [3, 4], with two other experimental groups.

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On the possibility to create a UCN source on a pulsed reactor

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Over the past years, a number of ultracold neutron (UCN) sources have appeared in the world, and several more of them are under construction. Although UCNs were discovered in Dubna [1], there is still no UCNs source in Dubna. The reasons for this are largely due to the peculiarities of the pulsed IBR-2 reactor of JINR. Its average power of 2 MW is relatively small for creating a continuous UCN source. At the same time, the pulsed flux of thermal neutrons is very large, since the interval between pulses significantly exceeds their duration. Under certain conditions, the pulsed UCN flux from a thin moderator can also be quite significant.

We have presented the concept of an intense UCN source at periodic pulsed reactor. It is shown that the implementation of the principle of time focusing [2], based on nonstationary neutron diffraction, in combination with neutron moderation, as well as the idea of pulsed filling of the UCN trap [3], make it possible to create a sufficiently intense UCN source based on a pulsed reactor with a moderate power.

This seems to be especially relevant in connection with the plans to create a new intense neutron source IBR3 "Neptune" at JINR.

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A moving amplitude grating as time lens for novel UCN source

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The possibility of creating a new intense source of ultracold neutrons (UCN) on a periodic pulsed reactor was considered in [1]. It was shown that the implementation of the principle of time focusing [2], based on nonstationary neutron diffraction, in combination with neutron moderation, as well as the idea of pulsed filling of the UCN trap [3], make it possible to create a sufficiently intense UCN source. In [1], a phase diffraction grating moving across a neutron beam was proposed as a time lens.

Unfortunately, the diffraction efficiency of such a time lens decreases with increasing neutron energy. To increase the diffraction efficiency of the time lens for high neutron velocities (energies), we propose to use an amplitude diffraction grating instead of a phase grating. In our work, the diffraction efficiencies of an absorbing amplitude grating based on boron-10, natural gadolinium, and gadolinium-157 were calculated.

It was shown that in the case of using gadolinium-157 for neutrons with velocities higher than 14 m/s, there is a gain in diffraction efficiency of 2–3 times. The results of the calculations show that the gain in diffraction efficiency for neutrons with high velocities is possible with the use of isotopes with a large absorption cross-section.

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The problem of creating neutron matter and hyperheavy nuclei in the laboratory

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The report discusses possible mechanisms for the creation of hyperheavy nuclei by electron-nuclear collapse [1] and neutron matter by condensation of ultracold neutrons (UCN) [2]. The fundamental possibility of the creation of such objects was previously substantiated by A.B. Migdal, who suggested that the well-known set of proton-neutron nuclei with mass numbers from 0 to 300 and a specific binding energy of about 8 MeV / nucleon at A≈60 corresponds to the first region, behind which (starting from about a charge Z≈1700) there is one more a region of a possible state of nuclear matter stabilized by a pion condensate. In this region the specific binding energy corresponds to 20 MeV / nucleon at A ≈ 100000. Analysis shows that neutron matter, which, due to the Tamm interaction, as well as the Hund beta equilibrium, should be sufficiently stable at the microlevel, can be stable not only at the mega-level (neutron stars) due to gravitational interaction, but also on the scale of "ordinary" macromatter. The formation of such systems due to the effect of neutronization is possible not only during critical gravitational interaction, but also through fundamentally different mechanisms (supercritical increase in the atomic number of elements due to electron-nuclear collapse and condensation of ultracold neutrons), which opens the way to the fundamental possibility of obtaining both neutron matter in laboratory conditions [2] and hyperheavy nuclei [1]. Possibility of existence (and obtaining in laboratory conditions) of stable neutron matter (at Z >> 175, N >> Z, A ≥ 10^3–10^5 with a size of 200–300 femtometers and more) at the microlevel, and not only at the mega-level, as is now believed in astrophysics, based on the works of Migdal, Tamm and Hund. The following technical approaches for the implementation of UCN condensation are considered: 1. Slow isothermal compression; 2. Use of a conical concentrator for UCN focusing (Vysotskii cone) [3]; 3. Magnetic trap; 4. Additional deep cooling of UCN.

Neutron matter is also seen as a potential candidate for cosmological latent mass. The possibility of the formation of fragments of neutron matter as part of a dark matter (neutrality, femto-, pico- and nanoscale, relic cooling complicates their detection at the present time) is considered already at the initial birth of the Universe, which is the dominant process, and not the fusion of the initial smaller number of protons, since neutrons predominate due to the fulfillment of the neutronization conditions in the synthesis of baryons. Further, as it cools, this process can proceed according to the generally accepted scenario of the Big Bang model with thermonuclear fusion (with the formation of light nuclides) and the observable part of the Universe is formed from the residual part of protons and subsequently decayed single neutrons and unstable fragments of neutron matter (with Z > 175, N >> Z, but A <10^3–10^5).

Key words: neutron, neutron matter, superheavy nuclei, electron-nuclear collapse, neutronization, condensation of ultracold neutrons, dark matter.

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New limit on the electric dipole moment of the neutron

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Abstract

A nonzero permanent electric dipole moment (EDM) of a non-degenerate particle with spin implies the violation of time-reversal symmetry. Invoking the CPT theorem indicates the violation of the combined symmetry of charge conjugation and parity (CP). We present a new limit on the neutron EDM, $|d_{\mathrm{n}}| < 1.8 \times 10^{-26} e\mathrm{cm}$ [C. Abel *et al.*, PRL124, 081803 (2020)], from an experiment performed at the Paul Scherrer Institute deploying Ramsey's method of separated oscillating magnetic fields on stored ultracold neutrons. Our measurement stands in the long history of EDM experiments probing physics violating time-reversal invariance. The salient features of this experiment were the use of a ^{199}Hg co-magnetometer and an array of optically pumped cesium vapor magnetometers to cancel and correct for magnetic field changes. Two separate groups performed the statistical analysis on blinded datasets while the estimation of systematic effects profited from unprecedented knowledge of the magnetic field.

Interaction of the neutron wave with a quantum objects moving with acceleration

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The report is devoted to a numerical study of the problem of interaction of the neutron with potential structures moving with constant acceleration. Among them were a potential step, a potential barrier, a potential well, a double potential stage, an interference filter, and a two-layer structure. The solution of the time-dependent Schrodinger equation was found by the method of evolution operator splitting. In all the cases considered the result of the interaction is a change in the velocity spectrum. In the first approximation the magnitude of the shift in the spectrum is determined by the product of acceleration by group delay time. Also, as the direction of acceleration reverses the effect changes its sign. The results are completely consistent with the idea of universality of the Effect of Acceleration [1] which consists in a change in the frequency of the wave at scattering on an object moving with acceleration.

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The HighNESS Project and Neutron Oscillation Searches at the European Spallation Source

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on behalf of the nnbar Collaboration

The European Spallation Source (ESS), presently under construction in Lund, Sweden, is a multi-disciplinary international laboratory that will operate the world's most powerful pulsed neutron source. Supported by 3 MEuro Research and Innovation Action within the EU Horizon 2020 program, a design study (HighNESS) is now underway for a second neutron source which will be complementary to the first source, and deliver longer wavelength neutrons and higher cold neutron intensities. Proposed experiments include a search for neutron conversions to antineutrons (NNBAR) and measurements with ultra cold neutrons.

This talk focuses on the HighNESS program and other fundamental physics possibilities at the ESS with an emphasis on NNBAR. The NNBAR experiment is a two-step program, starting with the HIBEAM stage which would make high precision searches for free neutrons converting to sterile neutrons and thus probing a possible dark sector whilst also performing R&D for the second stage of the experiment, the NNBAR stage, which would fully exploit the high intensity delivered by the new neutron source designed within HighNESS. This new source, together with other unique features of the NNBAR experiment, such as the 200-m long beamline, the optimized reflector system, and the dedicated detector, will allow an improvement in sensitivity, compared with the last such search, to neutrons converting to antineutrons by three orders of magnitude.

Properties of compound states, nuclear structure and others

Excitation functions of neutron-induced reactions of medical isotopes ^{32}P, ^{55}Fe, ^{74}As, ^{97}Ru, ^{103}Ru and ^{109}Pd

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Abstract

There are many stable and radioactive isotopes, each having their own physical and chemical properties, perform important roles in technology and actually existing in the field of research. The most common application is the use of radioisotopes in the medicine. The medical radioisotopes are classified as therapeutic and diagnostic radioisotopes, depending on the decaying properties [1]. The diagnostic radioisotopes, depending on the nature of radioisotopes, are used in two types of emission tomography i.e. Single photon emission computed tomography (SPECT) and Positron emission tomography (PET).

The knowledge of the excitation function is necessary, to get a governed and optimized medical radionuclide. In this regard, the theoretical model calculation is very helpful. TALYS-1.9 [2] and EMPIRE-3.2 [3] are used to determine the excitation functions of radionuclides ^{32}P, ^{55}Fe, ^{74}As, ^{97}Ru, ^{103}Ru and ^{109}Pd produced via ^{31}P(n,g)^{32}P, ^{32}S(n,p)^{32}P, ^{56}Fe(n,2n)^{55}Fe, ^{58}Ni(n,α)^{55}Fe, ^{74}Se(n,p)^{74}As, ^{96}Ru(n,g)^{97}Ru, ^{98}Ru(n,2n)^{97}Ru, ^{102}Ru(n,g)^{103}Ru, ^{103}Rh(n,p)^{103}Ru, ^{104}Ru(n,2n)^{103}Ru, ^{108}Pd(n,g)^{109}Pd, ^{109}Ag(n,p)^{109}Pd, ^{110}Pd(n,2n)^{109}Pd, and ^{112}Cd(n,α)^{109}Pd reactions in the neutron energy range 1-20 MeV. The calculated results are discussed and compared with the existing experimental data (EXFOR database) [4] as well as with the evaluated data. The excitation functions of ^{32}P, ^{55}Fe, ^{74}As, ^{97}Ru, ^{103}Ru and ^{109}Pd are medically important and widely used in bone disease treatment, heat source, in biomedical, monoclonal antibodies labelling, imaging, radio labelling and potential radio therapeutic agent.

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Decomposed Scattering Phase Shifts in the Complex Scaling Method

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Study of resonances in the scattering problem of light nuclei has been carried out using various methods, one of which is the complex scaling method (CSM) [1–2]. It is possible to investigate the resonance contributions and to obtain a deep understanding of resonance structure by separation of a scattering quantity. Suzuki et al. [3] showed that scattering phase shifts can be calculated from the continuum level density (CLD), which is expressed using the complex scaled Green's function.

We apply the complex scaling method to the calculation of scattering phase shifts and extract the contributions of resonances in a phase shift and a cross section. The decomposition of the phase shift is shown to be useful in understanding the roles of resonant and non-resonant continuum states. We apply this method to the α-p two-body system. We discuss the explicit relation between the scattering phase shifts and complex-energy eigenvalues in the CSM via the CLD. The results provide us with deeper understanding of the role of resonant states characterized by the widths described as an imaginary part of the eigen-energy.

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NEUTRON RESONANCES IN THE GLOBAL CONSTITUENT QUARK MODEL

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Neutron resonance spectroscopy is a part of Nuclear Physics based on the Standard Model (SM) as a theory of all interactions. We continue presentation at ISINN meetings the symmetry motivated and electron-based approach to the SM development.

The high accuracy in determining the neutron resonance energy, achieved by the time-of-flight method, allowed to consider together the problems of the mass spectrum (the distinguished character of the electron mass m_e=511 keV) and empirical correlations in nuclear data, the existence of fine and superfine structures, respectively, with periods ε' =1.2 keV and ε''=1.4 eV=5.5 eV/4, equal to the first and second QED radiative correction to the empirically found period of 1022 keV=$\varepsilon_\circ = 2m_e$ in few-particle excitations and binding energies. Recently observed correlations in the particle mass spectrum (with parameters $\delta = 16m_e$ and $M_q = 54\delta$) are given in Figure.

In these works, we consider additional empirical observation of the particle mass spectrum and nuclear data, including the important role of neutron resonance data in confirming the QED correction, which are used for the further SM development. We show that the masses of the fundamental fields $M_Z = m_\mu(\alpha/2\pi)^{-1}$ and $M_{H^\circ} = m_e/3(\alpha/2\pi)^{-2}$, as well as the main parameter of the ECQM and NRCQM models, $M_q = m_e(\alpha/2\pi)^{-1}$, are interconnected by symmetry motivated relations and the common QED correction, which can be investigated within neutron resonance spectroscopy.

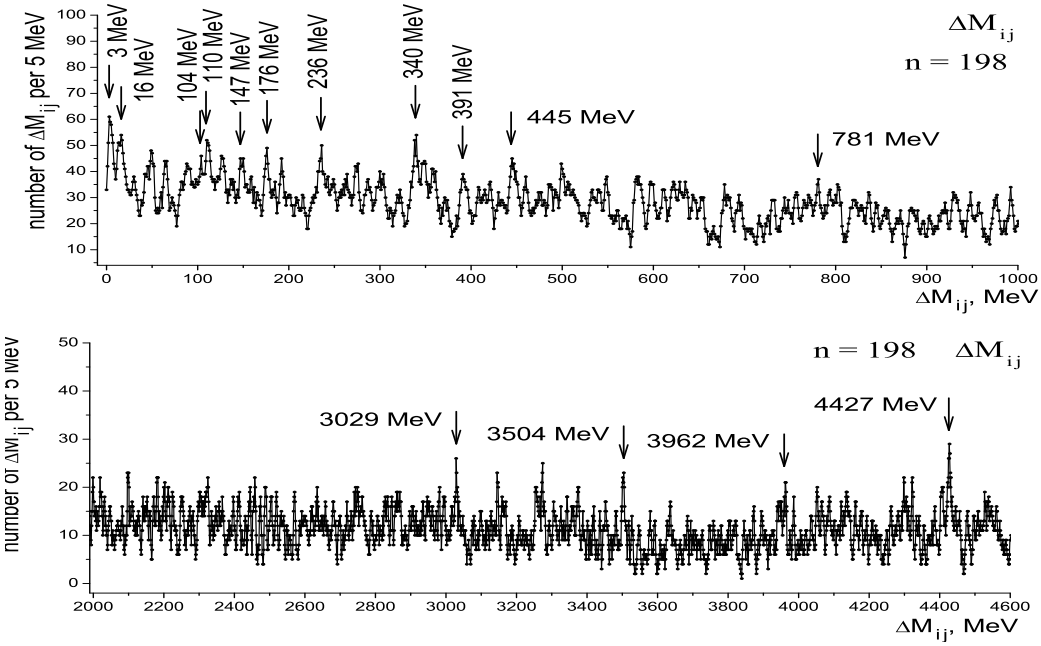

Figure. *Top:* ΔM distribution of all differences between particle masses from compilation PDG-2020 (interval of the averaging 5 MeV) for the energy region 0–1000 MeV. Maxima at 16 MeV= $2\delta = 2 \times 16m_e$, 391 MeV=$m_\omega/2$, 445 MeV=M_q, 781 MeV=m_ω are considered in text. *Bottom:* The same for energy region 2000–4600 MeV. Maxima are at 3504 MeV$\approx 8M_q = \delta^\circ/2$, 3962 MeV$\approx 9M_q$ and 4427 MeV$\approx 10M_q$.

FUNDAMENTAL ASPECTS OF NEUTRON SPECTROSCOPY

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Neutron resonance spectroscopy provides data on a large number of highly excited states. This information can be used to check nuclear microscopic models, including the Nonrelativistic Constituent Quark Model (NRCQM), which R. Feynman considered very successful. A global extension of NRCQM, called the Electron-based Constituent Quark Model (ECQM), combines the properties of hadrons and leptons with the universal character of the influence of physical condensate (vacuum) and provides a possibility to estimate the discreteness in nuclear excitations and binding energies, as well as nonstatistical effects in the neutron resonance positions and spacing distributions.

The properties of the ECQM model (the electron mass as a unique parameter, its symmetry and QED radiative correction to the particle masses) have been considered in many nuclei. Here we discuss recent results obtained for nuclei with Z=58-64. In these nuclei with closed shells N=82 and N=90, stable intervals were found that are multiples of the value of the first fine structure parameter $m_e/3$=170 keV, namely, in ^{141}Ce resonances D=21.7-43.1-86.2 keV=170 keV/2, stable 0^+ excitations in ^{150}Nd, ^{152}Sm, ^{154}Gd (675, 684, 681 keV=4 × 170 keV) and in ^{145}Sm a single-particle ($J = 7/2 - 11/2$) excitation E^*=1538 keV≈ $3m_e$. Simultaneously, in the positions of the strong neutron resonances of the magic ^{141}Ce, the exact ratio 9:4=21. kev+9.57 keV was found by M. Ohkubo (common period 21.6+9.6 keV/9+4=2.4 keV=$2\varepsilon'$). In D-distributions of neutron resonances in ^{145}Sm (for orbital momenta L=0 and 1, see Figure), the maxima are located exactly at $3\varepsilon'$ and $2\varepsilon'$.

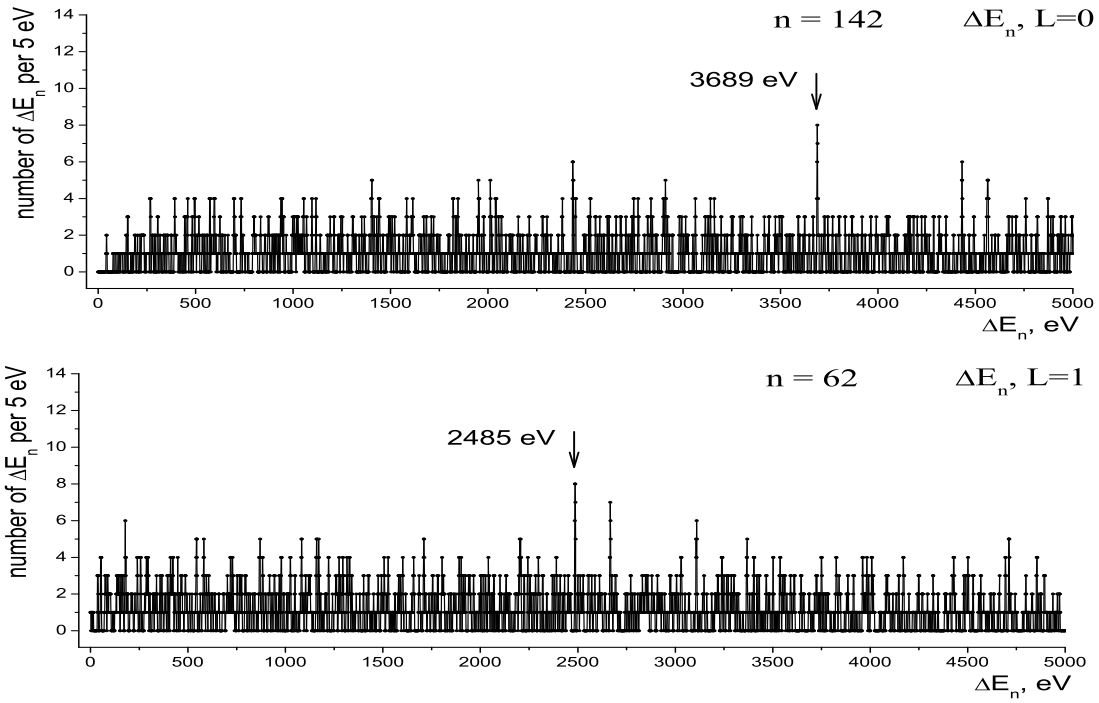

Figure. Spacing distributions of neutron resonances in ^{145}Sm (for orbital momenta L=0 and L=1 with maxima at $3\varepsilon'$ and $2\varepsilon'$, the ratio 3689 eV/2485 eV=1.48≈3/2, period ε'=1.229 keV).

NONSTATISTICAL EFFECTS IN RESONANCES OF HEAVY NUCLEI

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In a report at the First Geneva Conference (1955) of the Atomic Energy Institute (Kurchatov Institute, Moscow), attention was turned to the proximity of the positions of neutron resonances of different isotopes (E_n grouping at the value of ≈0.3 eV).

In the case of similar stable intervals D=99 eV=18×5.5 eV in the resonance spacing distributions of three neighbouring isotopes ^{241,243,245}Pu (shown in Figure, top), we can notice that the doubled value of stable 2^+ excitations in these isotopes (42.8-42.0-44.5-44.2 keV in ^{240,241,242,244}Pu) is in the ratio 99(1) eV/86(2) keV=115·10^{-5}, which is close to the QED radiative correction $\alpha/2\pi = 116 \cdot 10^{-5}$. Such superfine structure intervals have been observed in many heavy nuclei.

The possibility to check the common dynamics of the influence of physical condensate within a nuclear medium should be studied in different regions of the nuclear chart. In regions with stable collective excitations, such an analysis could be based on the expected relation between the well-established fine structure ($D = k$×5.5 eV) and the hyperfine structure corresponding to third-order effects with QED radiative correction parameter $\alpha/2\pi$. Stable superfine structure intervals (1.32-1.48 eV in ^{238}Np, close to 5.5 eV/4=1.38 eV=ε'') are connected with stable intervals of hyperfine structure $\varepsilon_\circ \cdot (\alpha/2\pi)^3$ corresponding to stable $E(8^+) = \varepsilon_\circ/2$ ≈511 keV (497-522=518-518-516-514-497-518 keV in ^{234,236,237,238}U, ^{236,238,240,242}Pu). From the relation 6:20:42:72 for excitations with $J = 2, 4, 6, 8$ one could expect the possible appearance of an additional hyperfine structure with the value (1.38 eV/72)×(6, 20, 42, or 100 meV, 400 meV and 800 meV). Intervals of the hyperfine structure of the order of 300-400 meV, observed as resonance positions in isotopes with Z=92-95, can be associated with the stability of 4^+ and 6^+ excitations in heavy nuclei.

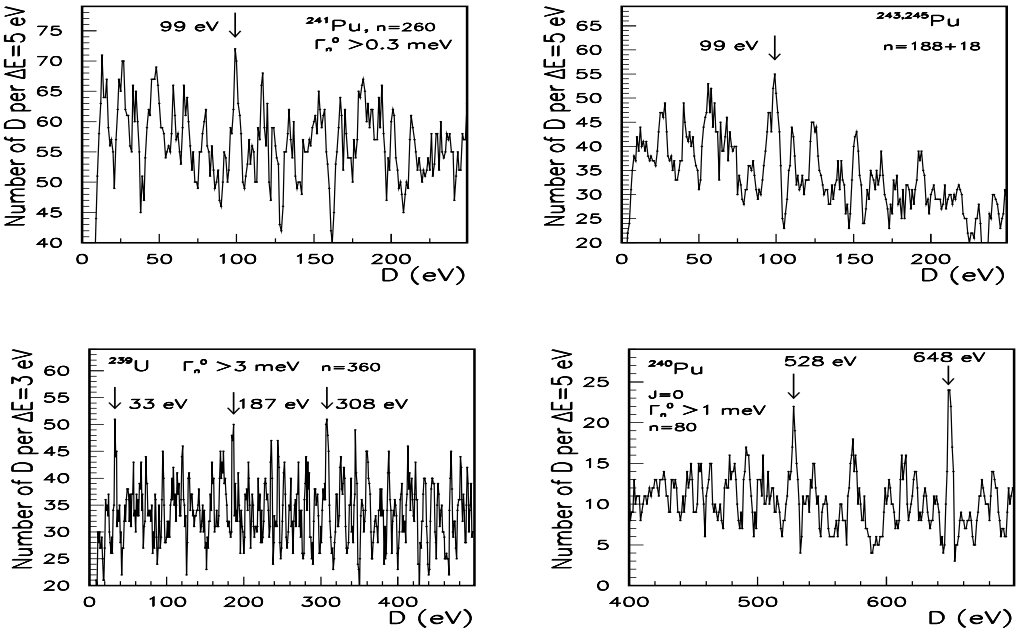

Figure. D-distributions in neutron resonances of heavy compound nuclei.

AN INVERSE-PROBLEM SOLVING BY THE EXAMPLE OF $^{238}U(n,2\gamma)^{239}U$ REACTION ANALYSIS

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As modern theory supposes that the wave function of any excited nuclear level includes both a quasi-particle and phonon components, interest has risen to study intra-nuclear processes experimentally. And just simultaneous obtaining of the nuclear-physical parameters, the nuclear level density ρ and partial widths Γ of emission products of a nuclear reaction, is very important for investigation of fundamental interaction between fermion and boson states of nuclear matter. As ρ and Γ enter into the measured spectra of indirect experiment as $\rho\times\Gamma$, there is a complicated problem of a search for inverse solution to extract these strong-correlated parameters simultaneously.

The empirical method, which is created and developed in Dubna in order to enable an investigation of dynamics of nuclear-structure change below the neutron binding energy in a nucleus, was applied to analyze the experimental γ-spectrum from the $^{238}U(n,2\gamma)^{239}U$ reaction measured using nearly 4π γ-ray calorimeter DANCE [1]. The Dubna method allows simultaneous extraction of the density of intermediate levels of the two-step γ-cascades in compound-nucleus and partial widths of dipole γ-transitions approximating the experimental intensities of only primary transitions of the two-step γ-cascades.

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